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УНИВЕРЗИТЕТ „СВ. КИРИЛ И МЕТОДИЈ" · СКОПЈЕ
ЗЕМЈОДЕЛСКИ ФАКУЛТЕТ

Optimization of agricultural production under climate change up to 2050 in Pelagonia region

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Double degree master's thesis · 30 hec · Advanced level
Degree thesis No 763 · ISSN 1401-4084
Uppsala 2012

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Credits: 30 ECTS
Level: A2E
Course title: Degree Project in Business Administration
Course code: EX0536
Faculty: Faculty of Natural Resources and Agricultural Sciences

Place of publication: Uppsala
Year of publication: 2012
Cover picture: Ordan Cukaliev, Faculty of Agricultural Sciences and Food
Name of Series: Degree project/SLU, Department of Economics
No: 763
ISSN 1401-4084
Online publication: http://stud.epsilon.slu.se

Key words: optimization of agricultural production, climate change, irrigation strategies, linear programming, adaptation measures

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About this publication

This master thesis has been produced within the International Master Program in Agribusiness (120 ECTS) with the financial assistance of the Swedish International Development Cooperation Agency, Sida, through the project UniCoop. The views herein shall not necessarily be taken to reflect the official opinion of Sida.

The master program leads to a double degree from two academic institutions: the Faculty of Agricultural Sciences and Food (FASF) at the University “Ss. Cyril and Methodius” (UKIM) in Skopje, Republic of Macedonia and the Swedish University of Agricultural Sciences (SLU) in Uppsala, Sweden. The master thesis is published at both universities, UKIM and SLU.

Магистерскиот труд е подготвен во рамките на Меѓународните студии по Агробизнис (120 ЕКТС) коишто се финансиски поддржани од СИДА. Не треба да се смета дека изнесените ставови во овој труд го искажуваат официјалното мислење на СИДА.

Магистерските студии водат кон двојна диплома од страна на две академски институции: Факултетот за земјоделски науки и храна - Скопје (ФЗНХ) при Универзитетот „Св. Кирил и Методиј“ во Скопје (УКИМ) и Шведскиот универзитет за земјоделски науки (СЛУ) во Упсала. Магистерскиот труд е објавен на двата универзитета, УКИМ и СЛУ.

UniCoop

Building Capacity for Macedonian Higher Education,
Research and Policy Analysis in Agriculture
- with a focus on Agricultural Economics

Acknowledgements

Doing this Master thesis was one of the most challenging issues that I've ever faced, but also a privilege and a pleasure at the same time. By joining the Master program, my dreams come true. This study program enlightens me with a deeper knowledge and broadens my horizons with new perceptions to how successfully cope various economic issues dealing agricultural sector. Thanks to the joint project "UniCoop", I've got an opportunity to study abroad by being home. Without the above mentioned project, I could never allow such education.

Now, when the studies are finished, I would like to express a special gratitude to all involved Professors and Assistants both from Institute of Agricultural Economics from the Faculty of Agricultural Sciences and Food in Skopje and from the Swedish University of Agricultural Sciences (SLU) for their efforts in providing such quality and interesting studies.

I am using this opportunity to express my sincere gratefulness to my supervisors, Professor Hans Andersson and Professor Dragan Gjosevski for generously sharing their knowledge and giving new perspectives of this thesis. Their unselfishness, dedication and continuous support during the whole period were crucial for successful accomplishment of the study. It was a great pleasure working with them.

Special thanks to UNDP, Environment Unit for providing me valuable data for preparation of the study and to Professor Ordan Cukaliev who guided me and taught me on all matters related to irrigation. Without his support, my efforts would be fruitless. Also, I want to thank to Professor Aleksandra Martinovska-Stojcevska for giving me continuous support and encourage me through the whole process.

At the end I am deeply indebted to my family, my daughter Jana and my mother Vasilka for being always with me and encouraging me all the time. Without their patience, understanding and love, this would be impossible and worth nothing.

Once again, thank you all!

Daniela Buzarovska

Abstract

This study aims to illustrate the variation in crop area in Pelagonia region in 2050 due to increased irrigation requirements of crops. The allocation of the crop area depends on the net return per unit of crop area. On the other side, the net return is strongly related to the irrigation water requirements. Both, rain-fed and irrigated crops are expected to have higher water demand driven by the higher temperatures and reduced soil moisture because of the decreased precipitation and runoffs. This study uses three climate scenarios for 2050. The optimistic scenario (2050 Low) where predicted climate variations are mild and the outcome is more optimistic, the most realistic scenario (2050 Medium) with the most expected outcome and pessimistic scenario (2050 High) with the highest variations in temperature and precipitation and the most negative outcome. The future climate change scenarios are subject to comparison with the Base case scenario that is a plausible interpretation of the today's climate conditions. The technique of linear optimization is used to identify the best cropping pattern under given constraints. The proposed methodology is applied to assess the economic value of the crop production in Pelagonia region given the climate change.

The study examines alternative crop production pattern in Pelagonia region which is one of the most important agricultural region in the Republic of Macedonia. The study is underpinned only by the climate variations in the forthcoming period, using assumptions and features such as constant ratio between price and costs in 2050, as in 2010. Other socio-economic factors including price movements based on future supply and demand, investments in agricultural productivity, technology and infrastructure, as well as other production factors are not taken into consideration in this study.

The findings of the study show that due to climate divergences in 2050, the crop structure differs in various climate scenarios. In general, the more severe climate in 2050 will cause decrease in net returns by 11% in the most optimistic scenario (2050 Low) and 22% in the pessimistic scenario (2050High), if no adaptation measures are applied. The production of the low profitable crops (cereals, industrial and fodder crops) will be reduced to their minimal levels, while the production of high profitable crops such as vegetable, especially green pepper, tobacco and other crops that increase net return per crop area should be intensified. The strategy of greater specialization in commodities in which Macedonia has a comparative advantage and potential trade with other countries which have comparative advantage in other commodities might prove to be economically efficient and valuable for both countries.

Key words: optimization of agricultural production, climate change, irrigation water requirements, Pelagonia region, irrigation strategies, linear programming, adaptation measures

Апстракт

Оваа студија има за цел да ги илустрира промените во производната структура во пелагонискиот регион во 2050 година како резултат на зголеменото барање за наводнување на културите. Распределената површина по култура е зависна од нето добивката по единица површина. Од друга страна, нето добивката е силно поврзана со барањата за вода за наводнување. И наводнуваните и ненаводнуваните култури се очекува да имаат зголемени потреби од вода поради повисоките температури и намалената влажност во почвата како резултат на намалените врнежи и истеци. Ова истражување користи три климатски сценарија за 2050 година. Во оптимистичко сценарио (2050 ниско), кое предвидува поблаги климатски промени резултатот е пооптимистички, реалното очекувано сценарио (2050 средно) со најверојатен исход и песимистичко сценарио (2050 висок) каде варијациите во температурата и врнежите даваат најнеповолен исход. Сценаријата за климатските промени се предмет на споредба со основното сценарио како веродостојна интерпретација на тековните климатските услови. Техниката на линеарно програмирање се користи да се идентификува најсоодветната производна структура земајќи ги предвид дадените ограничувања. Предложената методологија се примени за да се оцени економската вредност на растителното производство во Пелагонискиот регион при климатски промени.

Студијата испитува алтернативни комбинации на растителното производство во Пелагонискиот регион кој е еден од најважните земјоделски регион во Република Македонија. Студијата се фокусира само на климатските промени во наредниот период и користи одредени претпоставки како постојан сооднос меѓу цената и трошоците во 2050 година, како и во 2010 година. Другите социо-економски фактори, вклучувајќи го движењето на цените врз основа на идната понуда и побарувачка, инвестициите во земјоделското производство, технологија и инфраструктура, како и други производни фактори не се земени во предвид во оваа студија.

Резултатите покажуваат дека поради климатските разлики во 2050, структурата на култури е различна во различните климатски сценарија. Генерално, влошувањето на климатските услови во 2050, ќе доведе до намалување на нето доходот од 11% во најоптимистичкото сценарио (2050 ниско) до 22% во песимистичкото сценарио (2050 високо), доколку соодветни мерки на адаптација не бидат превземени. Сепак, производството на нискодоходовните култури (житни, индустриски и фуражни растенија) треба да биде доведено на минимум, а поголем акцент треба да се стави на високодоходовните култури како зеленчук, особено производството на зелена пиперка, тутун и други култури кои го зголемуваат доходот по единица површина. Стратегијата на специјализација во производи во кои Македонија има компаративна предност и потенцијалната трговска размена со други земји специјализирани во производство на други производи би можела да се покаже како економски ефикасна и корисна за обете земји.

Клучни зборови: оптимизација на земјоделското производство, климатски промени, потреби за наводнување, пелагониски регион, стратегии за наводнување, линеарно програмирање, мерки на прилагодување

Abbreviations

AEZ	Agro-Ecological Zones
DP	Dynamic Programming
DSSP	Discrete Stochastic Sequential Programming
ECA	Europe and Central Asia
Et_c	Crop evapotranspiration
Et_o	Referent evapotranspiration
FAO	Food and Agriculture Organization
GCM	General Circulation Model
GDP	Gross Domestic product
GP	Goal Programming
IFPRI	International Food Policy Research Institute
IPARD	Instrument for Pre-accession Assistance and Rural Development
IPCC	Intergovernmental Panel on Climate Change
IWR	Irrigation Water Requirement
k_c	Crop coefficient
k_y	Yield response factor
LP	Linear Programming
NARDS	National Agricultural and Rural Development Strategy
SNCCC	Second National Communication on Climate Changes
SSO	State Statistical Office
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USDA	United States department of Agriculture

Table of Contents

List of figures

List of tables

1 Introduction

Vulnerability of the agricultural sector due to climate change has substantial consequences for Macedonian economy. Considering that the majority of rural population dependents on agriculture, rural communities and especially farmers will be particularly sensitive to the forthcoming challenges of climate changes. The rural poor due to their high dependence on agriculture, relatively low ability to adapt and high share of food in total costs will be most affected of the adverse effects of climate over agriculture. Any severe climate changes could have devastating outcome reflecting on their financial power, food supplies and the country's economy in general, including export (www, World Bank, 2, 2010). In the event of such devastating scenario, the lack of institutional capacities to cope with climatic perils may further threaten the overall stability of the agricultural production system and the economic stability of Macedonia in general (www, World Bank, 2, 2010).

Although climate change will cause gains for certain crops in some regions of the world, the impact of climate change at global level is predicted to be negative. The threat of climate change on global level is likely to be much greater moving from 2030 to 2050 and 2080 (Nelson et al. 2010, pp.85-86). While average temperature is going to increase by 1°C by 2050 at world level, the increase will be even more dramatic beyond 2050, ranging from 2°C to 4°C by 2100. Yields of many crops will decrease seriously moving up from 4.2 to 12 % by 2050 and from 14.3 to 29% by 2080 considering climate change and economic and demographic drivers on yields for main crops (Nelson et al. 2010, pp.85-86).

Kaiser (1991) has shown that irrigated crops will be less vulnerable and the introduction of adaptive strategies will substantially mitigate climate change. Yields will remain relatively stable, with a decrease only in the worst case scenario.

One of the biggest challenges in the coming decades will be meeting the irrigation requirements and increasing of the food production especially in countries with limited water and land resources (www, FAO, 4, 2002, pp.1-2). In countries like Macedonia, where most of the production is rain-fed, the shortage of water, particularly during hot periods of the year may substantially worsen the agricultural production if cost-effective and timely irrigation is not applied (www, World Bank, 2, 2010).

Climate change may induce an additional price increase for major crops. Higher feed prices will cause higher meat prices that in turn will result in reduction of meat consumption and a more substantial decrease in cereal consumption (Nelson et al, 2009).

Another indirect effect of climate change is the decrease in net economic welfare (Kaiser, 1991). Although producers will gain from the increased market price, the consumer losses will be higher, thus in total, net economic welfare will be negative. In such cases, trade flows between regions with different comparative advantages and specialization in products with comparative advantage may partially compensate the adverse effect of climate change (Nelson et al., 2010).

This study, similar to Kaiser (1991) aims to examine changes in crop area in Pelagonia in 2050 due to increased irrigation requirements of crops. Agricultural area change dependents on the net return per unit of crop area. On the other side, net return is strongly related to irrigation water requirements. Both, rain-fed and irrigated crops are characterized by higher water demand driven by higher temperatures and decreased soil moisture due to lower precipitation and runoffs. This study uses three climate scenarios for 2050. The optimistic scenario (2050 Low) where predicted climate variations are mild and the outcome is more optimistic, the most realistic scenario (2050 Medium) and pessimistic scenario (2050 High) with the highest variations in temperature and precipitation and a more negative outcome. The future climate change scenarios are subject to comparison with a base case scenario that is a plausible interpretation of the today's climate conditions. The technique of linear programming is used to produce the best cropping pattern under given constraints. The proposed methodology is applied to accesses the economic value of crop production in Pelagonia region under climate change conditions.

Using this model, the study examines alternative crop production patterns in Pelagonia region which is one of the most important agricultural region in the Republic of Macedonia. The study is underpinned only on climate variations in the forthcoming period, using some simplified assumptions and features such as constant ratio between price and costs in 2050 as in 2010. Other socio-economic factors including price movements based on future supply and demand, investments in agricultural productivity, technology and infrastructure, as well as other production factors are not taken into consideration in this study.

1.1 Problem background

1.1.1 Climate in Macedonia

Macedonia is characterized with very diverse climate (IPARD Program 2007-2013, 2007). The territory is influenced by variable climatic conditions from alpine mountainous in the west and north-west part to Mediterranean climate in the south parts of the country. Hot and dry periods are typical for summer, autumn, and cold periods for winter. Rainfalls are uneven in terms of temporal distribution with average precipitation of 733 mm/yearly. With alternating period of long droughts and intensive rainfalls, 75% of the country is characterized as a semi-arid region. Such climatic variations have a substantial influence on agricultural production in the country. Spring's and autumn's frosts, hail and droughts in summer cause adverse effects to the agriculture production.

Drought is a very common phenomenon during the vegetation period. Soil humidity and rains are insufficient for normal growth of plants and fruits. Annual precipitation is low, varying from 400 mm in the central and east parts to 1,400 mm in the western parts (IPARD Program 2007-2013, 2007).

As stated in the SNCCC, 2008, pp.23, six climate subtypes are distinguished in Republic of Macedonia:

- "Sub-Mediterranean climate (regions from 50-500m),
- Moderate continental Mediterranean climate (regions up to 600m),
- Hot continental climate (regions from 600-900m),

- Cold continental climate (regions form 900-110),
- Sub forest continental mountainous climate (regions from 1100-1300m),
- Forest continental mountainous climate (regions from 1300-1650m),
- Sub alpine mountainous climate (regions from 1650-2250m),
- Alpine mountainous climate (regions above 2250m)”.

1.1.2 Agricultural production

Agriculture is the third largest sector in the country with 12% share in the overall GDP. If agro-processing industry is added, the share is even bigger (IPARD Program 2007-2013, 2007).

Agricultural products contribute with 16.8% to the total exports. However, the country with a 13.7% share in the total import remains a net importer of agro-food products in the period 2000-2006 (IPARD Program 2007-2013, 2007). In 2005, the most important export product is tobacco with 30% of the total value of the agro-food products followed by beverages (including wine), vegetables and fruits (NARDS 2007-2013, 2007). On the import side, meat has the biggest share (16.1%) of the total import of agro-food products. Among crop commodities, cereals are the dominating commodities accounting for 5.6% of total imports of the agro-food products (NARDS 2007-2013, 2007).

Agricultural sector employed almost 20% of the active labor force in 2005. Additionally, seasonal workers and part time farmers engaged in agriculture contributed to 5% more (NARDS 2007-2013, 2007). More than a half of the total engaged labor in agriculture was in crop production, while over 90% of the labor was employed on private farms (NARDS 2007-2013, 2007).

The total agricultural land in 2006 amounted to 1.225,513 ha out of which 438,925 ha was cultivated (IPARD Program 2007-2013, 2007). The structure of the cultivated land given in percentages is shown in *figure 1*:

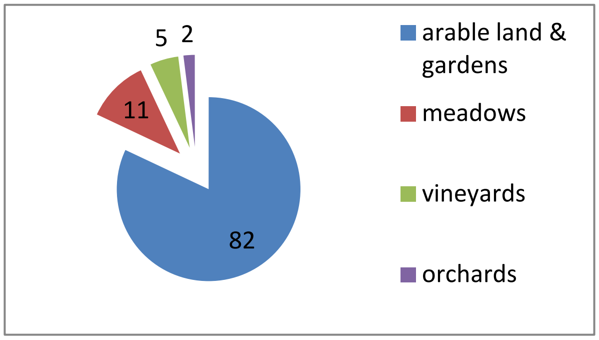


Figure 1: The structure of the cultivated land in Macedonia in 2006

Concerning crop production, cereals were the most prominent crops where wheat is dominating by more than half, followed by barley and maize (IPARD Program 2007-2013, 2007). Industrial crops accounted for 10% of the arable land where the dominant crop was tobacco followed by alfalfa. The fruit production was represented by grapes followed by apples, plums and sour cherries. Around 70% of the vineyards are used for wine production given that wine is the second most important product (after tobacco) in the export value of agricultural products. Grape and wine production contributes to 17-20% of the agricultural GDP (IPARD Program 2007-2013, 2007).

Vegetable production is one of the most important sub sectors in the Country. Most of the production is open field, followed by greenhouses and only small percentage of glasshouses. The structure of the represented crops in vegetable production is given in *figure 2* (IPARD Program 2007-2013, 2007):

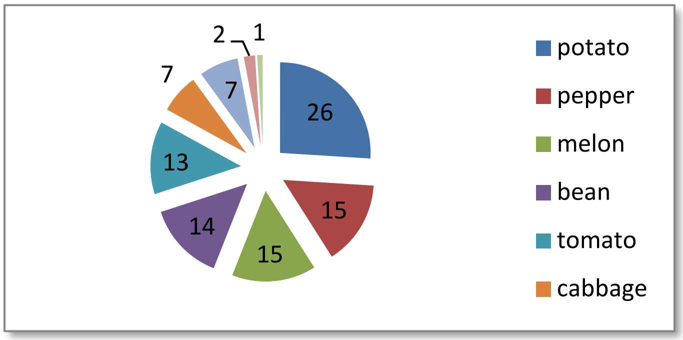


Figure 2: The structure of vegetable production in Macedonia in 2006

Recently, farmers are becoming more oriented toward production of value added horticultural crops that are demanded by the EU markets such broccoli, Brussels sprouts, asparagus and others (NARDS 2007-2013, 2007).

In general, most of the agricultural production is rain-fed, while less than 10% of the total cultivated area is irrigated. The existing irrigation systems are obsolete and inadequately maintained which worsens the situation. The on farm irrigation systems are mainly with old-fashioned furrows and very small portion with sprinkler and drip equipment (IPARD Program 2007-2013, 2007, pp.64-65).

1.1.3 Agro ecological zoning (AEZ)

“Agro-Ecological Zone is a land resource mapping unit, having a unique combination of land form, soil and climatic characteristics and/or land cover …..” (FAO, 1996 cited in the Second Communication to UNCCC, Sector: Agriculture, pp.77).

The concept of agro-ecological zoning (AEZ) introduced by FAO (1976) categorizes the geographical area in terms of its unique agro-climatic characteristics (www, UNDP PIU, 1, 2006, pp.77). Furthermore, in the Second Communication to UNCCC, Sector: Agriculture, 2006, the set of information relevant for categorization of the agro ecological zones is clearly explained in *figure 3*:

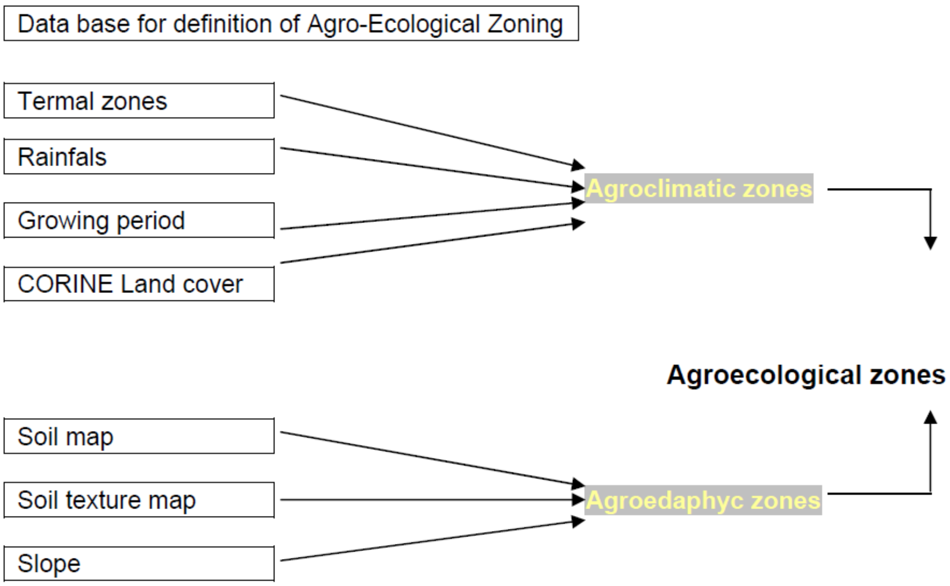


Figure 3: The categorization of agro-ecological zones

According to the World Bank, 2, 2010, Macedonia is divided in three agro-ecological zones: Mediterranean, Continental and Alpine zone (*figure 4)*.

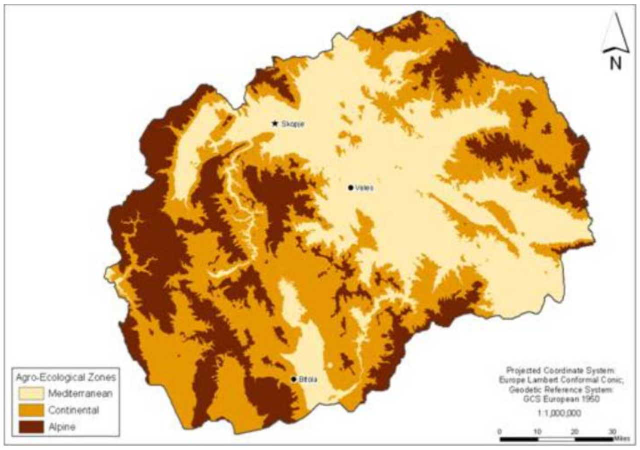


Figure 4: Agro-ecological zones in Macedonia

In Bergant (2006, pp. 14), Macedonia is divided in six geographical regions considering the different climate types and subtypes as:

- "South-eastern part with sub-Mediterranean climate,
- Central part with combined sub-Mediterranean /continental climate,
- Southern part with continental climate,
- South-western part with continental climate,
- Eastern part with continental climate, and
- Northwestern part with mountain/Alpine climate".

1.1.4 Climate change scenarios up to 2050

The SNCCC (2008) outlines climate change scenarios at the country level for the period until 2050. The performed analysis in the SNCCC (2008) of Macedonia is based on the four general circulation models (GCM's). However, there are obvious major differences in the extent of the envisaged changes between the four GCM models in association with the emissions scenarios.

According to the SNCCC (2008, pp.23), the temperature in Macedonia will increase, in combination with the decrease of precipitation with a trend of substantial decrease of summer precipitation and severe extreme events such as droughts and floods. On average, the temperature in Macedonia is predicted to increase by 1.0°C and 1.9°C by 2025 and 2050. The mean precipitation is projected to decline by 3% and 5%, respectively causing increased aridity in average on Country level.

A variation of the temperature and precipitation projections can also be noted on a seasonal basis, such as increased temperatures for all seasons varying from 1.5°C to 2.5°C for spring and summer in 2050 and increase in precipitation in winter (1%) and moderate decline in autumn (4%) and spring (6%). A significant decline in precipitation is noticed for the summer (17%). The trend toward a decline of precipitation in spring and summer is expected to seriously affect the agricultural production considering its importance for the crop growth.

Due to complex geography of the Country, climate change at the sub-national level is expected to be an important factor. The SNCCC (2008, pp.49-50) outlines these differences via localized empirical downscaling projections for the south-east, central and north-west parts of the country (*see table 1*).

Table 1: Future Sub-National Climate Projections for Macedonia compared to the 1961-90 period

Time horizon	Mean temperature Projection °C			Mean Precipitation Projection (%)		
	South-East	Central	North-west	South-East	Central	North-west
2025	1.2	1.1	1.3	-3	-3	-2
2050	2.3	2.2	2.6	-5	-6	-3
2075	3.4	3.3	3.9	-9	-9	-5
2100	4.6	4.5	5.3	-12	-13	-8

Source: SNCCC, 2008, pp.49-50

The biggest changes in terms of temperature increases are projected to occur in the north – east region, which also has the lowest project reduction in precipitation for 2050. The south-east and central regions may warm more moderately, but the participation will decline at a greater rate.

In respect to the agro-ecological zoning (www, World Bank, 2, 2010), the most vulnerable zone is expected to be Povardarie region, especially area of confluence of Crna and Bregalnica River with Vardar. Other highly vulnerable zones are the southeastern parts of the country, southern Vardar valley, Skopje - Kumanovo valley and Ovche Pole. As less vulnerable zones are considered Pelagonija Valley, Polog and Prespa - Ohrid region. The most vulnerable crops in regards to the agro-ecological zone are given below (*see figure 5*):

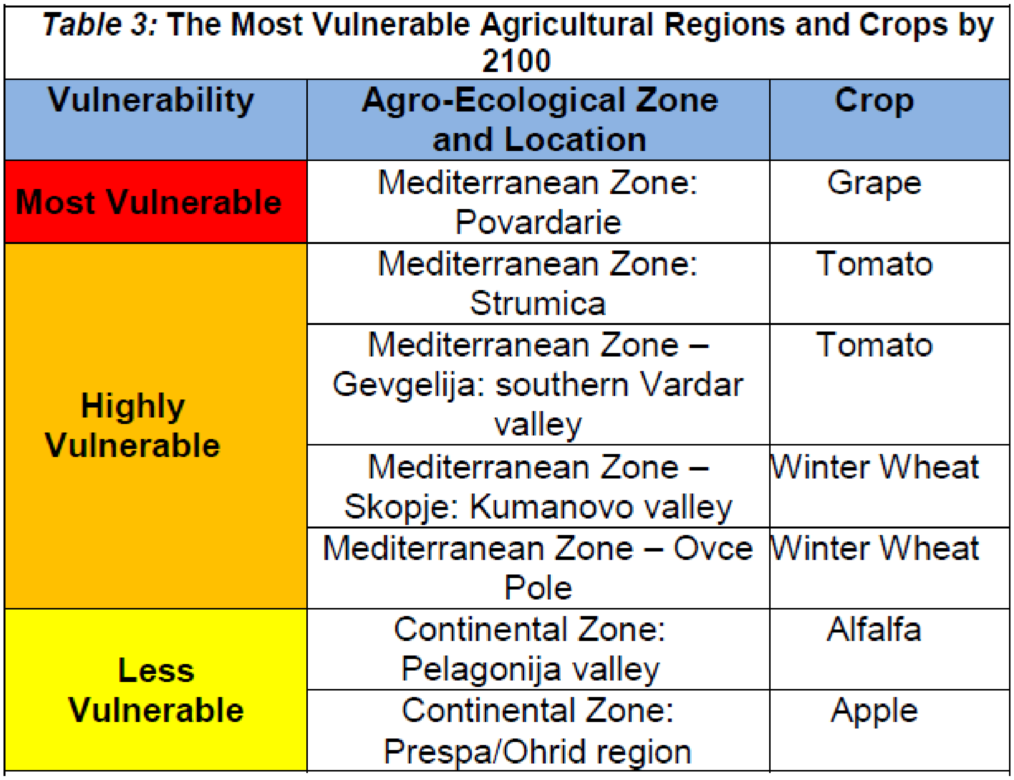


Table 3: **The Most Vulnerable Agricultural Regions and Crops by 2100**

Vulnerability	Agro-Ecological Zone and Location	Crop
Most Vulnerable	Mediterranean Zone: Povardarie	Grape
Highly Vulnerable	Mediterranean Zone: Strumica	Tomato
	Mediterranean Zone – Gevgelija: southern Vardar valley	Tomato
	Mediterranean Zone – Skopje: Kumanovo valley	Winter Wheat
	Mediterranean Zone – Ovce Pole	Winter Wheat
Less Vulnerable	Continental Zone: Pelagonija valley	Alfalfa
	Continental Zone: Prespa/Ohrid region	Apple

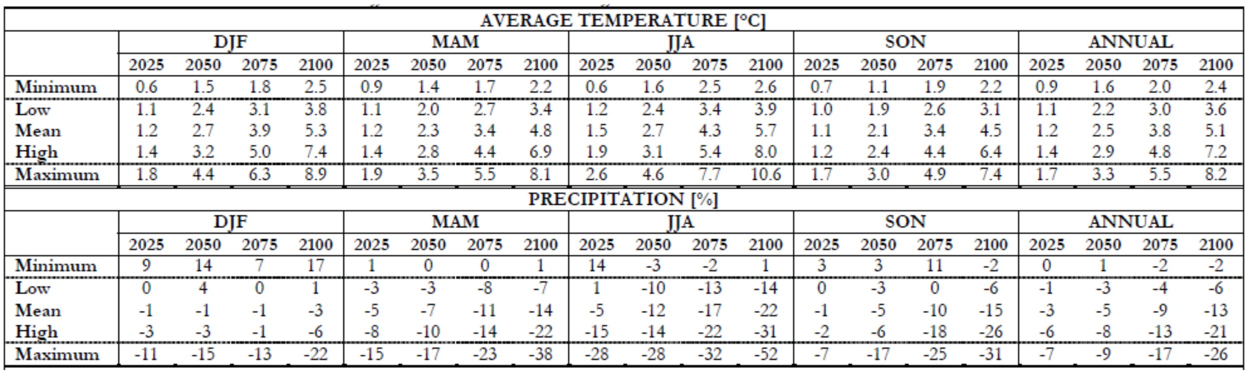
Figure 5: The most vulnerable regions and crops by 2100
Source: www, World Bank, 2, 2010, pp.7

1.1.4.1 Southern part of Macedonia

Bergant (2006) gives more extensive analysis for different sub-regions in the Country. Bitola region, together with Prilep is classified as southern part of the country. This region, together with south-western region, is characterized by similar climate conditions of continental climate (Ristevski, 2006 stated in Bergant, 2006, pp.28).

In line with the projected changes for Sub-Mediterranean climate regions, the precipitation is expected to decrease during the year, with the exception for the winter months where no changes are expected. The temperature will move up more dramatically relative to the decrease of precipitation, with the highest increase during summer months (Bergant, 2006). The projected changes of temperature and precipitation for southern part of the Country are given in the *table 2* (Bergant, 2006, pp.33).

Table 2: The projected changes of temperature and precipitation for southern part of Macedonia (Bitola and Prilep)



AVERAGE TEMPERATURE [°C]																				
	DJF				MAM				JJA				SON				ANNUAL			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Minimum	0.6	1.5	1.8	2.5	0.9	1.4	1.7	2.2	0.6	1.6	2.5	2.6	0.7	1.1	1.9	2.2	0.9	1.6	2.0	2.4
Low	1.1	2.4	3.1	3.8	1.1	2.0	2.7	3.4	1.2	2.4	3.4	3.9	1.0	1.9	2.6	3.1	1.1	2.2	3.0	3.6
Mean	1.2	2.7	3.9	5.3	1.2	2.3	3.4	4.8	1.5	2.7	4.3	5.7	1.1	2.1	3.4	4.5	1.2	2.5	3.8	5.1
High	1.4	3.2	5.0	7.4	1.4	2.8	4.4	6.9	1.9	3.1	5.4	8.0	1.2	2.4	4.4	6.4	1.4	2.9	4.8	7.2
Maximum	1.8	4.4	6.3	8.9	1.9	3.5	5.5	8.1	2.6	4.6	7.7	10.6	1.7	3.0	4.9	7.4	1.7	3.3	5.5	8.2

PRECIPITATION [%]																				
	DJF				MAM				JJA				SON				ANNUAL			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Minimum	9	14	7	17	1	0	0	1	14	-3	-2	1	3	3	11	-2	0	1	-2	-2
Low	0	4	0	1	-3	-3	-8	-7	1	-10	-13	-14	0	-3	0	-6	-1	-3	-4	-6
Mean	-1	-1	-1	-3	-5	-7	-11	-14	-5	-12	-17	-22	-1	-5	-10	-15	-3	-5	-9	-13
High	-3	-3	-1	-6	-8	-10	-14	-22	-15	-14	-22	-31	-2	-6	-18	-26	-6	-8	-13	-21
Maximum	-11	-15	-13	-22	-15	-17	-23	-38	-28	-28	-32	-52	-7	-17	-25	-31	-7	-9	-17	-26

Source: Bergant, 2006, pp.33

1.1.5 Vulnerability of crop production sector

The projected scenarios for Macedonia with regard to the climate changes for the future 50 years present both threats (increasing temperatures, potential for droughts etc.) and prospects in certain agricultural sub-sectors (a longer production period, increased yields for certain crops). Taking into consideration the overall level of development of the Country, the institutional capacity and the awareness and ability to adapt and cope with the potential threatening circumstances, at both the national and individual level, it is likely that the risks might outweigh any potential opportunities (www, World Bank, 2, 2010).

The rain fed crops will be more negatively affected by climate change than the irrigated crops depending of the varieties and the agro-ecological zones. Winter wheat may be even positively affected by climate change in some regions with a slight increase of the yield up to 10%. Maize will experience a negative effect of the predicted climate variations causing a yield decrease of 10 to 25% in entire country, while in the most affected regions yield reduction will be even more severe. Other summer crops, including vegetables, are expected to follow similar negative trend as for the maize (www, World Bank, 2, 2010).

The yield of the high value fruits, grape and apple is expected to decrease, while horticultural products will be less sensitive and are not expected to decrease if there is sufficient water supply. The adverse effects of the projected climate change will affect forage production and pasture areas that in turn can lead to volatile forage prizes and a shortage of pasture and water resources. In addition, the negative consequences facing the livestock sector will be felt by decreased productivity of the livestock breeds, specially affecting highly productive breeds. In that sense, the domestic breeds are considered to be more resistant to high temperatures and droughts (www, World Bank, 2, 2010).

The more severe projections of yield decrease are given by Second Communication to UNCCC, Sector: Agriculture, (2006). The yield decrease for the most vulnerable crops in 2050 vary from 12% for winter wheat to 78% for tomato. Winter wheat is expecting to decline by 12-17% depending on the production region despite the positive trend according to the World Bank projections. Yields of apples and grapes will be reduced for half, and alfalfa will face a decline of around 62%. The more severe projections for yield decrease are attributable to the fact that projections are based on rain-fed production without supplemental irrigation.

Although projections vary significantly, there is general agreement that impacts will be negative after 2050 for variety of summer and perennial crops across the majority of the country. However, the yield impact on winter crops like wheat is less certain, with both increasing and decreasing yields projected, depending on the assumptions of the underlying studies.

1.1.6 Crop production in Strezevo hydro-meliorative system (Pelagonia)

The Hydro System Strezevo is one of the most massive irrigation schemes in Macedonia built in 1978. It is located in the Southern part of Pelagonia Valley, covering a net area of 20,200ha and designed to provide approximately 95 million cubic meters of water yearly for the purposes of irrigated agriculture. Except for agricultural use, the system was indented to supply the additional needs for water to the Public water supply enterprise “Vodovod”, the Thermal power plant “Bitola” and the Sugar Factory ”Sekerana”. In addition, it provides water for electricity production through the four hydroelectric power plants: Strezevo, Bioloski minimum, Filternica and Dovledzik (Cukaliev, 2011 draft report).

The system is comprised of water reservoir and earthen dam; main canal and piping network and distributes water to the farms and other above mentioned users by feeding from the water flows from the nearby Baba Mountains: Kisavska, Graeska, Ostrecka, Zlokukanska, Stara Reka, Kinderka, Dragor River and Shemica River (Cukaliev, 2011 draft report).

In the last decades, in the process of transformation of the Country’s economy from a planned to market economy, this system has suffered great losses due to the restructuring of the formerly state owned enterprises, destruction of the infrastructure or burglary of the equipment. As a result of the above mentioned reasons the system’s capacity is now downsized to the current level of 5 208 ha (Cukaliev, 2011 draft report).

The storage capacity of the reservoir is estimated to 110 million cubic meters, but the effective supply of water is designed to 90 to 95 million cubic meters per year for irrigation purposes in agriculture. The system is equipped with various irrigation equipment of liner systems (photo 1), corners systems, portable sprinklers (photo 2), self-propelled vans (photo 3), automatic nozzles that are correlated to the pressure, soil characteristics and cropping pattern (Cukaliev, 2011 draft report).

Picture 1: Liner system

Photo 2: Portable sprinklers

Photo 3: Self-propelled vans

As one of the most extensive crop production regions, the Strezevo hydro-meliorative system is currently utilizing only one quarter (5,208 ha) of its area. The current crop production structure in Strezevo hydro-meliorative system is given in *table 3.*

Table 3: Crop structure in Strezevo hydro-meliorative system (ha)

	ha	%
Winter wheat	523	10.04%
Barley ISA	17	0.33%
Maize ISA	2016	38.72%
Tobacco oriental ISA	32	0.61%
Sunflower ISA	38	0.73%
Soybean ISA	183	3.51%
Sugar beet ISA	103	1.98%
Sugar beet ISB	0	0.00%
Alfalfa ISA	841	16.15%
Alfalfa ISB	0	0.00%
Maize silage ISA	427	8.20%
Maize silage ISB	0	0.00%
Meadow and grass ISA	308	5.92%
Watermelon and melon, ISA	51	0.98%
Potato and Onion, ISA	56	1.08%
Green pepper including industrial, ISA	213	4.09%
Tomato including industrial, ISA	33	0.63%
Vegetable include cabbage, ISA	159	3.05%
Orchards and grape, ISA	208	3.99%
TOTAL	5208	100.00%

Source: Cukaliev, 2011 draft report

As shown in the table 3, the most dominant crop is maize with a share of 38.72%, followed by alfalfa 16% and wheat 10%. The share of high value crops is relatively small. The most dominant horticultural crop is green pepper present with 4.09%, while other horticultural products have a share of less than 4%.

Cereals are the dominant crop in the region that is the most important grain region in the country. Due to intensive livestock breeding, feed production is well established. In the past, sugar beets amounted to more than 20 % but after the closure of the Sugar factory production is significantly reduced.

Nowadays, the system is only utilized to 25% of the full capacity. At present, about 5,208 ha are irrigated and 14,992 ha are rain-fed due to weak management and poor infrastructure condition of the irrigation system. The efficiency of the irrigation is unsatisfactory, implying that the water is spent 2.2 times more than actually needed (Pejovska, 2009).

1.2 Problem

Agriculture is one of the most affected sectors by climate change and strongly dependent on weather and climate (Bergant, 2006). The Climate Change 2007: Synthesis Report (www, IPPC, 1, pp. 28) points out that in vulnerable regions in South Eastern Europe climate change will worsen the conditions by increasing of the temperatures and drought and reducing of the water availability.

According to World Bank Report (www, World Bank, 1, 2009, pp.7), the Republic of Macedonia has an index of vulnerability slightly below 15 which ranks the country on the twelfth place (*figure 6*). The Climate Change Vulnerability Index takes into account three sub-indices: exposure, sensitivity and adaptive capacity of the country to climate change. Considering the three sub-indices, the country is characterized by a high exposure to climate change, limited adaptive capacity and moderate sensitivity to climate change. In that respect, Macedonia is the most vulnerable to the exposure of climate change, ranged on the fifth place in the ECA region (Europe and Central Asia) which indicates that the magnitude of the forthcoming climate change relative to the present natural variability is expected to be substantial.

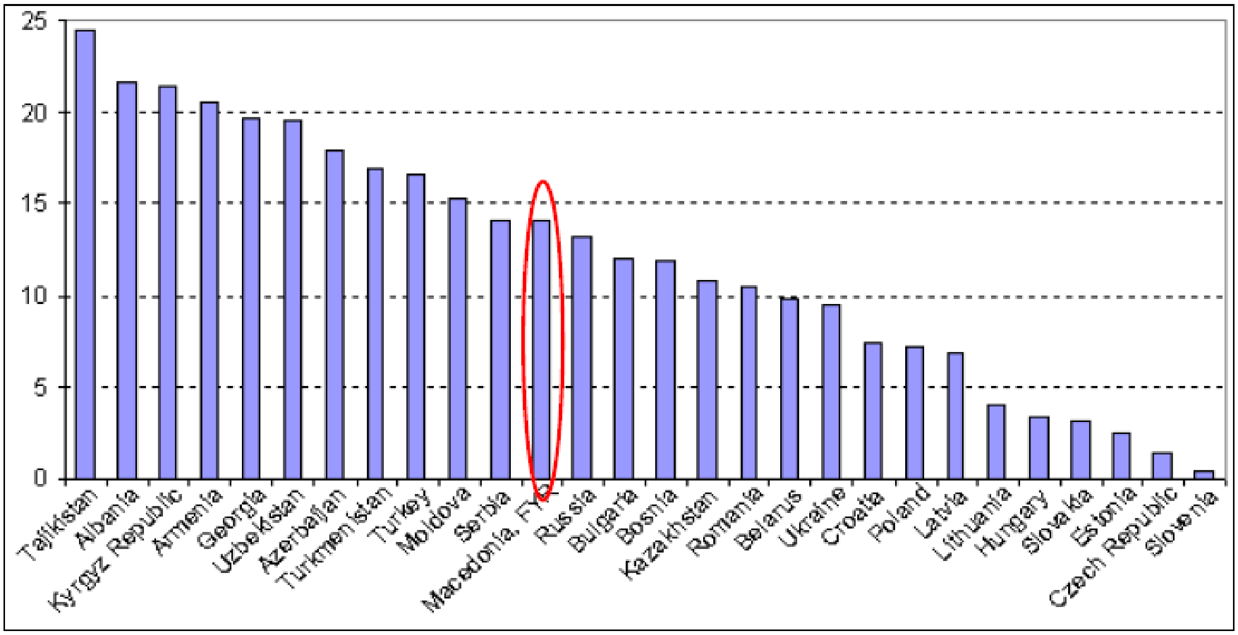


Figure 6: The index of vulnerability to climate change
Source: www, World Bank, 1, 2009, pp.7

The SNCCC (2008) identifies agriculture as one of the most vulnerable sectors in the Republic of Macedonia. With an unemployment rate of 32.2% in the country (SSO, Macedonia in figures, 2010, pp.29), agriculture is one of the most important sectors in the country contributing with 12% share in GDP in 2006 (IPARD Program 2007-2013, 2007). According to NARDS (2007) approximately 17% of the total working population is engaged in agriculture, 44% live in rural areas and agro-food products contribute with 17% to the total trade (2002-2005). Consequently, the agricultural sector is “prioritized as one of the most important sectors in the country’s economy in almost all strategic documents due to its importance for the socially security and poverty reduction" (SNCCC, 2008, pp.50).

According to the World Bank (www, World Bank, 2, 2010), the sensitivity of agricultural production to climate poses serious implications for Macedonia. The climate changes projections reveal high risks to agriculture, availability of water, food security and economic growth of rural population (www, World Bank, 2, 2010). Agriculture is "particularly important part of GDP" in Central Asia, South Caucasus and Southeastern Europe (www, World Bank, 1, 2009, pp.54). Considering that a large share of rural population is dependent on agriculture (19% employment in agriculture in 2008), rural population is particularly vulnerable to the risks caused by climate change (www, World Bank, 2, 2010). The influence is even higher because of a relatively low productivity in Macedonia due to the lack of capacities for climate change adaptation (www, World Bank, 2, 2010). Thus, for comparison the average wheat yield in Macedonia in 2008 is 3.4 t wheat/ha compared to 5.7 t/ha in EU 27 or with countries in the region, 4.2 t wheat/ha in Bulgaria and 5.5 t wheat/ha in Croatia (www, SSO, 1, 2010, pp.72).

Having in mind that only one quarter of the agricultural land in Macedonia is irrigated (SNCCC, 2008, pp.52), the adverse impact on agricultural production is expected to be even greater. The climate change scenarios predict adverse consequences to agricultural production and direct economic loss. According to the SNCCC (2008), major factors that may influence agricultural production are water deficit, aridity and occurrence of drought. The crop production will be the most vulnerable activity affected by the climate change. An increase in air temperature of 1.9°C in 2050 and 3.8°C in 2100 and an decrease in precipitation of -5% in 2050 and -13% in 2100 in comparison with 1990 may cause increased aridity and decreased yield in vulnerable areas, if crops are cultivated without irrigation (SNCCC, 2008, pp.13).

Some approximate estimates of the economic losses of some strategic crops such as winter wheat, grape and alfalfa due to climate changes indicate severe economic losses (www, UNDP PIU, 1, 2006, pp.121). The economic loss of decreased production of 42,000 t winter wheat in 2050 will be 5.4 million Euro, 19.7 million Euro for grape (122,700 t decreased production) and 7.5 million Euro for alfalfa (66,500 t decreased production). Yet, these figures are based on the worst case scenario without irrigation and adaptation strategies and should be taken with some caution. Currently, irrigation is applied only to a part of the production system. However, it is expected that irrigation will be more intensive in future.

Despite the adverse effects, climate change may create opportunities for crop production that have to be mentioned. Prolonged growing season, higher concentration of carbon dioxide and increased rainfall in some areas can positively influence on crop yields. (www, World Bank, 3, 2011, pp. 4).

1.3 Aim and delimitations

The aim of this study is to assess the potential effect of the projected climate change upon farm profitability, in particular to crop production in 2050 in one pilot region of the country. Latter, the same method could be used for assessment of the climate change over agricultural production in the country and used as an indicator for creating effective plans and programs for adaptation of the agricultural production towards climate variability and future climate change on national level. The objective of the study is to determine and adapt available land for crop production in Pelagonia region given the constraints in water availability and land in 2050 three climate change scenarios (High, Medium and Low). The study aims to address the following questions:

- What is the optimal allocation of land that maximizes total profit in 2050?
- What is the loss in net farm profit due to the climate change?
- What is the marginal value of additional units of water and land?

The study focuses on Pelagonia region, one of the most important agricultural regions in the Republic of Macedonia. Despite the classification as a less vulnerable region, the fact that Pelagonia is the most important region for cereal production and availability of data (meteorological, irrigation data, etc.) makes this region suitable for this analysis. Due to time constraints and resources, the study is limited only to part of the country and does not cover the entire territory.

The impact upon the climate on crop yield is analyzed by examining the two most relevant elements, air temperature and precipitation. Other factors such as soil salinization, changes in soil organic matter, extreme events (floods), prolonged duration of growing season and such are not taken into consideration. In this study, increased concentration of carbon dioxide, so called “fertilization effect” that can stimulate crop yields is not considered.

An important limitation of the study is the omission of the influence of technological change and application of adaptation measures in the assessment of the effects of the climate change. Technological improvement and adaptation strategies are considered to be important factors in assessing the impact of the climate change on agriculture. However, the current model includes deficit irrigation strategy for certain crops as an adaptation strategy.

An additional delimitation of the study is the lack of reliable price and costs projections. The IFPRI Impact world price data (per. comm. Mason-D'Croz, 2011) provides price projections for main agricultural commodities for 2050 at world level under several different climate scenarios. However, the projections are based on a partial equilibrium model and the costs of production are not modeled within it. In addition, an Impact model might not be super conducive to analyze a sub-national region since it aggregates several countries into a regional aggregate/group.

1.4 Outline

The *figure 7* provides an outline of the thesis. Chapter 1 provides a broad introduction to the problem that is going to be addressed in the study and formulation of the aim. Theoretical background in Chapter 2 helps to understand the nature of the problem and methods used by different authors to address similar problems. In Chapter 3, a detailed description of the method used in this study is explained. The results of the study, supported by empirical background of Strezevo case study to which the method is applied is given in Chapter 4 and Chapter 5. Subchapters of irrigated water requirements, crop area, net return and net profit are discussed in Chapter 5. Analysis and discussion in Chapter 6 explains the aim of the study and research questions. At the end, conclusion of the undertaken study, including suggestions for further research are presented in Chapter 7 and Chapter 8.

The chart below presents the outline of the thesis (*see figure 7*).

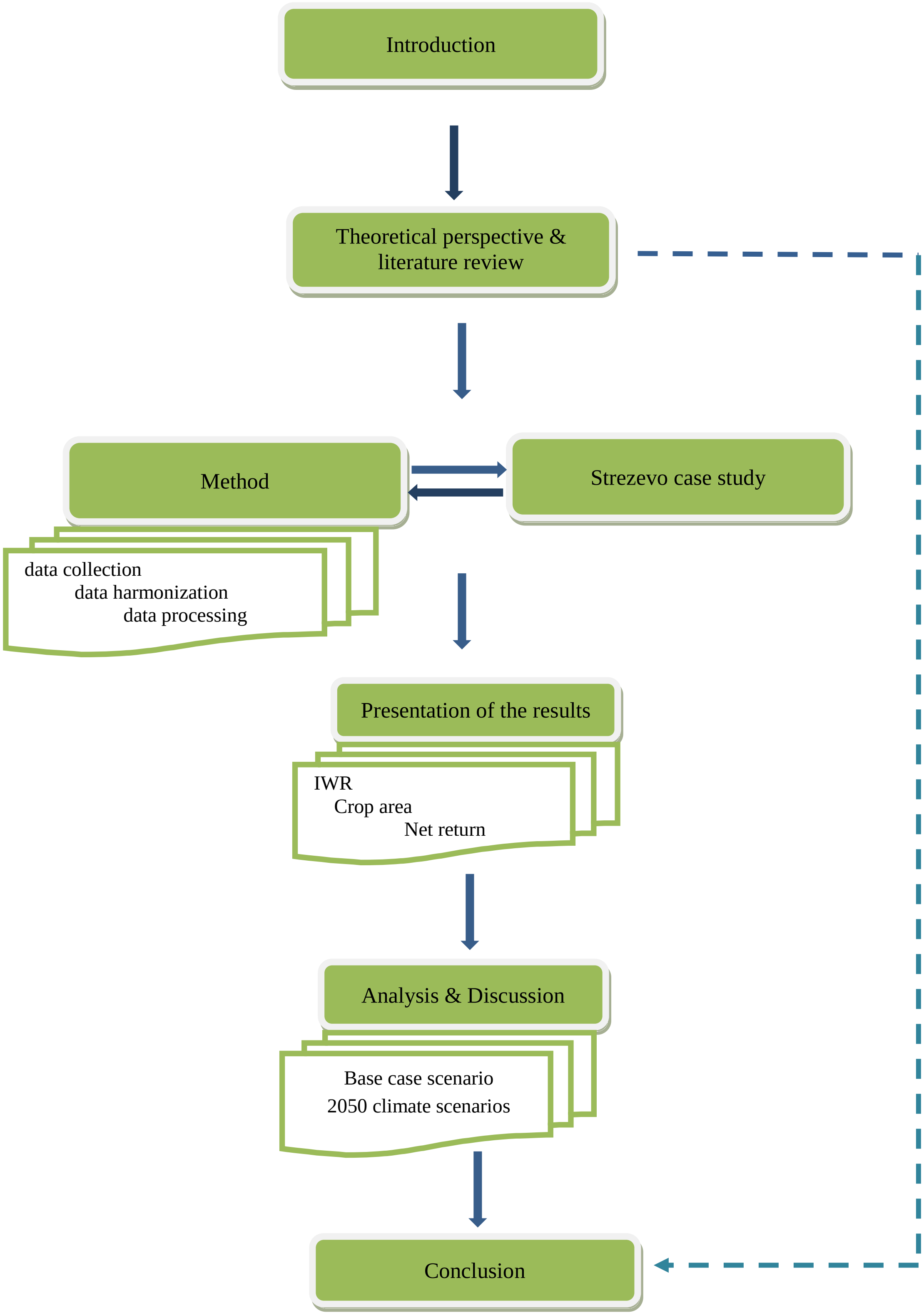


***Figure 7: Illustration of the outline of the study*.**

2 Theoretical perspective and literature review

This chapter gives an overview of the theoretical background of the problem studied. Brief introduction about the impact of climate change to agriculture followed by different approaches, methods and techniques for assessment of the climate change in agricultural production are discussed below. Adaptation measures and practices for mitigation of the adverse effects of the climate variability are also subject of review.
The chapter aims at better understanding the complexity of the problem and to recognize how it can be examined by extending the already-developed models.

2.1 Climate change and agriculture

The relationship between climate change and agriculture has been one of the most important topics on the research agendas and intergovernmental panels. Climate change is posing serious challenges especially when the world is facing food and economic crises. Hunger is on the rise threating the millions of people (pers. mess., Braun, 2009).

“Developing countries will be hit hardest by climate change and will face bigger declines in crop yields and production than industrialized countries. Small scale farmers will suffer the most. Without new technology and support for adjustments by farmers, climate change will significantly reduce yields” (pers. mess., Braun, 2009).

As a comparison, when the world wheat price rises by 75% over the last year, and the same is true with rice, for Americans who spent one-tenth of their income for food this is not a calamity. But for two billion poorest people on the planet, who spent almost 70% of the income on food, doubling the prices of main crops may cause switching from two to one meal per day (Foreign Policy, 2011).

The Food Policy Report reveals that in developing countries, climate change will reduce yield of the most important crops. Despite some positive effects to certain crops, the overall impact is expected to be negative, threatening global food security. As a result of climate change, an additional price increase of the most important crops is expected. In particular, this refers to wheat, rice, maize and soybean. An increase of the feed price will reduce meat consumption and cause a substantial fall in cereals consumption (Nelson et al., 2009).

Fairly consistent results are presented in Kane, Reilly and Buklin stated in Kaiser (1991). Generally, the crop prices tend to increase due to reduced production at global level due to climate change. Price changes will be higher for corn and soybean then for wheat and coarse grains. Most of the world production of maize and soybean is concentrated in the mid-latitude countries, as United States, Europe and Canada, that will be the most severely affected and will face the largest yield decline. The rice price will increase slightly as the majority of the production is concentrated to less affected regions. Northern latitude countries will, on the contrary, face positive effects. Apart from this fact, irrigated crops will suffer less than rain-fed crops (Adams et al., 1990 stated in Kaiser, 1991). Further research by Kaiser (1991) on the application of adaptive production strategies for three different climate warming scenarios, including temperature increase and increase/ decrease in precipitation, has revealed an actual increase or relatively stable yields when farmers use adaptive strategies. In fact, soybean and sorghum yields increase slightly by 2060, while corn yields remain relatively stable, with decrease only in the worst case scenario.

As projected by Nelson et al. (2010) by 2050, the wheat yields will decrease by 4.2-9 percent. The likely price increase varies from 100.7 for maize to 54.8 and 54.2 for rise and wheat respectively (% change from 2010 to 2050 year). This indicates imbalances in supply and demand of commodities as a result of demand (growing population and income), or supply factors (decreased productivity because of climate change).

Several studies have examined the economic and agronomic impact of climate warming at farm level. Climate changes will undoubtedly affect farmers in a variety of ways. A case study from Southern Minnesota reveals that depending on the geographical location, grain farmers from relatively cooler location could benefit from the climate warming and opposite, more southern locations could suffer more in terms of yield and revenue declines (Kaiser et al., 1993).

Many other authors have been investigated climate change in combination with economic and technology effects on the crop productivity. Li et al. (2011) claim that changes in temperature and precipitation when accompanied with economic and technology variables may not necessarily cause negative effects. Middle China where most of the maize production is rain-fed is a highly dependable on precipitation in comparison with the Midwest area of the United States where water is not a limiting factor. Thus, different climate scenarios will pose different impact on maize productivity in both regions. By increases of temperature by 1.46 °C and precipitation by 30% including technology improvement, maize yields will drop by 7.44% in US and increase by 23% in Middle China due to China’s higher sensitivity to precipitation. Other extreme scenarios with a temperature increase of 1.46°C and precipitation decrease by 30% including technology improvement, the increase in maize yield will be much higher in US than in Middle China as the water is not limiting factor in the Midwestern US.

Concerning food security, a more comprehensive approach is discussed by Nelson et al. (2010). The model for assessing of the impact of climate change upon three key commodities relies not only on biophysical data (climate, land, soil) but includes socioeconomic parameters of supply on demand on certain crops. As such, trade flows are discussed as a factor that contributes toward climate change mitigation. In particular, due to the worsen climate conditions, productivity of the affected crops is likely to decrease and large increase in imports can lead to a higher world price. Thus, for the country, that has a comparative advantage in production of certain crops due to favorable climate conditions and resource endowments, a change of the climate may endanger its comparative advantage. Climate change, as well changes in consumer preferences, alters the comparative advantage.

Climate change will affect the market supply and demand and has a potential to change quantities produced and consumed as well as market prices. For example, when climate is becoming hotter and drier, domestic crop production is expected to decline while domestic prices rise. In other circumstances, alteration of climate could reduce consumption of goods and prices of these commodities may start to fall (Callaway et al., 2010).

Many countries will encounter a net decrease in net welfare due to climate warming, with exceptions of the two large exporters of agricultural commodities, Argentina and Australia (Kane et. Al; Adams et al., 1990 stated in Kaiser, 1991). Consumers will be major losers. As prices increase, the consumer surplus decreases. Instead, producers will gain. Producer surplus will increase because market price will increase more rapidly than decrease of production. In total, net economic surplus of the society will be negative because consumer losses will be bigger than producer gains.

2.2 Adaptation measures and strategies for tackling climate change

The climate change consequences where climate factors are considered may not be as dramatic as predicted. (Li et al.2011). Technology improvement effects may contribute in alleviating of climate change over the maize yields and prevention of intense yield decrease (Li et al.2011). According to Nelson et al., (2010), pp.86, “the challenges from climate change are manageable”. With specific adaptation measures for intervention in land and water productivity, the undesirable effects from climate change can be partially or even substantially reduced.

Various on-farm adaptation strategies for combating climate warming have been discussed by Kaiser et al. (1993). As discussed in the study, the negatively affected regions could effectively adapt to the climate warning through introduction of technological and agronomical improvements. Adaptation strategies such as adjustment of crop mix, alteration to later-maturing crops, changing the sequence of field operation, switching to draught resistant crops and such could help these regions to take advantage of the prolonged growing season and successfully combat climate change. Other research by Kaiser (1991), has shown that the difference in corn yields could be improved to about thirty percent with introduction of adaptive strategy (climate change scenario for 2060 with increase of temperature for 2.5°C and 10% less precipitation). When farmers are not able to introduce the adaptation strategy, corn yields start to decline continuously in all three climate change scenarios. In all cases, adaptation has an important role in mitigating consequences of the climate change over crop productivity.

Similary, Deressa et al. (2009) argue that adaptation policies should be created for specific agro-ecological zone/s instead as a uniform intervention, in line with advantages and constraints of the specific area. As claimed by Deressa et al. (1993), technology investment in irrigation, introducing of draft resistant and early growing crop varieties, as well as enhanced education could buffer the economic impact of harsh climate conditions in Ethiopia.

The uncertainty of agricultural farm business is discussed by Kandulu (2011). Agriculture, especially rain-fed, is a high-risk associated business. Climate change is the main factor of uncertainty of economic sustainability of the rain-fed agriculture on long run (Marton et al., 2007; Iglesias and Quiroga, 2007; Lotze-Campen, 2009 stated in Kandulu, 2011). As claimed by Kandulu (2011) diversification of farming activities is a powerful strategy for mitigation of risk.

Because climate change affects the productivity of crops with different intensity depending of the crop variety, a diversified farming system could substantially reduce risk and variability of economic returns. Introduction of diversified farming system such as a multiple crop system instead single one and combination of crop and livestock production could successfully reduce standard deviation of economic returns for about 50%. Diversified production offers possibility for hedging against risk in rain-fed agriculture.

Li at el. 2011 argue that adaptation strategies based on greater specialization of the country/region that has benefited from the climate change will partially offset the adverse effects of the climate change by stabilization of maize production and shortage at a global level.

In line with above, Nelson et al. 2010 argue that trade flows between regions based on their relative comparative advantage can partially compensate for the reduced productivity of certain crops. By allowing positively affected regions to exchange goods with other negatively affected, the climate variation can be offset to a certain degree, but cannot be eliminated. Specialization in certain crop production based on the resource endowment under new climate conditions will be beneficial for the county. Additional factors, free trade regime, economic incentives or disincentives play an important role in mitigation of the negative effects of climate change in agriculture (Kaiser, 1991). Naylor et al (2006) claim that adaptation to climate change could not be successful without taking into consideration markets, preferences of producers and buyers, and technological changes in future.

On a country level, adaptation to climate change in agriculture is discussed on national and farm level (www, World Bank, 3, 2011). Measures for adaptation on national level include strengthening institutional capacities in terms on introduction of dry resistant crops and high temperature resistant livestock, training of farmers for more efficient water utilization, provision of short term weather forecasts, land consolidation for enabling larger investments in agricultural technology.

Among the highest priority adaptation measures on AEZ and farm level are extension of the irrigation infrastructure, especially in the AEZ with continental climate, optimization of the water utilization on farm level, cultivation of more-resistant crops and know-how for high yield cultivation in all AEZ (www, World Bank, 3, 2011).

2.2.1 Agriculture and water scarcity

“Agriculture is having to adapt to significant impacts of climate change, while at the same time providing food for a growing population. Meeting climate change, food security and trade commitments presents both challenges and opportunities for the agri-food sector”. (www, OECD, 1, 2010). Today, agriculture is the biggest consumer of water contributing with about 70% of all withdrawals, and even up 95% in developing countries depending on the applied technology (www, UN-Water, 1, 2011). The main use of water in agriculture is for irrigation. Irrigated agriculture plays a crucial role in agricultural production with a share of 40% of the food production and 29% of the harvested land. By 2030, around 50% of the agriculture will be irrigated (www, UN-Water, 1, 2011).

Concerning that 70% of the water withdrawals belong to agriculture, utilization of the irrigation water cannot simply be taken as granted, but should be considered as a major concern for the global land use balance (Hertel, 2010).

Irrigation is one of the most important strategies, if not the most important, for adaptation to climate change. Kaiser (1991) finds that irrigated crops suffer less and have higher yields than not irrigated. In line with this, the author claims that costs for irrigation and area under irrigation would increase considerably in future. Determination of the demand and supply of irrigation needs will become more and more important in assessment of the future climate change in agriculture.

Different irrigation strategies and techniques for more effective and rational use of limited water supplies are discussed by different authors. As claimed by Kirda (2002), sprinkler and drip irrigation are considered to be more effective than traditional surface techniques. New approaches such as deficit irrigation are becoming more popular methods for improvement of water productivity.

With deficit irrigation practices at certain period of the crop growth or during the whole period, water supply to the crop is reduced at the level where the yield reduction is insignificant. Water savings due to deficit irrigation are used for irrigation of other crops or extension of the irrigated area. Such techniques enable optimal use of water and ensure a high level of water efficiency to achieve higher productivity per unit of water applied. Most suitable crops for deficit irrigation are drought resistant crops and preferably with a short growing period (Kirda, 2002).

Mousavi et al. (2011) claim that although maximum yield can be achieved with full irrigation and by meeting of complete crop water requirements, application of deficit irrigation strategy could increase irrigated area or frequency of cultivation. The optimal water application for deficit irrigation should be adjusted towards achieving maximum economic value in response to yields and costs function.

In parallel, Shock&Feibert, (2002), claim that as deficit irrigation strategies expose crops to a certain degree of water deficit, they cause reduction in yield and reduce water costs. Considering the economic objective for application of deficit irrigation, the reasons behind is that the benefit of the reduced water costs exceeds the reduction in income caused by yield decrease.

2.2.2 Deficit irrigation strategies

Having in mind the great challenge of the future for increasing of the food production with less utilization of fresh water resources, improvement of the water productivity is one of the main targets in agriculture, especially in arid and semi-arid regions (www, FAO, 4, 2002, pp.1-2).

Among many irrigation strategies for optimization of water use efficiency, deficit irrigation is becoming more and more popular. Irrigation techniques and scheduling are one of the more rational and effective strategies. While drip and sprinkler irrigation are considered as a less efficient traditional surface practices, deficit irrigation is a more innovative method for increasing water use efficiency (Kirda, 2002).

The deficit irrigation aims to save water by exposing crops to periods of water deficit when yield reduction is minimal. According to FAO (www, FAO, 7,1979), the water deficit exposes crops to a certain level of water stress, either in a specific stage of the individual growth or during the entire growing period. Despite the fact that the maximum yield is reached when crop water requirements are fully satisfied, application of deficit irrigation is a compromise between yield reduction and reduction of irrigation costs. Through application of water saving techniques, the irrigation area or frequency of cultivation could be extended.

When a deficit irrigation strategy is applied, it is very important to know yield response to water deficit. The various crop development stages react different to water stress exposure. Therefore, period when water is applied and quantity of the applied water determine the yield decrease. For efficient utilization of irrigation water, optimization of irrigation scheduling and amounts of water applied are crucial (Zhang et al., 2002)

2.3 Approaches and models to measure the economic impacts of climate change

Different approaches and methods for assessing of the influence of the climate change are employed by different authors. Kaiser (1991) argues that assessment of the climate change in agriculture has to rely on different climate change scenarios. In such way, even in a situation with high level of uncertainty of the climate change scenarios, the existence of best-case and worst-case scenarios could set the limits of the possible economic output. Measment of the economic impact of the climate change is based on partial-equilibrium or general-equilibrium models. The partial-equilibrium models may exaggerate the impact of the climate change because they do not encompass input substitution that will apparently appear to any change in a climate. Computable general equilibrium (CGE) models take into consideration impact of all resource to the certain degree and allow greater flexibility regarding input substitution. Thus, assuming that agricultural markets will be spread on international level, general-equilibrium models will provide a more accurate estimation of price effects driven by climate change.

Deressa et al. (2009), similar to Kaiser (1991), stress out two main models for assessing the economic impact: general equilibrium (economy wide) and partial equilibrium model. General equilibrium models assess the economic impact as a complex system of interactions among industry, production, institutions and the world. Partial equilibrium models are narrow down on a specific part of the global economy, for instance single market. As climate change influences different sectors of the overall economy, economy wide model (CGE) is more convenient for assessment of the environmental issues (Oladosu et al., 1999; Mabugu, 2002) stated in Deressa et al. (2009). However, complexity of these models constrains their application.

The partial equilibrium models differ in regards to the approach used: crop pattern, production function and Ricardian approach (Deressa et al., 2009). In parallel, Callaway et al. (2010) has distinguished three approaches and models for estimation of the economic and agronomic impact: agronomic, agro-economic and Ricardian approach. As discussed by Deressa et al., (2009), the crop pattern approach relies on agro ecological zoning (AEZ) where soil characteristics and biophysical parameters of crops determine the agricultural output and cropping pattern.

Similar, agronomic approach discussed by Callaway et al. (2010) determines crop yields in response to soil, climate and cultivation variables. The economic output of yield variation is estimated as a multiplied value of the crop yields with referent crop prices and crop areas. The models based on the agronomic approach use simulation models for estimation of the crop yield in response to climate in different periods and different spatial distribution. As such, these models are used to measure the impact of different management practices in relation to the type, time and quantity of input applied (water, fertilizer, plowing etc). The advantage of agronomic models is that they are successful in the selection of different management practices such as tillage method, row spacing and such. A similar view is given by Deressa et al., (2009), pointing out that adaptation options could be easily addressed by the crop pattern approach.

Other advantages of agronomic models are their application in a variety of problems, not necessarily connected to climate change. These models provide “no regret” decision what means finding the most suitable decision without any harmful consequences on any possible output (Callaway et al., 2010).

Among their weaknesses are that they are data-intensive and are not applicable for assessment of the climate change on farm-level (Callaway et al., 2010). Also, all relevant parameters should be explicitly modeled and oversight of one relevant factor could seriously threaten the results (Deressa et al., 2009). Advanced crop yield simulation models such as CERES, EPIC and WOFOST are applied for yield response to weather variations.

The second approach discussed by Deressa et al., (2009) is the production approach. This approach takes into consideration climate change by the introduction of climate variables (temperature, precipitation, CO_2) in the production function. Kaiser et al.(1993) has used this model for estimation of crop yields in relation to the climate variables.

The limitation of the model is that it does not address farmer adaptation to climate change (Mendelsohn et al., 1994; Dinar et al., 1998 stated in Deressa et al., 2009). In addition, because of the extensive research for each crop involved in the model and intensity of the workload, the model is used only for the major crops for production.

In parallel, Callaway et al. (2010), discuss the agro-economic approach. This approach is based on estimation of crop prices in relation to agricultural markets and production function (crop yields in response to climate variables). Models applied in this approach are based on spatial equilibrium models. They simulate decision making processes in relation to the supply and demand of agricultural commodities at different agricultural markets. In fact, introduction of climate variables cause changes in the volume of production of a certain commodity. Because of that, disturbances in the supply and demand of the agricultural commodity on the regional or international markets occur. In this course, prices of agricultural commodity change.

Similarly to the agronomic models, the agro-economic models provide “no regrets” approach. The real value of these models lies in the possibility to assess the economic impact of the climate change over agricultural sector and help decision makers in adapting most suitable agricultural and rural development policies. Based on the expected income and risks associated with the future crop price, they determine the most profitable combination of crops including timing and management regime. These are non-linear models where objective function is defined as maximization of the net welfare.

The last approach discussed by Callaway et al., (2010) is the Ricardian approach. It examines the behavior of consumers, producers and suppliers in relationship to the economic value of the market output. Under the climate change conditions, the market output depends on the climate variation. The approach is also known as “revealed preferences” because it determines preferences of the economic agents based on their behavior.

The Ricardian model relies on the changes of consumer and producer behavior to foodstuffs in relation to the climate changes. This model uses a land value equation for estimation of the agricultural land values as a function of metrological variables. The metrological variables reflect climate variability and other physical and socioeconomic features that determine the land prices (Mendelsohn et al. 1994, stated in Callaway et al., (2010).

The Ricardian model is also discussed by Deressa et al. 2009. In comparison with the production function approach and its limitation to assess the farmer adaptation to climate change, Ricardian model allows profit maximization based on adaptation techniques such as changes in the crop mix, scheduling of periods for planting and harvesting and other agricultural techniques.

The advantage of the model is that it is a less data demanding model in comparison to the previously discussed models by Callaway et al. (2010) and in lack of available data for developing of agronomic models this model is particularly useful. Similarly Deressa et al. (2009) claimed that an advantage of this model is its cost effectiveness because many of the data needed related to production, climate and socio-economic analysis are easily available. The main limitation of Ricardian models is very poor management of natural resources if they are not connected to the climate change (Callaway et al., 2010).

Kaiser et al. (1993) when assessing the economic and agronomic impact of climate warming at farm level use a combined model of three components: atmospheric, agronomic and economic. The atmospheric component stimulated daily weather variations (temperature, precipitation and solar radiation) in four climate change scenarios. The agronomic component estimates crop yields in response to climate variations and predicted different cropping patterns in relation to the grain moisture and field time availability. The economic component makes projections on the crop prices in relation to the supply and demand variations caused by the climate modifications. At the end, the model produces an optimal crop mix, timing of the field operations and projections of the net farm income.

Similar approach is used by Alexandros (www, FAO, 5, 2010, pp. 14-15) stated in Hertel W.T. (2010). The assessment of the climate change is a successive process of four main stages: estimation of the future GHG based on the development of the global economy; conversion of the GHG emissions into regional or local projections on changes into atmospheric composition (temperature and precipitation) with General Circulation Models (GCM); appliance of these stimulations on plant growth and agricultural productivity in various agro-ecological zones; and determination of the impact on agricultural economy through assessment of production, consumption and trade.

Yin (2003) introduces a much broader integrated model to study the impact of climate change to regional sustainability. The model incorporates physical, biological and socio-economic components of the region. The physical component considers climate, vegetation and land characteristics in order to group regions according to their similar physical features. Biological simulation models examine crop or plant growth in response to altered climate regime. Similar to Calaway et al (2010), crop yield simulation models such as CERES, EPIC and TAMW are used to predict growth response. These simulation models also offer a possibility to assess alternative options for adaptation, but they are limited on a small spatial scale and economic and technological changes are ignored. The social impact assessment models try to incorporate future social conditions into the method. The economic component of the model estimates economic implications of the climate change and appraises adaptation options. Most widely used methods for economic assessment are cost-benefit analysis and input-output analysis (Yin, 2003).

2.4 Techniques for managing resources to maximize profit

Depending on the model applied for measuring the economic impact of the climate change, different techniques are employed. Mathematical programming is a useful technique for system analysis when best possible option among set of feasible options should be made (Wagner, 1969; Chiang, 1984 stated in Yin, 2003).

According Lee & Olson, (2006, pp.42-43) linear programming is “perfectly suited” for typical decision problems that require consumption of limited resources. Debertin (1986, pp.331) states that problems that involve maximization or minimization of function that is subject to a constraint are typical mathematical programming problems. Further, it is explained that problems that involve either an objective function that is nonlinear, or nonlinear constraint, or both are nonlinear programming problems. In linear programming problems, the precondition is objective function and constraints to be linear (pp.331-332).

Cook & Russell (1989) have pointed out some distinctions on the methods used for solving linear programming problems. While graphical method is limited to problems with three or less variables, the Simplex method is suitable for solving larger problems with more variables. Many of the environmental assessment models are set as single objective models, or single sector problems, thus a linear programming (LP) technique seems appropriate for managing these models (Yin, 2003).

Brklacich & Smit (1992) employ a linear programming model for assessment of the effects of climate change upon the productivity of grain crops. Linear programming model is used to estimate maximum revenues that can be obtained and optimal allocation of available resources: land, labor and capital. The model is applied for optimization of crop production at farm level, but also for optimization of the crop production that would be feasible at macro scale, provincial level.

Similary, Cheng & McCarl, 1989 in Kaiser (1991) use LP technique for assessment of the impact of the climate change on agricultural markets. Namely, the maximization of the total economic surplus is defined by an objective function given the constraints on land, water and labor. The technique is applied for 64 production regions in US. Later, Kaiser, 1991has used dynamic and multi-stage linear programming at farm level for optimization of cropping mix, scheduling the field operations and net returns over a hundred year period.

A linear programming model is also applied by Frizzone et al. (1997) for determining optimal water resources used for irrigation. In case when water supply is a limiting production factor, the resource management should be based on crop profitability under the technical factor constraints that influence the profitability of the irrigation project. The yield functions are correlated to the water deficit and a strong yield-water relationship is established.

Yin, 2003 discusses multiple objective mathematical programming models. When the integrated climate change assessment is needed and different social, economic and environmental factors have to be integrated in the same model, the objective function is a multi-objective decision or multi-criteria decision. For such integrated models, Goal Programming (GP) technique might provide satisfactory solution.

The GP, as a multi-criteria linear programming, has a much broader application and much more capabilities to analyze decision-making process. It may handle with management of multiple objective problems and incorporate the decision maker’s preferences when decisions are made. The GP has three wide areas of application: allocation of resources to achieve the set of objectives, determination of the level of attainment of the established objectives and provision of the best solution under varying amounts of resources and established preferences (Lee&Olson, 2006). However, in reality the GP models are not without limitations. For the decision maker, defining a clear set of objectives well-matched to the real application of the climate change is very difficult (Yin, 2003). In reality, many of the goals are intangible and not measurable, thus GP cannot be applied under such circumstances.

Another mathematical programming technique is applied by Kaiser et al. (1993). The determination of optimal crop pattern under climate conditions is based on discrete stochastic sequential programming (DSSP). Given this technique, the decision making process is treated as a multi-stage process where decision made at a particular time depends of the previous decisions and outcomes. The optimal economic solution is dependent of the field operations that are divided in two stages: pre-harvesting and harvesting. Thus, the outcome of the decision made in the second stage is highly dependent of the decision made in the first stage (pre-harvesting).

Similar, Tran et al. (2011) claim that dynamic programming is proven to be one of the most suitable optimization techniques for managing a water reservoir operation. Namely, for the management of the reservoir operation, the most commonly used techniques are linear programming, non-linear programming and dynamic programming. The linear model is most popular technique for management of the water use in reservoirs and suits very well with the nature of this problem, but due to limitation in linearity and stochastic nature of hydrological relationships, it has a limited application. The non-linear programming overcomes the limitation in linearity, but the stochastic nature of the problem causes many difficulties for integration into the model. Due to the large numbers of calculations and time needed to find a solution, the non-linear programming is not a widely accepted technique for such problems.

The dynamic programming (DP) overcomes the above-mentioned limitations and perfectly accommodates this type of problems. By dividing the problem in sequences, the DP can manage time-sequential decision problems such as management of the water regime in the reservoir based on optimization of water demands for irrigation, water supplies in the field, water level in the reservoir and water needed for other purposes.

3 Method

The purpose of the study is to assess impact of the climate change over agricultural production in Pelagonia region in 2050. Numerous studies use different approaches and methods for assessment of the climate change over crop production. While Yin (2003) examines complex integrated model that incorporates physical, biological and socio-economic components of the region for assessing of the climate change over agricultural production, this model, in line with the developed model by Kaiser et al. (1993), is narrowed down to assessment of three main components: atmospheric, agronomic and economic component (*see figure* 8)

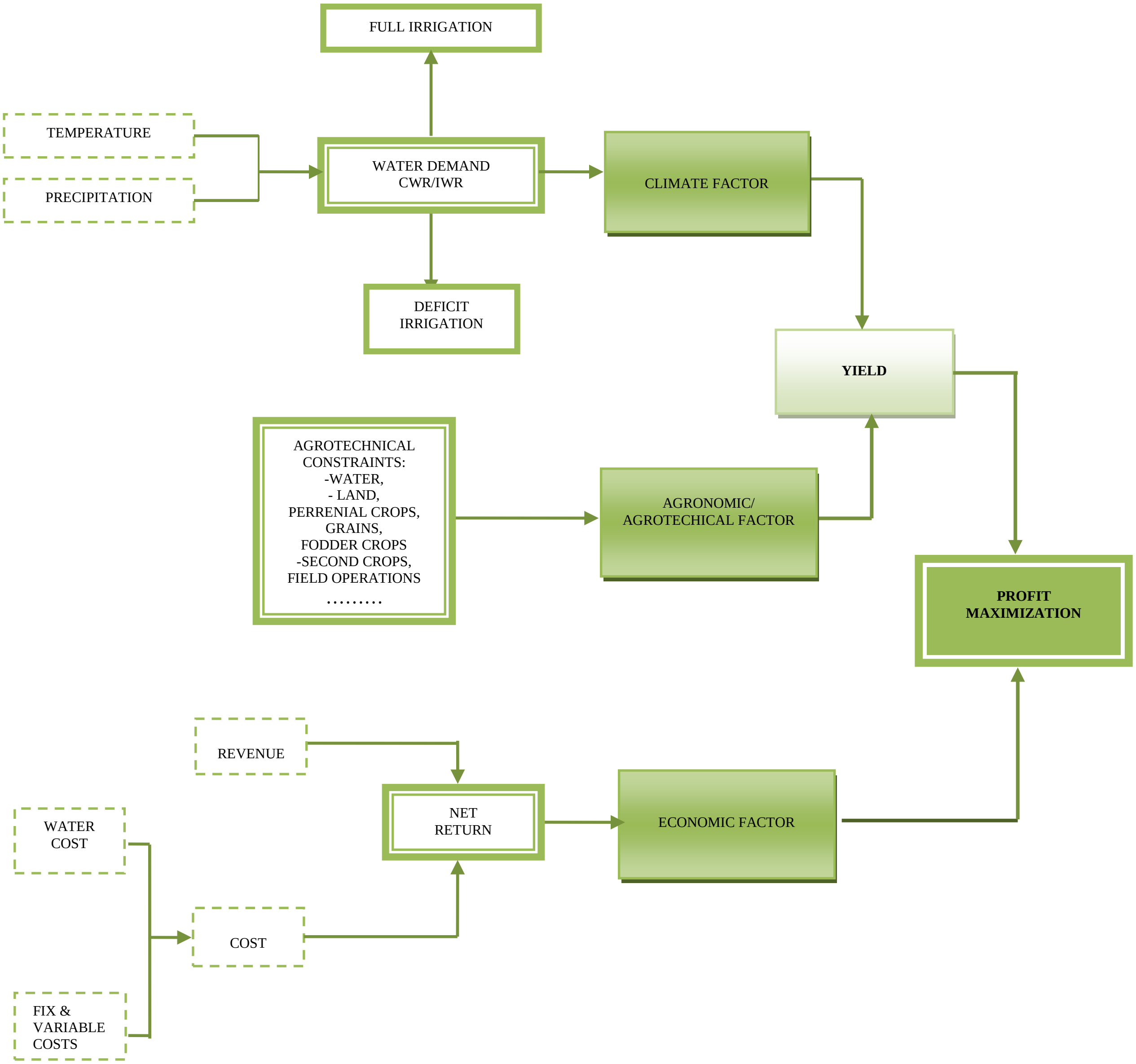


Figure 8: Model of the study

The atmospheric component includes weather variations (temperature, precipitation and solar radiation) in the base case scenario and three climate change scenarios for 2050 (Low, Medium, High). The agronomic component determines crop yields in response to the climate (changes in temperature and precipitation), while the economic component considers monetary value of yields based on net returns (revenue less cost) and allocated crop area.

Having in mind the nature of agricultural production, this approach does not consider influence of agricultural markets and technological improvements. In that respect, Macedonia as a small country with relatively small scale agricultural production could not influence the global supply and demand in the EU and world markets, as well as on the global market prices of agricultural commodities. Hence, the influence of agricultural markets and price changes are not taken into consideration. Considering the average size of Macedonian farms of 2.5 – 2.8 ha (NARDS, 2007, pp.23) fragmented in 0.3-0.5 ha parcels, technological factor such as machinery, field operations, harvesting techniques and alike is assumed to have relatively low effect to farm productivity in comparison to the effect on high scale agricultural production in other countries, thus it is not a subject of this analysis.

Despite, the novelty of the study lies in involvement of not only several major crops (wheat, corn, alfalfa), but huge variety of crops, especially including high value crops and sequential crops. Another novelty of the study is the possibility to choose the best gainful alternative among the available ones, such as selection of a more favorable irrigation strategy (full or deficit irrigation for certain crops) or possibility to choose between irrigated and non-irrigated crops. This modeling feature provides an opportunity for introduction of deficit irrigation as an adaptation measure based on the economic value of the production and resource endowment.

3.1 Mathematical programming model

Many integrated models for climate change impact assessment have been discussed in the previous chapter. Such complex models that incorporate social, economic and ecological variables require dynamic or discrete stochastic sequential programming with multi-objective or multi-stage decision making.

The model chosen in this study is based on a partial-equilibrium model using the agronomic/agro-economic approach where net farm return is determined in relation to the crop yields that are closely related to climate variables (changes in temperature and precipitation). Since the scope of this study is limited to a small spatial scale, or more exactly to a particular area, incorporation of the socio-economic factors such as population growth and income, economic development and technological change factors are not considered as relevant factors for farm-level assessment. In such circumstances, when supply and demand are not part of the analysis, prices are taken as an exogenous factor.

In this model, the objective function is defined as a single objective of profit maximization expressed as a difference between total income and total costs. The constraints in water, land and other agro-technical requirements are also defined as linear relationships. In addition, the model is designed to provide a possibility for selection of the more favorable irrigation strategies. Having in mind the nature of the problem for resource allocation, linearity of both, the objective function and constraints and selection of irrigation strategy, the linear programming technique, in particular Simplex method, is considered to be an efficient technique for providing a satisfactory solution. In line with this, Lee&Olson (2006) claim that this technique is a useful tool for decision-making problems that require a resource allocation problem. The strength of the model is ability to choose more effective irrigation strategies. In that term, application of integer programming is considered as a pre-requisite. For each crop that allows choice for selection of irrigation strategy, integer decision variables are introduced.

3.1.1 Mathematical formulation of the problem

Optimization techniques are applied to decisions made for optimal allocation of land. Using optimization, resource allocation problems are formulated as a mathematical programming model by defining the objective function, decision variables and constraints. The optimal solution of the model is determined by the objective function and values of the decision variables and constraints. The algorithm of the decision making process for optimal allocation of land is presented in *figure 9*.

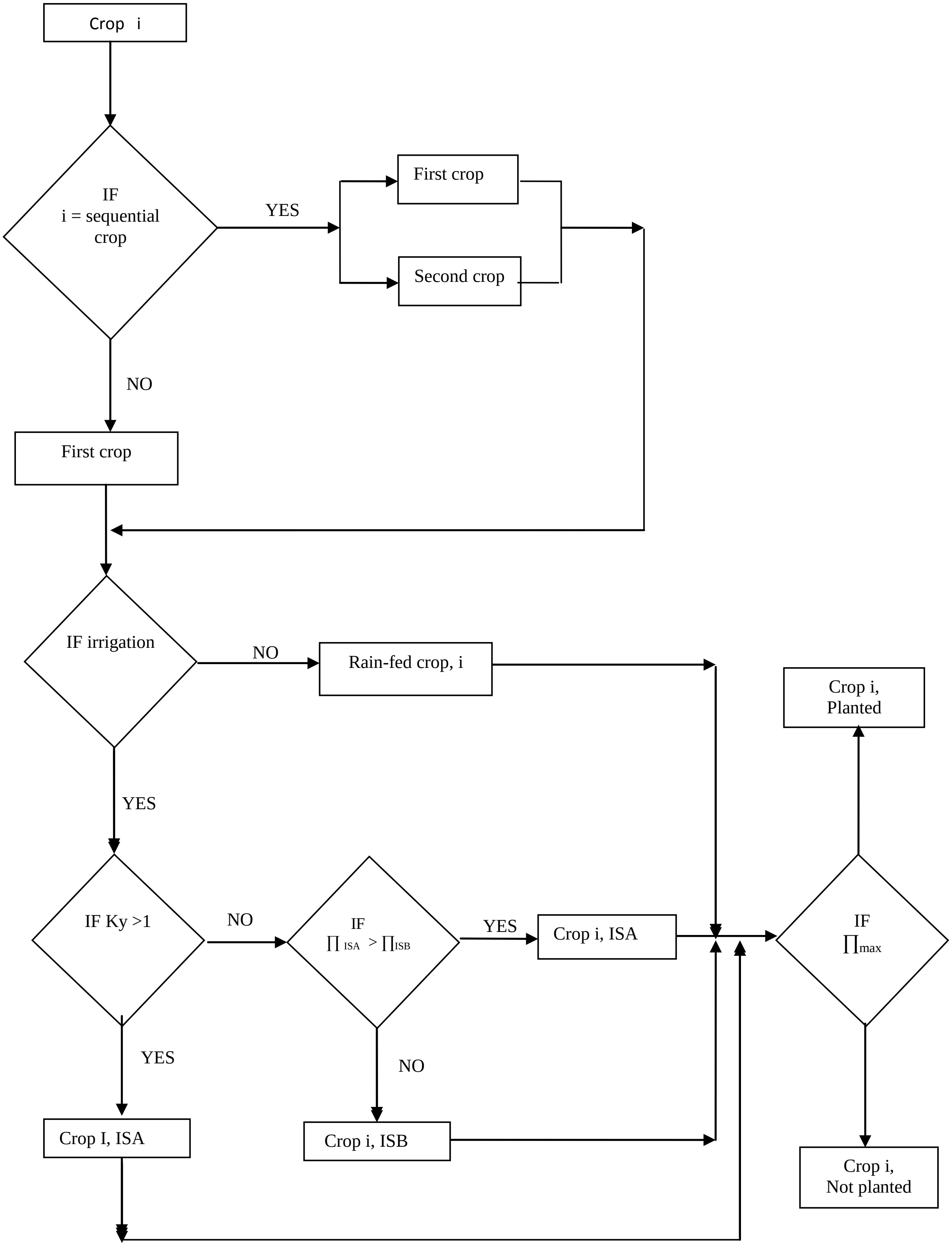


Figure 9: The algorithm of the model

The model includes first and second crops, as well as irrigated and not-irrigated crops. If the crop is suitable for double cropping, then it appears as a first and second crop. Otherwise, it is cultivated only as a first crop. Further, the decision is brought in respect whether the crop is cultivated as an irrigated or rain-fed crop. If the outcome of the decision-making process is positive (irrigated crops), the following question relates to its sensitivity to water deficit. If the crop is less water sensitive (k_y less or equal 1), then the same crop appears under full or deficit irrigation. For high sensitive crops, only the full irrigation strategy appears. Rain-fed crops are directly subject to the decision-making process of profit maximization. The choice between full and deficit irrigation strategy is determined based on profit maximization criteria and resource availability. The irrigation strategy that maximizes profit given that water and land are constrained is selected.

At the last stage, crops including first and second crops, crops under full or deficit irrigation as well as rain-fed crops are subject to selection depending on the maximization of the objective function and in respect to the limitation of land, water and other agro-technical restrictions.

3.1.1.1 Objective function

The objective function is defined based on the research objective to choose an optimal solution of the production structure that maximizes aggregate profits in Pelagonia region. The objective function is formulated as net profit from sixteen different crops or group of crops subject to constraints on land, water and agro-technical practices. Considering the possibility that different crops could appear under different conditions including irrigated (either full or deficit irrigation strategy), rain-fed or second crops, a total 36 variables of crops appear in the model.

The profit maximization function is defined as difference between total income and total costs. The total production costs are consisted of fixed costs, variable costs not related to irrigation and costs for irrigation.

$$\prod_{max} = I - TC = I - (FC + VC_{exclw} + WC) \qquad (1)$$

where:

I – total income (MKD),
TC – total production cost including water (MKD);
FC – fixed production costs (MKD);
VC_{exclw} – variable production costs excluding water (MKD);
WC – water cost (MKD).

The total income is expressed as sum of irrigated (full and deficit), rain-fed and second crops:

$$I = \sum_{\substack{i=1\\k=A}}^{\substack{B\\N}} I_{ik} * X_{ik} + \sum_{\substack{i=1\\j=1}}^{\substack{J\\N}} I_{ij} * X_{ij} + \sum_{\substack{i=1\\s=1}}^{\substack{S\\N}} I_{is} * X_{is} \qquad (2)$$

$i=\{1,\ldots\ldots..N\}$
$k=\{A \vee B\}$
$j=\{1,\ldots\ldots..J\}$
$s=\{1,\ldots\ldots.S\}$
N-total number of irrigated crops,
A-crops with irrigation strategy A,
B-crops with irrigation strategy B,
J-total number of rain-fed crops,
S-total number of secondary crops.

where:

I – total income (MKD),
I_{ik} - income of crop i with k irrigation strategy (MKD/ha),
I_{ij} - income of crop i, not irrigated (MKD/ha),
I_{is} - income of crop i planted as secondary crop (MKD/ha),
X_{ik} – area of crop i with k irrigation strategy (ha),
X_{ij} –area of crop i, not-irrigated (ha),
X_{is} –area of planted as secondary crop (ha).

The remark given here is that irrigation strategy A (full irrigation) and irrigation strategy B (deficit irrigation) are mutually exclusive, thus each crop can appear either with full or deficit irrigation. The exclusiveness is defined by decision variables (chapter 3.1.1.2).

The income of crop i is calculated as yield per unit of area multiplied with price per unit of crop as follows:

$$I_i \text{ (MKD/ha)} = \text{yield(kg/ha)} * P_i \text{(MKD/kg)}, \quad \forall\ i=1,\ldots.N \qquad (3)$$

where
I_i - income of crop i (MKD/ha),
P_i – market price of crop i (MKD/kg).

The total costs for production of crop i are expressed as costs excluding water costs (fixed costs and variable costs without water costs) and water costs for irrigation:

The unit cost for irrigated crop i is expressed as:

$$TC_i = FC_i + VC_{i,exclw} + C_w * W_i, \qquad \forall\ i=1,\ldots N \qquad (4)$$

or

$$TC_i = PC_{i,exclw} + C_w * W_i \qquad \forall\ i=1,\ldots N \qquad (4a)$$

where:

$PC_{i,exclw} = FC_i + VC_{i,exclw} \qquad \forall\ i=1,\ldots N \qquad (4.b)$

TC_i – total production cost including water for crop i per unit area (MKD/ha);
FC_i - fixed production costs for crop i per unit area (MKD/ha);
$VC_{i,\ exclw}$ - variable production costs excluding water costs for crop i per unit area (MKD/ha);
$PC_{i,exclw}$ – production costs not related to water consumption (fixed production costs and variable production costs) for crop i per unit area (MKD/ha);
C_w – water cost (MKD/m3),
W_i-quantity of supplied water for crop i (m3/ha).

Or, as total costs of production including irrigated, non-irrigated and secondary crops:

$$TC=\sum\limits_{\substack{i=1\\k=A}}^{\substack{B\\N}}(PC_{ik,\ exclw} * X_{ik} + C_w * W_{ik} * X_{ik}) + \sum\limits_{\substack{i=1\\s=1}}^{\substack{J\\N}} PC_{ij} * X_{ij} + \sum\limits_{\substack{i=1\\j=1}}^{\substack{S\\N}}(PC_{is,\ exclw} * X_{is} + C_w * W_{is} * X_{is}) \qquad (5)$$

for $\forall\ k = \{A \vee B\}$

where:
TC - total cost for production (MKD),
$PC_{ik,\ exclw}$ – production cost for crop i with k irrigation strategy excluding water costa (MKD/ha),
PC_{ij} - production costs for crop i, non-irrigated (MKD/ha),
$PC_{is,\ exclw}$ – production cost for crop i planted as secondary crop excluding water costs (MKD/ha),
W_{ik} - quantity of supplied water for crop i with k irrigation strategy (m3/ha),
W_{is} - quantity of supplied water for crop i planted as secondary crop (m3/ha).

The objective function of the crop production in Pelagonia region is then defined as:

$$\prod\nolimits_{max} = I - TC = \sum\limits_{\substack{i=1\\k=A}}^{\substack{B\\N}} I_{ik} * X_{ik} + \sum\limits_{\substack{i=1\\j=1}}^{\substack{J\\N}} I_{ij} * X_{ij} + \sum\limits_{\substack{i=1\\s=1}}^{\substack{S\\N}} I_{is} * X_{is} - \sum\limits_{\substack{i=1\\k=A}}^{\substack{B\\N}}(PC_{ik,\ exclw} * X_{ik} + C_w * W_{ik} * X_{ik}) -$$

$$- \sum\limits_{\substack{i=1\\j=1}}^{\substack{J\\N}} PC_{ij} * X_{ij} - \sum\limits_{\substack{i=1\\s=1}}^{\substack{S\\N}}(PC_{is,\ exclw} * X_{is} + C_w * W_{is} * X_{is}) \qquad (6)$$

For simplicity of defining of the objective function, the aforementioned formula is rearranged in a way that total income and production costs excluding water per unit of area are expressed as gross margin coefficients per individual crop or group of crops and costs for water are separately expressed. Thus, the objective function is formulated as:

$$\prod_{max} = \sum_{\substack{i=1\\k=A}}^{\substack{B\\N}} C_{ik}*X_{ik} + \sum_{\substack{i=1\\j=1}}^{\substack{J\\N}} C_{ij}*X_{ij} + \sum_{\substack{i=1\\s=1}}^{\substack{S\\N}} C_{is}*X_{is} - \left(\sum_{\substack{i=1\\k=A}}^{\substack{B\\N}} C_w*W_{ik}*X_{ik} + \sum_{\substack{i=1\\s=1}}^{\substack{S\\N}} C_w*W_s*X_{is}\right) \quad (7)$$

where:
$\prod_{max}$ – maximal profit (MKD),
C_{ik} – gross margin for irrigated crop i with k irrigation strategy (MKD/ha),
C_{ij} – gross margin for non-irrigated crop i (MKD/ha),
C_{is} – gross margin for crop i planted as secondary crop (MKD/ha).

The gross margin coefficients are calculated as net income per unit area less costs excluding water cost per unit area, or:

$$C_{ik} = I_{ik} - PC_{ik,\ exclw} \quad (8a)$$
$$C_{ij} = I_{ij} - PC_{j,\ exclw} \quad (8b)$$
$$C_{is} = I_{is} - PC_{s\ exclw} \quad (8c)$$

This model is then further expanded to consider two irrigation strategies and possibility for cultivation of secondary crops. Hence, for irrigated crops, two irrigation strategies (full and deficit irrigation) are taken into consideration where individual gross margin coefficients for all adequate crops are calculated separately for both strategies. In addition, if crop is cultivated as secondary crop, different gross margin coefficient appears.

An adjustment of the real-world problem to the represented model was done by modifying nonlinear function of yield response to water to a “piecewise” linear function. The non-linearity of the yield response to water is eliminated through linearization of the problem by dividing the growing period in small intervals Δt where yield response to water can be considered as linear function and thus the possible error of the present model to be diminished to a non-significant value. Initially, the growing period for every crop was divided in four stages: initial, development, mid and late season stage (www, FAO, 7, 1979). Latter, these stages were divided on smaller intervals, 10 day periods (decades) within particular month (Pejovska, 2009). In response to the specific growth period, exact value of the single crop coefficient (k_c) was appointed. The value of the crop coefficient (k_c) per specific crop differs at different stages of the crop growth because of the variation in evapotranspiration during the various growing stages (see Appendix 1). Further, the values for crop evapotranspiration and irrigation water requirements are summarized on a monthly basis (mm/month) as given in Appendix 3.

3.1.1.2 Decision variables and constraints

The problem is based on the most relevant factors that pose a constraint in agricultural production. Although in a real-world there is a large number of criteria that could affect agricultural production, this study is pondered on the following decision variables and constraints:

3.1.1.2.1 Decision variables

This model provides a possibility for selecting the irrigation strategy that will maximize net return. For crops with $k_y < 1$, second irrigation strategy (strategy B) for deficit irrigation is introduced. The decision making problem whether strategy A or strategy B will be more profitable for a particular crop is attained with introduction of integer variables (Lee & Olson, 2006, pp.159-168). These variables are defined as an integer number of either 0 or 1. If a decision variable is selected, the value 1 is assigned to its solution and the value of the net return of representing strategy is added to the maximization function. If the outcome of the decision making process is 0, the strategy is not selected.

The decision making process for selection of more favorable strategy is defined by the relationships as expressed bellow:

$$X_{ik} \leq IX_{ik} * \bar{A}_i, \quad \forall\ i=1,\ldots.N, \ \forall\ k = \{A \vee B\} \qquad (9)$$

$$IX_{i,k=A} + IX_{i,k=B} \leq 1, \ \forall\ i=1,\ldots.N \qquad (10)$$

Where
X_{ik} – area of irrigated crop i with irrigation strategy k (ha),
$\bar{A}_i$ – land constraint for crop i (ha),
IX_{ik} – integer variable for crop i with irrigation strategy k (probability for occurrence of irrigation strategy A or B),

The restriction (9) defines that irrigated crop i with irrigation strategy k is cultivated only if integer variable IX_{ik} has value 1, on an area less of equal to its maximum restriction ($\bar{A}_i$). The restriction (10) enables only one strategy (A or B) to be chosen.

3.1.1.2.2 Resource constraints

These constraints restrict the use of available resources such as land and water. For utilization of available resources, the following relationships are used:

$$\sum_{\substack{i=1\\k=A}}^{\substack{B\\N}} X_{ik} + \sum_{\substack{i=1\\j=1}}^{\substack{J\\N}} X_{ij} \leq \bar{A}_i \qquad \text{(total feasible area for production)} \qquad (11)$$

$$\sum_{\substack{i=1\\k=A}}^{\substack{B\\N}} X_{ik} * W_{ik} + \sum_{\substack{i=1\\s=1}}^{\substack{S\\N}} X_{is} * W_{is} \leq W \qquad \text{(available water for irrigation)} \qquad (12)$$

$$\sum_{\substack{i=1\\k=A}}^{\substack{B\\N}} X_{ik} + \sum_{\substack{i=1\\s=1}}^{\substack{S\\N}} X_{is} \leq \bar{A}_w \qquad \text{(feasible area for irrigation)} \qquad (13)$$

The agro-technical and market constraints restrict minimum or maximum allowable area per particular crop:

$$X_{ik} + X_{ij} \leq b_{i1} \qquad \text{(maximum area per crop)} \qquad (14)$$

$$\text{for } \forall\ i=1,\ldots.N, \qquad \forall\ j=1,\ldots.J, \qquad \forall\ k = \{A \vee B\}$$

$$X_{ik} + X_{ij} \geq b_{i2} \qquad \text{(minimum area per crop)} \qquad (15)$$

$$\text{for } \forall\ i=1,\ldots.N, \qquad \forall\ j=1,\ldots.J, \qquad \forall\ k = \{A \vee B\}$$

$$X_{ik} + X_{ij} = b_{i3} \qquad \text{(for perennial crops)} \qquad (16)$$

$$\text{for } \forall\ i=1,\ldots.N, \qquad \forall\ j=1,\ldots.J, \qquad \forall\ k = \{A \vee B\}$$

Where:

A - total arable land (ha),
A_w - total feasible area for irrigation (ha),
W – total available water for irrigation (m3/year),
b_{i1} – maximum allowable area per crop i including irrigated and non-irrigated (ha),
b_{i2} – minimum allowable area per crop i including irrigated and non-irrigated (ha),
b_{i3} - area allocated for perennial crops that is considered constant (ha).

The values of the constraints (b_{i1}, b_{i2}, b_{i3}….) are determined based on the current situation in Strezevo system (Pejovska, 2009) and expert's opinion (pers.comm. Gjosevski, 2011, Martinovska-Stojcevska, 2011) considering agro-technical restrictions and market demand.
The values of the constraints used in this study are defined as follows:

- The total arable land of 20,200 ha of Strezevo Hydro-meliorative System (constraint A);
- The available water for irrigation in the reservoir changing from 95, 92.72, 89.57 and 87.71 (10^6 m^3) in Base Case, 2050 Low, 2050 Medium and 2050 High climate change scenario respectively (constraint W),
- Feasible area for irrigation (constraint A_w),
- Maximum allowable area for wheat (25%), barley (5%), maize (25%), tobacco (1%), sunflower (2.5%), soybeans (3%), sugar beets (2%), alfalfa (15%), maize for silage (7.5%), meadow and grasses (6%), orchards and grape (1%) given in constraint b_{i1},
- The land under orchards and vineyards that should not be subject of changes (constraint b_{i3}),
- Fodder crops of minimum 25%, given as minimum area of 20% for alfalfa and meadows and 5% for maize for silage (constraint b_{i2}), and
- Small grains (winter wheat and barley), a minimum 15% (constraint b_{i2}).

3.1.1.2.3 Sequencing constraints

The sequencing constraints ensure a proper sequence of crop planting. These constraints guarantee that second crops (maize for silage, cabbage, sunflower and soybean) are always planted after the first crop (winter wheat and barley). Hence, the restriction to what the second crop is subjected to, is that the cropped area of second crop (is) must not exceed the cropped area of the first crop (i) after which second crop is planted:

$$\sum_{\substack{i=1\\s=1}}^{\substack{S\\N}} X_{is} \le \sum_{\substack{i=1\\k=A}}^{\substack{B\\N}} X_{ik} + \sum_{\substack{i=1\\j=1}}^{\substack{J\\N}} X_{ij}, \qquad \exists\, X_{ik} \vee X_{ij} \qquad (17)$$

where
ΣX_{is} is the sum of all crops planted after the crops X_i (i=1, 2…., N).

In this study, the sequencing constraints are used for:
- Cabbage, sunflower and soybean planted as secondary crops after barley, and
- Maize for silage planted after winter wheat.

3.1.1.2.4 Non-negativity constraints

The non-negativity constraints are used to protect negative value of the cropped area. These constraints are defined as follows:

$$X_i \geq 0 \quad \text{for } \forall \ i=1,\ldots.N \qquad (18)$$

The restriction (18) has to be satisfied for all crops planted (irrigated with full or deficit irrigation strategy, rain-fed crops as well as secondary crops).

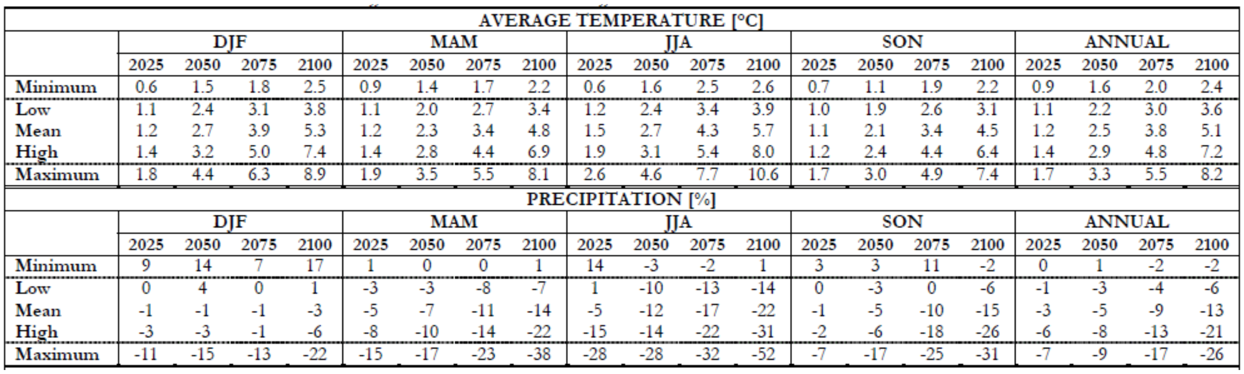
3.2 Defining different scenarios

For the purpose of this study, four climate scenarios are defined: base case scenario and three climate scenarios for 2050 (Low, Medium, High). In all climate scenarios, determination of the irrigation water requirements (IWR) and water availability are crucial for the assessment of the impact of the climate changes. Based on the climate variables (temperature, precipitation, solar radiation, wind speed), the reference evapotranspiration is calculated for each scenario. Further, in regards to the individual crop coefficients and effective rainfalls per particular scenario, irrigation water requirements for all crops are calculated. Depending on the yield response factor, second irrigation strategy for deficit irrigation is introduced. Separately, IWR for second crops are calculated. For non-irrigated crops, yield reduction due to water deficit is calculated for all scenarios.

The Base case scenario presents the optimal allocation of land under current climate conditions. Here, clear distinction should be made between current situation (what is actually cultivated) and optimal production under current conditions. In that respect, base case scenario in regards to the crops grown, area planted, irrigation water requirement and profits earned is different than the actual situation. Currently, the cropping pattern differs than optimal (base case scenario) in regards to the crops cultivated and their percentage representation. In addition, at present only 25% of the area is cultivated. In order to be able to compare all four scenarios, the base case scenario is considered on the total area and under optimal cropping pattern as it is a case in all other scenarios. This scenario is further elaborated in the data analysis chapter.

The 2050 Scenarios (Low, Medium, High) differs from Base case in regards to the projected climate change and yield reduction. The temperature increases and precipitation decreases (*table 4*) varies in all three scenarios. The 2050 Low case scenario is the most optimistic one, providing the most favorable outcome in 2050. The 2050 Medium case scenario is the most realistic scenarios with an output worse than optimistic, but better than pessimistic scenario. The 2050 High case scenario assumes more severe climate conditions and the expected net profit is the lowest compared to other scenarios.

Table 4: Projected changes of average temperature and precipitation for southern part of Macedonia under continental climate (Bitola and Prilep)



AVERAGE TEMPERATURE [°C]																				
	DJF				MAM				JJA				SON				ANNUAL			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Minimum	0.6	1.5	1.8	2.5	0.9	1.4	1.7	2.2	0.6	1.6	2.5	2.6	0.7	1.1	1.9	2.2	0.9	1.6	2.0	2.4
Low	1.1	2.4	3.1	3.8	1.1	2.0	2.7	3.4	1.2	2.4	3.4	3.9	1.0	1.9	2.6	3.1	1.1	2.2	3.0	3.6
Mean	1.2	2.7	3.9	5.3	1.2	2.3	3.4	4.8	1.5	2.7	4.3	5.7	1.1	2.1	3.4	4.5	1.2	2.5	3.8	5.1
High	1.4	3.2	5.0	7.4	1.4	2.8	4.4	6.9	1.9	3.1	5.4	8.0	1.2	2.4	4.4	6.4	1.4	2.9	4.8	7.2
Maximum	1.8	4.4	6.3	8.9	1.9	3.5	5.5	8.1	2.6	4.6	7.7	10.6	1.7	3.0	4.9	7.4	1.7	3.3	5.5	8.2

PRECIPITATION [%]																				
	DJF				MAM				JJA				SON				ANNUAL			
	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100	2025	2050	2075	2100
Minimum	9	14	7	17	1	0	0	1	14	-3	-2	1	3	3	11	-2	0	1	-2	-2
Low	0	4	0	1	-3	-3	-8	-7	1	-10	-13	-14	0	-3	0	-6	-1	-3	-4	-6
Mean	-1	-1	-1	-3	-5	-7	-11	-14	-5	-12	-17	-22	-1	-5	-10	-15	-3	-5	-9	-13
High	-3	-3	-1	-6	-8	-10	-14	-22	-15	-14	-22	-31	-2	-6	-18	-26	-6	-8	-13	-21
Maximum	-11	-15	-13	-22	-15	-17	-23	-38	-28	-28	-32	-52	-7	-17	-25	-31	-7	-9	-17	-26

Source: Bergant, 2006, pp.33

This study is based on three climate scenarios for 2050 (Low, Medium and High) excluding the two most extreme scenarios (maximum and minimum).

3.2.1 Water availability in Strezevo system

The water availability in Strezevo reservoir also varies depending on the projected changes of average temperature and precipitation. The estimated water capacity of the system of 95 million cubic meters due to climate change is expected to be reduced by 2050. The estimation regarding the available water supply is given in *table 5* (Cukaliev, 2011, draft report):

Table 5: Available water for irrigation (Strezevo reservoir)

Scenario	Water available for irrigation (m^3/year)
Base Case	$95.00*10^6$
2050 Low	$92.72*10^6$
2050 Medium	$89.57*10^6$
2050 High	$87.71*10^6$

Source: Cukaliev, 2011, draft report

The water constraint (W) in all climate scenarios is considered respectfully as in the table 5.

3.3 Method of data collection and harmonization

3.3.1 Data collection

This study relies on many different agronomic and economic data related to the climate variables, crops grown and prices and costs for production of the respected crops. Data for this study are obtained from different reliable sources such as published reports, studies, relevant institutions (Faculty of Agricultural Sciences and Food, Hydro-meteorological station), experts' opinion and other sources of information.

The agronomic data for crop production in Pelagonia region, including crop structure, cropping calendar, individual crop growth stages (vegetative, flowering, yield formations and ripening) and other related data are obtained from Cukaliev (2011, draft report) and Pejovska (2009).

The same sources are used for climate data, including meteorological data and reference evapotranspiration for base case scenario and three case scenarios for 2050 in Pelagonia region (Cukaliev, 2011 draft report and Pejovska, 2009). The Bergant (2006) report is used for estimation of climate variations (temperature and precipitation) in 2050 in Macedonia considering Low, Medium and High scenario.

Data related to the irrigation requirements such as k_c (crop coefficient), k_y (yield response factor), irrigation and agro-technical constraints and such are obtained from FAO sources (www, FAO, 2, 1998 and www, FAO, 7, 1979) and from the Department for irrigation of agricultural crops at the Faculty of Agricultural Sciences and Food (Cukaliev, 2011 draft report).

Calculation of net crop income and cost for production for 2050 are based on the calculations made by the Department of Agro-economics at the Faculty of Agricultural Sciences and Food (Pers. comm., Gjosevski; Martinovska, 2011).

3.3.2 Data harmonization

The data harmonization is applied in order to obtain reliable crop structure in Pelagonia region. Due to the lengthy procedure for each crop for determination of the irrigation water requirements, crops with similar biophysical characteristic and less common crops are classified in compatible groups. From a total of 27 crops cultivated in the hydro-meliorative system Strezevo, crop production is downscaled to 16 of the most common crops or groups of compatible crops. Additionally, non-irrigated crops and crops with deficit irrigation are introduced as separate control variables due to variations in yield and costs for irrigation.

Further, the lengths of the crop growth stages and respected crop coefficient, kc for each crop is related to the respected month and specific growth stage (vegetative, flowering, yield formation and ripening). This is primarily important for calculation of the crop evapotranspiration ($Et_c=k_c*Et_o$) which is calculated on a monthly basis (mm/month). Crop evapotranspiration per month is then summarized and calculated on a yearly basis in mm/year for all crops (*Appendix 3*). Changes in precipitations for 2050 are adjusted according to the climate change scenarios for 2050 (Bergant, 2006, pp.22, table 7).

Irrigation water requirements are calculated for each crop or group of compatible crops on a monthly basis as a difference between crop evapotranspiration and effective rainfall defined as a portion of the rainfall that can be effectively used by plant (www, FAO, 7, 8, 1979). The monthly values are summarized on a yearly basis in mm/year. Similar approximations are made for crops where deficit irrigation is applied in a way that yield and water reduction are estimated on a yearly base. Later, for modeling purposes, irrigation water requirements given in mm/year are converted in m^3/ha using the following relationship:

$$1\text{mm} = 10\ \text{m}^3/\text{ha}$$

Further, economic data are harmonized in standardized format using the enterprise budget structure (Olson, 2004, pp.97). In line with Olson (2004), the net return for every crop (irrigated, non-irrigated or secondary) is calculated as net income less production cost in MKD/ha. The income and production costs including fixed costs and variable costs not related to water costs are expressed in MKD/ha. The water costs are calculated as separate factor since they depend on the weather conditions and vary in all climate change scenarios. The water costs are calculated as product of irrigation water requirements (m^3/ha) and water price (MKD/m^3). Finally, the net profit of the production is expressed in MKD. More detailed description is given in part 3.5.4 *(table 6).*

3.4 General Description of the Method

The model relies on determination of the optimal cropping pattern at Pelagonia region under different climate change scenarios. The optimal cropping pattern is transformed into a monetary value (net return per unit of crop area) in order to determine economic impact of the future climate change.

In the circumstances where the supply of irrigation water is a limiting factor, the irrigation water requirement per each individual crop has to be estimated. For the purposes of this study, reference evapotranspiration and evapotranspiration water are determined in relation to the Bergant’s climate change scenarios for Macedonia for 2050. The crop water requirements are calculated as a difference between crop evapotranspiration and effective rainfall for the current scenario. Further, irrigation needs are transformed in two irrigation strategies. The first strategy is based on the full irrigation, while second strategy is defined as deficit irrigation (80% of the full irrigation need over the total growing period). The deficit irrigation strategy displays a more restrictive nature meaning that it is applied only for crops that are less sensitive to water deficit (with yield response factor less or equal to one). For crops with crop response factor higher than one, deficit irrigation is not applied. The respective yield reduction in response to the water deficit is calculated and taken into consideration in the objective function (www, FAO, 7, 1979). According to economic theory, if applied water costs for full irrigation under the given constraints in land and water result in a net return per unit of land higher than net return for deficit irrigation, than irrigation strategy for full irrigation is applied and opposite.

Based on the expected yields and net return per unit of crop area, the optimal cropping system in Pelagonia region in 2050 is determined. The realized net return is determined by crop price and costs for production (costs excluding water and water costs).

3.5 Estimation of irrigation requirements

For the purpose of this study, irrigation water requirements for all crops grown in the region are calculated. The calculation of the irrigation requirements is of essential importance for planning and designing irrigation systems. It is a valuable parameter for policy formulation for optimization of the use of water resources and for appropriate management of irrigation systems.

The calculation of irrigation water requirement is based on the FAO approach as it is suggested by the Department for irrigation of agricultural crops (pers. comm. Cukaliev). Other reliable methods used for calculating irrigation water requirements are not subject to analysis as water requirements represent data for achieving the aims of the study, but not an objective itself.

Before approaching to the estimations of the irrigation requirement (IWR), distinction between crop water requirement (CWR) and irrigation water requirement (IWR) has to be made. The irrigation water requirement is the amount of water that supplied through irrigation in order to meet full water needs of the crop, whereas crop water requirement (CWR) defines the amount of water used by crops for cell building and transpiration (www, FAO, 3, 2002). The detailed description of the calculation procedure is given in the sub-chapters bellow (3.5.1-3.5.4).

Irrigation water requirements for all crops in all different scenarios are given in *Appendix 4*.

3.5.1 Crop water requirements

3.5.1.1 Evapotranspiration

The crop evapotranspiration is actually the crop water requirement for a certain crop during a particular period, dependable on the cropping pattern. The crop evapotranspiration is calculated as a product of reference evapotranspiration, ET_o and crop coefficient, k_c (www, FAO, 2, 1998).

$$ET_c = k_c * ET_o \qquad (19)$$

where

ET_c - crop evapotranspiration,
K_c - crop coefficient,
ET_o - reference evapotranspiration.

The crop coefficient is a tabulated value that is determined by crop characteristics and effects of soil evaporation.

Reference evapotranspiration, Et_o is a climate parameter that depends on the atmospheric evaporation. Determination of the Et_o values is based on weather data (minimum and maximum temperature, humidity, solar radiation and wind speed) and is calculated in accordance to the

FAO Penman-Monteith method. The values for Et_o for base case and for 2050 scenarios (Low, Medium, High) are calculated with Cropwat program (www, FAO, 1). These data are obtained by Cukaliev (2011, draft report) and are given in *Appendix 2*.

3.5.2 Irrigation requirements

Irrigation water requirements refer to irrigation needs for a particular crop and are calculated according FAO approach (www, FAO, 3, 2002, pp. 57-65.):

$$IR=Et_c-(P_e+G_e+W_b) + LR \qquad (20)$$

where

IR – irrigation requirement (mm),
ET_c – crop evapotranspiration (mm),
P_e – effective rainfall (mm),
G_e – groundwater contribution (mm),
W_b – stored water in the soil (mm),
LR – Leaching requirement (mm).

In accordance with the expert's opinion (per.com, Cukaliev, September 2011), the groundwater contribution (G_e), stored water in the soil (W_b) and leaching requirements (LR) will affect the irrigation water requirement insignificantly. Hence, they are excluded and the formula narrows down to:

$$IR=Et_c-P_e \qquad (21)$$

Calculation of the effective rainfall is given in the subchapter 3.5.2.1

3.5.2.1 Effective rainfall

The effective rainfall is the part of the rainfall that is effectively used by the crop, not considering water losses through surface runoffs, percolation and evapotranspiration (www, FAO, 3, 2002. pp. 59.). It depends on soil type, slope, crop canopy, rain intensity and soil water content at the beginning. The relationship between average monthly dependable and effective rainfall is bellow (www, FAO, 3, 2002. pp. 57-65):

$$P_e=0.6*P_{mon}-10, \qquad \text{if } P_{mon}<=75 \text{ mm}; \qquad (22)$$
$$P_e=0.8*P_{mon}-25, \qquad \text{if } P_{mon}>=75 \text{ mm}; \qquad (23)$$

Where
P_e - effective rainfall (mm/month),
P_{mon} - average monthly rainfall (mm/month).

The above formula for calculation of effective rainfall includes both probability and efficiency of the rain. Monthly average dependable rainfalls are obtained from Pejovska (2009) and are based on a historical data records for Pelagonia region (Bitola, Hydro-meteorological station) in a period 1971-2000. Given the climate change scenarios for 2050, the dependable rainfalls are calculated in accordance with the projected changes in precipitation in 2050 (Bergant, 2006, pp.33, table 7).

3.5.3 Irrigation strategies employed

In order to achieve aim of the study, two irrigation strategies (full and deficit irrigation) are employed in this study. While irrigation strategy A meets the full irrigation needs, the irrigation strategy B satisfies 80% of the water needed.

The full irrigation strategy (irrigation strategy A) refers to adequate water supply when crop water requirements are fully met. In such circumstances, there is no water reduction, thus yield reached its maximum ($Et_a=Et_m$ and $Y_a=Y_m$). Under such conditions, profit maximization is achieved by attaining of best combination of water and other inputs per unit of land within feasible area (www, FAO, 8, 1979).

Under the circumstances of limited water supply, the maximization of total net return might be done in two ways, either to satisfy full water requirements over a reduced area ($Et_a=Et_m$ and $Y_a=Y_m$) or to partially satisfy crop water requirements ($Et_a<Et_m$ and $Y_a<Y_m$) over the total area (www, FAO, 8, 1979). In addition, when deficit irrigation is applied, water shortage might occur in a particular growth period (vegetative, flowering, yield formation, ripening) or over the total growing period. When water decrease is equal over the total growing period, the yield decrease is proportional to increase in water deficit. Crops with higher yield response factor (k_y) suffer more than crops with a lower factor. When water deficit occurs in particular periods of the crop growth, the decrease in yield depends on the growth stage. The yield decrease is relatively small during the vegetative and ripening period while relatively large during flowering and yield formation period.

The deficit irrigation strategy (strategy B) applied in this study refers to limited water supply that partially satisfies crop water requirements ($Et_a<Et_m$ and $Y_a<Y_m$) over the total area. The irrigation strategy B is based on an equal water reduction during the entire growing period. The deficit irrigation strategy applied in this study is based on crop sensitivity to water deficit (www, FAO, 8, 1979). In respect to yield response factor (k_y), the water reduction is 20% to less sensitive crops (crops with $k_y \leq 1$) while water requirements are fully satisfied for crops with $k_y>1$.

The purpose behind the introduction of deficit irrigation is to assess the benefits of the reduced water costs despite a decrease in yield. The method of linear programming used in this study has to choose strategy that maximized profit per unit of water applied given constraints in land and water. By introducing integer variables, for all crops that are suitable for full and deficit irrigation strategy, selection of only one strategy (either A or B) is allowed. Considering that net return is higher for crops with full irrigation, only when water is limited factor the deficit irrigation is chosen. Having in mind that water price is relatively low in Macedonia, appliance of deficit irrigation because of the reason that savings of water costs are greater than losses in yield decrease, is still not justified.

3.5.4 Crop yield response to water deficit

When deficit irrigation is applied, crop yield response to water deficit needs to be known. The yield response to water deficit is defined with the linear relationship between relative yield decrease and relative evapotranspiration deficit (www, FAO, 2, 1998, pp.176):

$$1\text{-}Y_a/Y_m=k_y(1\text{-}Et_a/Et_m) \qquad (24)$$

Where:
Y_a- actual yield (t/ha);
Y_m- maximum yield (t/ha);
Et_a – actual evapotranspiration (mm),
Et_m – maximal evapotranspiration (mm);
K_y- yield response factor.

Given the above formula, the relative yield decrease is calculated for all crops (k_y<1) where deficit irrigation is employed. The maximal evapotranspiration is considered to be achieved under the full irrigation. The actual evapotranspiration is calculated as 80% of the maximal evapotraspiration for the respective climate change scenario given that deficit irrigation (20% less water supply over the total growing period) is applied. Relative yield decrease for three climate change scenarios for 2050 (Low, Medium, High) is estimated according the calculation procedure given by FAO (www, FAO, 7, 1979) as shown in *table 6*.

Table 6: Calculation procedure for yield decrease in respect to the water deficit

Crop	**Strategy A: Full irrigation ETm (mm/year)**	**k_y (total growing period)**	**Strategy B: Deficit irrigation ETa (mm/year)**	**Relative evapotranspiration deficit: 1-ETa/ETm**	**Relative yield reduction strategy B: 1-Ya/Ym (%)**	**Actual yield Strategy B: Ya/Ym (%)**
Maize	$Etm_{(maize)}$	1.25 (no deficit irrigation)	$Eta=Etm_{(maize)}$	0.00	0.00	100.00
Alfalfa	$Etm_{(alfalfa)}$	0.85 (deficit irrigation)	$Eta=0.8*Etm_{(alfalfa)}$	0.20	$k_{y(alfalfa)}$*(1-Eta/Etm)	1-[k_y*(1-Eta/ETm)]

For rain-fed crops, the yield reduction in 2050 is calculated in relation to decreased precipitation (pers. comm., Cukaliev, 2011) as:

$$\text{Eta}_{2050}=\text{Eta}_{2010}*(1-x/100) \qquad (25)$$

Where x is a percentage of reduced precipitation/month (Bergant, 2006, pp.33, table 7).

3.6 Economic data requirements

An estimate of the economic value of crop production is required to assess the potential of the cropping system in the respected area. In order to transform the volume of the crops produced, or potentially produced, into a monetary value, the model requires estimation of current prices and cost of production, as well as long-term projections for 2050.

The estimation of crop production is based on the net returns of crops and cultivated crop areas. For calculation of the net returns, the standardized form of an enterprise budget structure slightly modified to the current needs is used (Olson, 2004, pp.97):

Table 7: Form used for calculation of net return

Income
-Income from crop
-Income from by-products
-Subsides
Total income
Variable costs
-Seed
-Fertilizer
-Crop chemical
-Machinery fuel and lubricants
-Custom hire and rental
-Operator and hired labor
-Other variable costs
Operating interest
Total variable costs excluding water
Fixed costs
-Insurance
-Depreciation
-Other fixed costs
Total fixed costs
Total costs excluding water = variable + fixed costs
Gross margin=Total income-total costs excluding water
-Water costs
Net return = Gross margin – water costs

The calculation is employed for each crop separately under different growing conditions (different irrigation strategies, rain-fed conditions or second crops). The water costs are distinguished as a separate factor since water quantities are highly dependent on the climate variation and are changeable in all scenarios. The net return is expressed in MKD/ha. Detailed calculations of gross margin and net return per each crop are given in *Appendix 6*.

The base case scenario relies on current prices and costs taken from the Department of Agro-economics at the Faculty of Agricultural Sciences and Food (pers. comm., Gjosevski; Martinovska, 2011). For 2050 climate change scenarios, the long-term projections of crop prices and costs of production are required. Many reliable sources for price and cost predictions have been assessed. However, the outcome is highly unpredictable and varies significantly from source to source.

Different papers state different price projections for food and agricultural commodities in 2050 (www, FAO, 5, 2010). While some predict that grain prices on global level will further increase by 30-50% more than the current levels, others claim that the prices for some commodities will be more than double (www, FAO, 5, 2010). As an illustration, Alexandratos (www, FAO, 5, 2010) has made a comparison between IIASA and IFPRI projections for 2050. According IIASA, agricultural price index on global level is expected to be just ten percent higher measured from 2003/2005 as base year and far below current prices measured from 2006/08. As projected by IIASA cereal price indices will increase faster, by slightly above 30% measured from 2003/2005, while other crops and livestock commodities will move slower. According to the revised IFPRI analysis (2009), the most rapid increase of around 50% is expected for rice and maize measured from the pre-surge period (2003/2005). This is almost at the same level as the current prices from the surge period (2006/08), but not much in line with the statement that "grain prices are to increase 30-50% before 2050" (www, FAO, 5, 2010).

Much investigation has been put into finding plausible price and cost projections for 2050. Based on what has been available, two most relevant reports that include both prices and costs of production are obtained by USDA: Agricultural Projections to 2020 (www, USDA, 1, 2011) and FAPRI 2010 Agricultural Outlook: U.S. Crops (www, FAPRI, 1, 2011). Both reports provide almost same data (revenues, expenses and net returns) for more than a dozen of crops. Despite the fact that the projections are up to 2020, due to lack of available data for prices and cost of production for 2050 originating from the same source, the current trend of price movements (USDA and FAPRI projections) is extrapolated up to 2050. An example of extrapolated price and cost projections for wheat for 2050 according USDA and FAPRI are given in *Appendix 8.1.2* and *Appendix 8.2.2* accordingly.

The relative changes of revenues, expenses and net returns given the tabulated values for 2009/2010 *(www, FAPRI, 1, 2011)* and extrapolated values for 2050 for wheat are presented in *table 8*:

Table 8: FAPRI extrapolated projections for wheat for 2050

Item	2009/10	2050	Δ	Δ (%)
Wheat				
Yield	44.40			
Farm price	4.92	5.19	0.05	5.00
Gross Market revenue	218.46	255.08	0.17	16.76
Variable expenses	108.07	149.79	0.39	38.60
Market net returns	110.39	103.61	-0.06	-6.14

where Δ is a relative change for 2050 calculated as:

$$\Delta = (V_{i\ 2050}/V_{i\ 2009/2010}) \qquad (26)$$

$V_{i\ 2050}$ – extrapolated value for 2050;
$V_{i\ 2009/2010}$ – tabulated value for 2009/2010

According FAPRI projections for 2050, revenue will increase by 16.76% while variable expenses will increase more rapidly for about 38.60%.

The extrapolated prices, revenues and costs for wheat for 2050 according USDA: Agricultural Projections to 2020 (www, USDA, 1, 2011) are presented in *table 9*:

Table 9: USDA extrapolated projections for wheat for 2050

Item	2009/10	2050	Δ	Δ (%)
Wheat - long term projections				
Yield (bushes/acre)	44.50			
Price ($ /bushel)	4.87	5.714347	0.17	17.34
Gross revenue ($/acre)	216.72	265.67	0.23	22.59
Variable costs of production ($/acre)	129.00	162.88	0.26	26.26
Net returns ($/acre)	87.72	78.27947	-0.11	-10.76

Comparing FAPRI and USDA data, the results obtained using FAPRI 2010 Agricultural Outlook are more consistent in terms that trend lines for both, revenues and costs, are more precise, moving smoothly by the given points (very high R^2 values).

The extrapolation is conducted for five crops: wheat, corn, barley, soybean and sunflower. The relative price and costs projections for 2050 are calculated using the formula 26 above. When extrapolated FAPRI projections for wheat (relative revenue change for 17 % and relative cost change for 39 %, *table 9*), are used for all other crops except above mentioned (corn, barley, soybean and sunflower), the net return for majority of the crops become negative in 2050 due to the rapid increase of costs and slow increase of prices (*Appendix 8*).

Despite, the relative change for wheat returns using the USDA projections to 2020 is far more optimistic (relative revenue change for 23 % and relative cost change for 26%, *table 9*), but the trend line is not very precise, characterized with more substantial deviations and noticeable lower R^2 values (*Appendix 8*).

Latter, data on prices (2000 US$/mt) for many commodities under different climate change scenarios are obtained from IFPRI database (per. comm. Mason-D'Croz, 2011). The developed IMPACT model used for price projections incorporates combined effects of economic, population and climate factors; however this model is not a very good source of information for farm-level costs (per. comm. Mason-D'Croz, 2011). The IMPACT model's supply side is determined by a series of area and yield functions that only marginally reveal costs. Area and yield vary primarily on own and cross prices, with a simplified supply elasticity to take into account the effects of fertilizer and labor prices. However, the IMPACT model is a partial equilibrium model. The factor prices for labor and other inputs (fertilizer, crop chemicals, etc) are not modeled with IMPACT, but are obtained from a general equilibrium model. In addition, IMPACT model aggregates certain regions in a group that might not be very conducive to a sub-national level in the country. Macedonia, together with Albania, Bosnia and Herzegovina, Croatia, Serbia and Slovenia forms a regional aggregate labeled Adriatic Europe.

Considering the high uncertainty and variations of the USDA and FAPRI projections for 2050 and the incompatibility of the IMPACT model for a reasonable estimation of net returns, this study assume that net returns in 2050 are equivalent to the current returns in 2010. This yields results very similar to those of the USDA projections (fairly equivalent increase of revenues 23%) and costs (26%)). The assumption is that despite production and cost factor volatility up to 2050, the relative ratio between revenues and costs for particular crop will stay the same. This assumption is underpinned by the rapid technological advance that is expected to contribute in alleviating adverse effects of the climate change (Li et al, 2011; Kaiser et al, 1993).

4 The empirical study / Results

This chapter presents a summary of the findings regarding irrigation water requirements, allocated area per crop and net returns per unit of crop area. For this study, four climate change scenarios, base case and three scenarios for 2050 that span the range of minimum and maximum temperature and precipitation for 2050 are used. Furthermore, net profit for all scenarios is also presented here.

4.1 Irrigation Water Requirements (IWR)

In order to assess the economic impact of the climate change, irrigation water requirements are estimated for all four scenarios. The changes in the irrigation water requirements strongly depend on the crop evapotranspiration and effective rainfall. Estimation of the evapotranspiration and effective rainfall is based on the climate change projections for the specific region.

The costs related to irrigation are part of the objective function and profit maximization is conducted in response to the water supplied to particular crop.

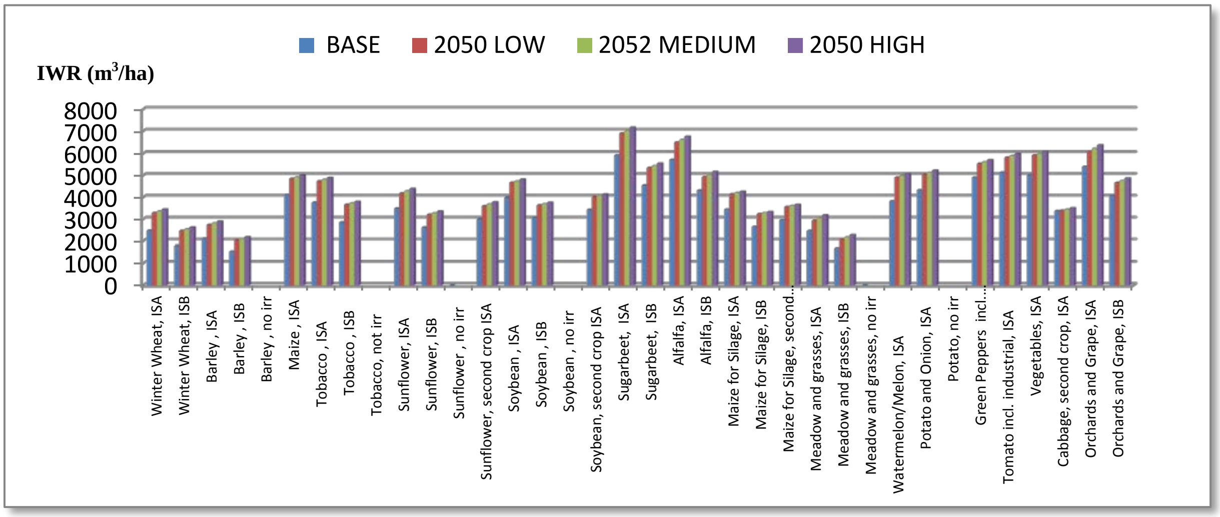


Figure 10: Irrigation water requirements (m3/ha)

The *figure 10* provides a summary of the irrigation water requirements. Each crop is first grown with today's climate conditions and then with 2050 climate under identical circumstances. The irrigated crops are assumed to receive full amount of water needed while irrigation needs for deficit irrigation is reduced to eighty percent of the water needed. The irrigation water requirements for all crops are increasing as the projected climate changes become more severe (Low-Medium-High). The difference of IWR between crops with irrigation strategy A (ISA) and crops with irrigation strategy B (ISB) is apparent. Irrigation water requirements for deficit irrigation (ISB) are 20% lower than for full irrigation (ISA). For the rain-fed crops, the IWR is not a relevant factor.

As indicated in the chart above, the most water demanding crops are sugar beet and alfalfa. Irrigation water requirements for both crops vary from slightly below 6000 m3/ha in the base case scenario to almost 7000 m^3/ha for alfalfa and slightly over that amount for sugar beets in the most extreme scenario (2050 High). Horticultural crops and fruits are also highly demanding crops regarding the water needs. In line with the above mentioned, the alfalfa, grape, tomato, apple and winter wheat are outlined as the most vulnerable crops to the exposure of climate change (www, World Bank, 2, 2010).

The *figure 11* shows graphically the effect of climate change on irrigation water requirements as a relative change from the base case scenario ($IWR_{\text{base case}}$=100%).

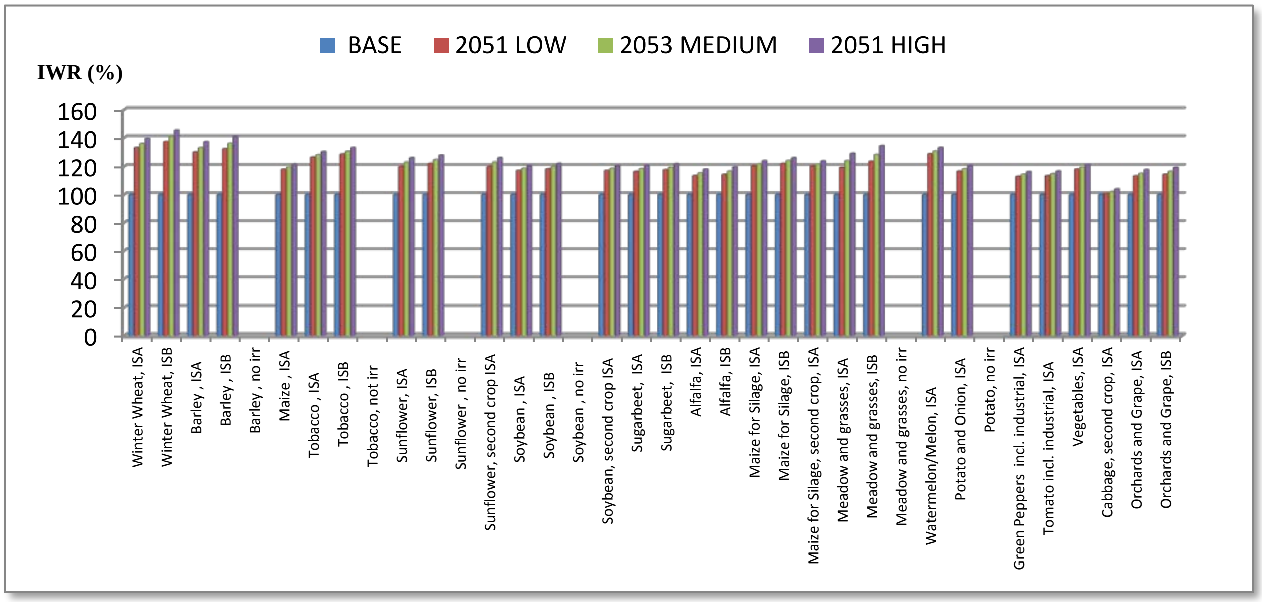


Figure 11: Irrigation water requirements as a relative change from the base case scenario (%)

As indicated in the chart, the IWR are increased for around 40% due to the effect of climate change in 2050 for wheat, followed by barley (30-40%) and meadows/ grasses (20-40%) for both irrigation strategies. The lowest increase is noticed for cabbage (1-4%) in all three scenarios for 2050. Irrigation water requirements per particular crop per month in all scenarios are provided in *Appendix 4.*

4.1.1 Yield outcome

The assumption given in this study is that yield is assumed to stay constant if irrigation requirements are fully met (pers. comm., Cukaliev, 2011). Hence, the yield reduction will not be a subject of assessment for the full irrigation strategy (ISA). The analysis of the yield reduction is thus, relevant only for deficit irrigation and rain-fed crops.

Having in mind that deficit irrigation is applied for less water sensitive crops, only crops with crop response factor $k_y \leq 1$ are exposed to deficit irrigation (*figure 12*). For other crops, deficit irrigation strategy (ISB) is not applied. Second crops due to the shorter vegetative period are also prone to yield reduction. Yield reduction is calculated using the formula (24) in relation to the water reduction (less Eta value) according to the FAO approach (www, FAO, 7, 1979). For deficit irrigation, water reduction is 20%, while for rain-fed crops water reduction refers to reduction in precipitation from current scenario to 2050 scenarios (formula 25). Detailed values of yield reduction for deficit irrigation (ISB) are given in Appendix 5. The results for yield reduction of crops with deficit irrigation are presented in *figure 12*, while for rain-fed crops in *table 10*.

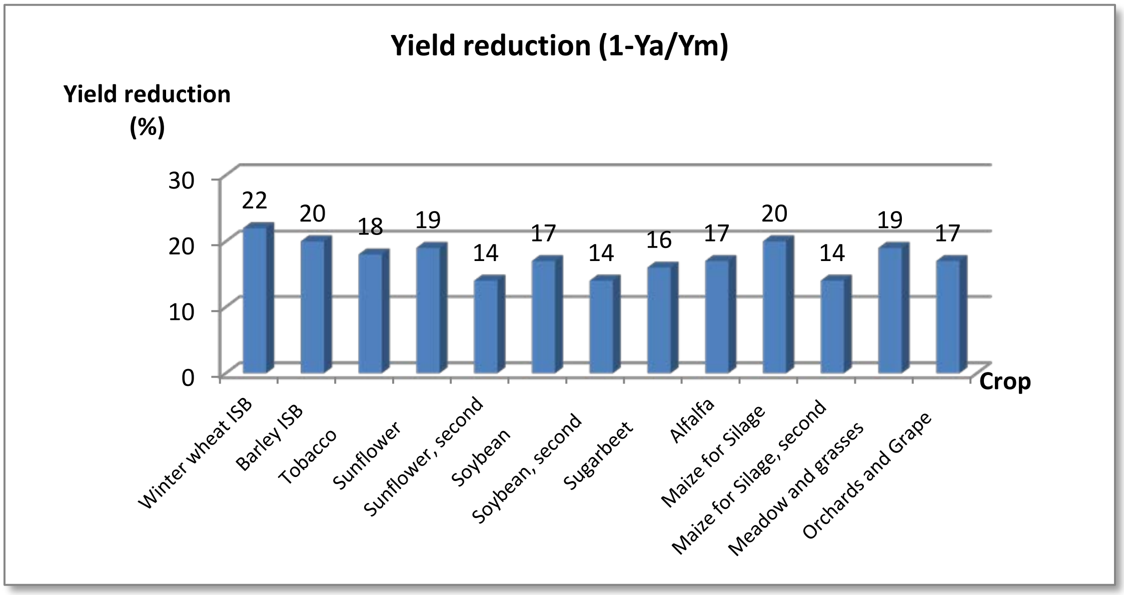


Figure 12: Yield reduction for crops given that deficit irrigation is introduced (%)

The yield reduction is highly dependent on the crop response factor to water deficit (k_y). As it is evident from the chart below the greatest yield reduction is recorded for winter wheat (22%) due to its higher sensitivity to water deficit (k_y=1.10), followed by barley and maize for silage with k_y=1.0. The least sensitive crops to water deficit are sugar beets and orchards. Apart, yield reduction for second crops (sunflower, soybean, and maize for silage) is 14%.

For rain-fed crops, yield effects are driven by the temperature and rainfalls.

Table 10: Yield reduction of rain-fed crops in 2050 (%)

Crop	Scenario	Ya/Ym (%)	1-Ya/Ym (%)
IWR winter wheat	2050 LOW	74.94	25.06
IWR winter wheat	2050 MEDIUM	72.84	27.16
IWR winter wheat	2050 HIGH	69.87	30.13
IWR barley	2050 LOW	82.40	17.60
IWR barley	2050 MEDIUM	80.61	19.39
IWR barley	2050 HIGH	78.05	21.95
IWR tobacco	2050 LOW	75.27	24.73
IWR tobacco	2050 MEDIUM	73.67	26.33
IWR tobacco	2050 HIGH	71.48	28.52
IWR sunflower	2050 LOW	81.50	18.50
IWR sunflower	2050 MEDIUM	79.01	20.99
IWR sunflower	2050 HIGH	76.19	23.81
IWR soybean	2050 LOW	83.75	16.25
IWR soybean	2050 MEDIUM	82.36	17.64
IWR soybean	2050 HIGH	80.51	19.49
IWR meadow/grasses	2050 LOW	87.33	12.67
IWR meadow/grasses	2050 MEDIUM	84.53	15.47
IWR meadow/grasses	2050 HIGH	81.10	18.90
IWR potato/onion	2050 LOW	77.91	22.09
IWR potato/onion	2050 MEDIUM	75.65	24.35
IWR potato/onion	2050 HIGH	72.56	27.44

The table above provides a summary of yield reduction due to the more adverse conditions in 2050. The yield reduction is most daunting for 2050 High scenario and most encouraging for the 2050 Low scenario. Generally, the most severely affected crop will be winter wheat in all three scenarios, varying from 25-30% and least affected will be meadow and grasses (13-19%).

4.2 Crop Area

The allocated cropping area in all four scenarios is based on maximization of net returns from crop production given the restriction in land, water and agro-technical constraints. The *figure 13* presents the allocated area per crop in all scenarios.

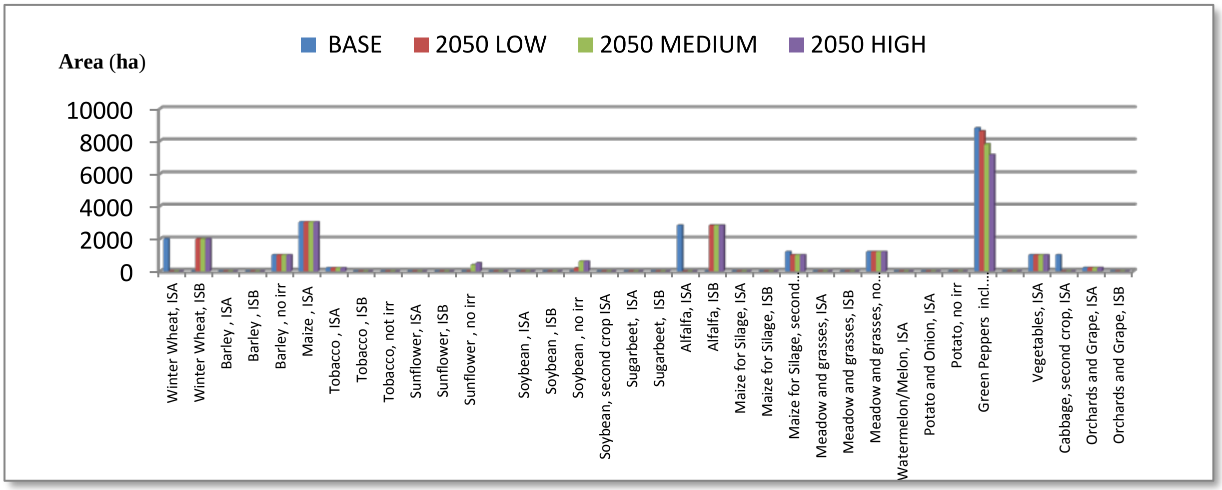


Figure 13: The allocated area per crop in different scenarios (ha)

As *figure 13* reveals, the effects of climate change scenarios on the allocated area per crop are relatively small. Most of the crops are planted on the same area in all four scenarios, with the exception of green peppers, maize for silage, cabbage, sunflowers and soybeans. Depending on particular scenario, the most prominent difference is noticed for green pepper. The area allocated to green pepper varies from 8792 ha in base case scenario to 7173 ha in 2050 High scenario what presents a reduction of 18.5 % in the cultivated area under pepper. Other high value crops such as tobacco, vegetables and fruits are cultivated on the same area as in the base case scenario. Cabbage is cultivated on 1000 ha in base case scenario, while it is not present in 2050.

Regarding the winter wheat, the total area of 2000ha in base case scenario is allocated using the full irrigation strategy (ISA), while under the climate change condition where available water is reduced, deficit irrigation strategy (ISB) is chosen. The same situation appears for 2800 ha of allocated land for alfalfa.

Rain-fed crops such as sunflowers and soybeans although not cultivated given the base case scenario, are represented in 2050. Soybeans are represented with 186 ha in 2050 Low and with maximum of 600 ha in Medium and High scenario. Sunflower appears in the Medium and High case scenarios with 383 ha and 500 ha (maximum) respectively. The cultivated area of barley, maize (first crop), tobacco, meadows, vegetables and orchards/grape stays the same in all cases.

The total cultivated area records a negative trend of less than 10%. The cropping area decreases from 22,400 ha in base case scenario to 21,200 ha in 2050 Low and Medium scenario to 20,681 ha in the High case scenario *(figure 14).*

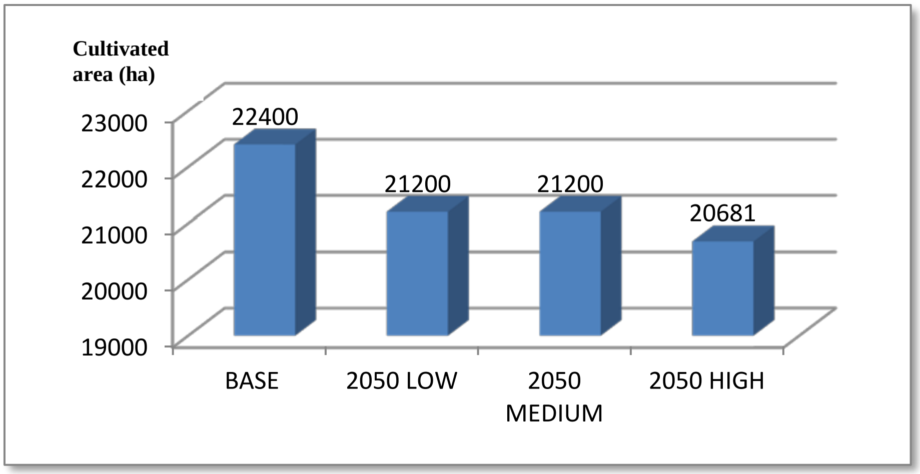


Figure 14: Total cultivated land (ha)

4.3 Net returns

The yield and water changes produce variations in net returns in all scenarios. Net returns are calculated as gross margins (revenues - costs excluding water) less water costs. The variations of yield and water quantities in all three climate change scenarios result in different net returns. The net returns per unit of crop area are shown in *figure 15*.

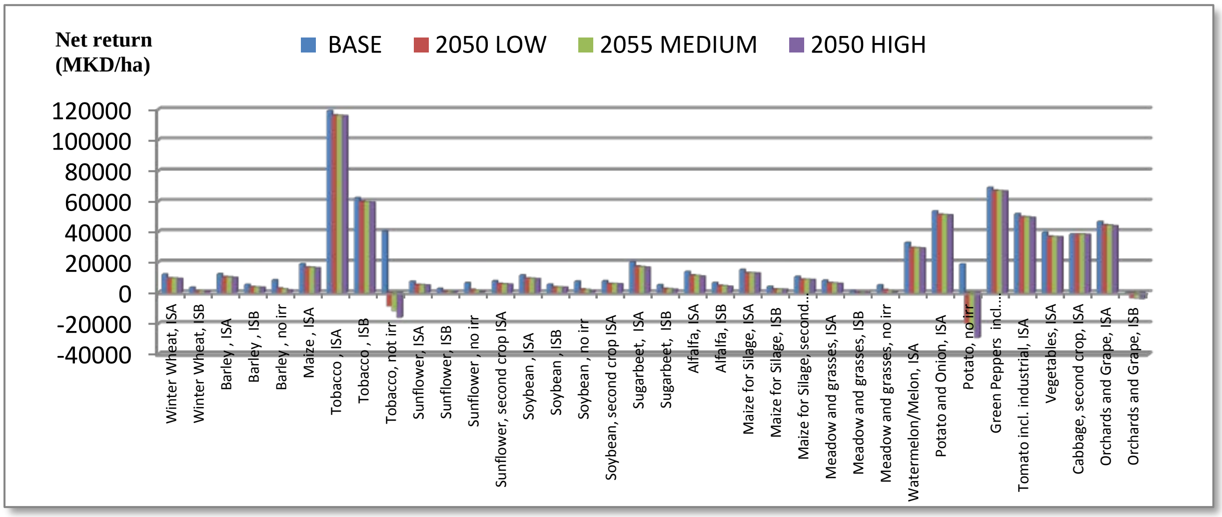


Figure 15: Net returns per crop (MKD/ha)

The *figure 15* illustrates some dramatic variations in net returns among different crops. The highest net returns of 120,000 MKD/ha is calculated for tobacco, followed by horticultural crops and orchards. Peppers, including green peppers and industrial are the most profitable crops among horticultural crops. The bulky commodities, including small grains, cereals and fodder crops are characterized by rather low net returns. Among them, maize is the most gainful. Similarly, industrial crops are low value crops. The most beneficial industrial crop is sugar beets cultivated under full irrigation strategy (ISA).

The net returns decline in 2050 in comparison to the baseline scenario. Prominent changes are for rain-fed tobacco and potato where even losses are noted. From a 40,000 MKD/ha net return in baseline scenario, the production of rain-fed tobacco in 2050 is unprofitable (losses up to 16,000 MKD/ha appear in 2050 High scenario). Similarly, rain-fed potato changes from a profitable crop in baseline scenario to a loss-making crop in 2050.

Generally, net returns decrease in 2050. Although the variations in net returns among climate scenarios in 2050 are mild, the pessimistic scenario (2050 High) reveals the highest decline in net returns. Diminutions of net returns in 2050 are due to yield decreases for rain-fed crops and increases of water costs for irrigated crops.

4.4 Net profit

The aggregate profits potentially obtained in each of the four scenarios are a result of net return and area changes. An optimal allocation of cropping area under given constraints produces the maximum net return. The total profit obtained under each scenario is given in *figure 16*.

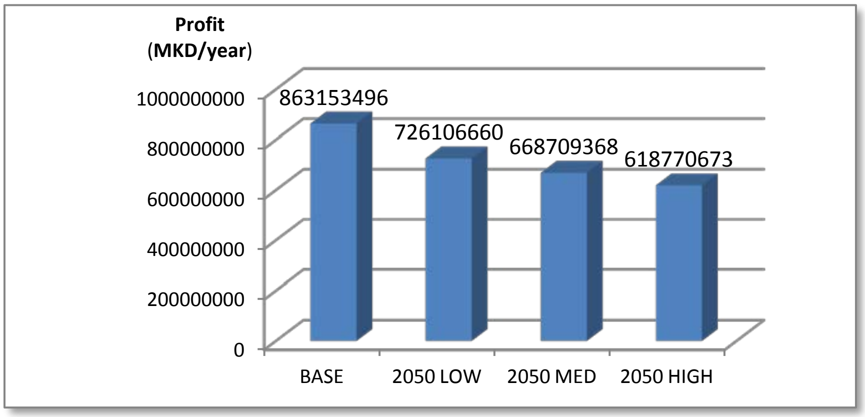


Figure 16: Total profit (MKD/year) in different scenarios

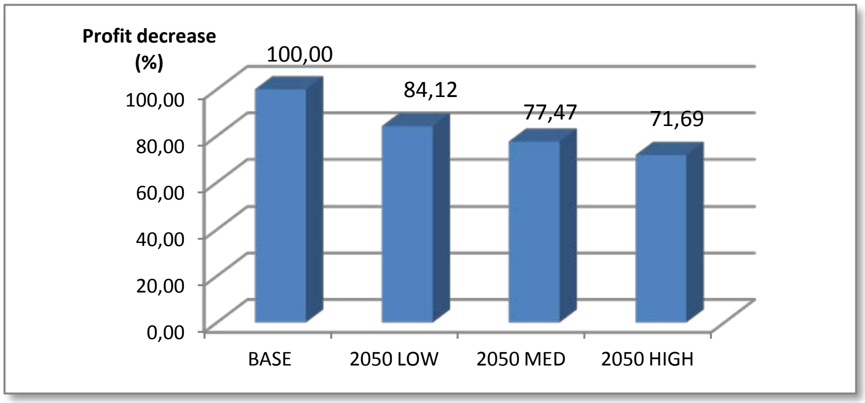


Figure 17: Profit decrease in 2050 (%)

As shown in the *figure 17*, climate change decreases total profit. When the water quantity is becoming a limiting factor, the total profit in 2050 is reduced by 16 % in the optimistic scenario (2050 Low), 23% in the realistic (2050 Medium) to 28% in the most pessimistic scenario (2050 High).

Considering the current situation of only 5208 ha cultivated area, the profit earned is 110,118,568 MKD/year, what is actually 12.75% of the profit that could be attained under optimal cropping pattern (Base case scenario) at today's conditions (*figure 18*).

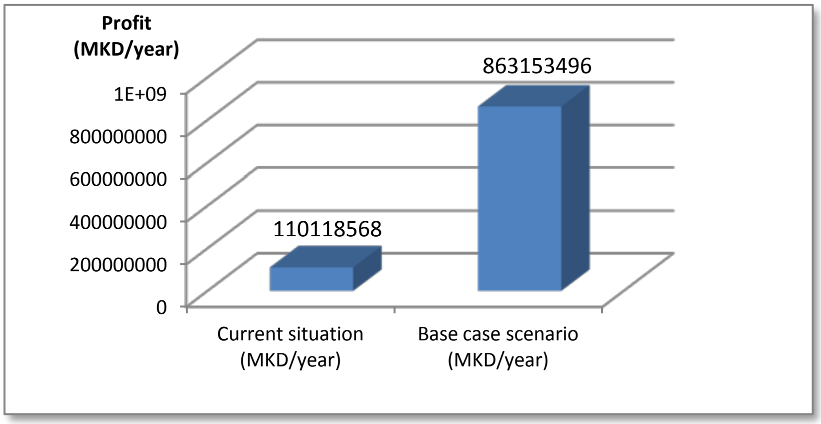


Figure 18: Total profit given the current situation and optimal scenario (base case scenario) in MKD/year

5 Analysis and discussion

This chapter analyses the possible solutions in the Base case scenario and three climate change scenarios in respect to the optimal cropping pattern compatible with the specific features of the area, the profit decrease due to the climate change and the marginal value of the additional units of water and land. The comparisons of base case and climate change scenarios in 2050 illustrate the importance of climate change upon agricultural production, in particular crop production in Hydro-meliorative system “Strezevo”, Pelagonia region in 2050.

For optimal allocation of available resources, the optimization technique is used. The agro-technical constraints imposed in the model are defined based on the current practices and experts’ opinions (pers.com. Gjoshevski; Martinovska). The linear programming method is firstly applied to the base case scenario (under today’s climate conditions) and then for climate scenarios in 2050 (Low, Medium, High).

5.1 The Base case scenario

This scenario considers optimal solution for the present situation that differs from actual cropping pattern.

5.1.1 Crop area

Under the present conditions, the water volume available for irrigation is $95*10^6$ m^3. Using the imposed water constraints and meeting the requirements for minimum and maximum crop area, the Base case scenario results are given in *table 11* below:

Table 11: Area per crop in the Base case scenario (ha)

Crop	area (ha)	area (%)
Winter Wheat, ISA	2000	8.93
Barley , rain-fed	1000	4.46
Maize , ISA	3000	13.39
Tobacco , ISA	200	0.89
Alfalfa, ISA	2800	12.50
Maize for Silage, second crop, ISA	1200	5.36
Meadow and grasses, rain-fed	1200	5.36
Green Peppers incl. industrial, ISA	8792	39.25
Vegetables, ISA	1000	4.46
Cabbage, second crop ISA	1000	4.46
Orchards and Grape, ISA	208	0.93
Total	22400	100

The optimal cropping pattern in Base case scenario results in the utilization of all available area of 20,200ha (binding constraint). The consumption of water amounts to 90,323,600 m3 with an excess of water amounting to 4,676,400 m3. The total cultivated area is 22,400 ha due to 2,200 ha of second crops (maize for silage and cabbage). All feasible area for irrigation (20200 ha) is used.

The current situation at "Strezevo" hydro-meliorative system refers to 5208 ha cultivated land what is 25% of the available area. Considering the actual situation, maize is the most dominant crop accounting to 38.72 % of the cultivated area. In comparison to the optimal scenario under current conditions (base case scenario), the share of maize has experienced a drastic decline to only 13 % due to a decrease in profitability. In parallel, green pepper with 4% in the current situation increases to 39% in the base case scenario what is the highest incline compared to other crops. The reason for such enormous increase is a high net return obtained from this crop. However, due to the long tradition of cereal production and current farmers' practices, the maize is still the most popular crop in this region. Variations for other crops are not so drastic, varying with less than 5% (*table 12*).

Table 12: Comparison between current situation and optimal scenario

	Current situation		**Base case scenario**		**Δ (%)**
	ha	**%**	**ha**	**%**	
Winter wheat	523	10.04	2000	9	-1.04
Barley	17	0.33	1000	4	3.67
Maize	2016	38.72	3000	13	-25.72
Tobacco oriental	32	0.61	200	1	0.39
Sunflowers	38	0.73	0	0	-0.73
Soybeans	183	3.51	0	0	-3.51
Sugar beets	103	1.98	0	0	-1.98
Alfalfa	841	16.16	2800	13	-3.16
Maize silage	427	8.2	1200	5	-3.2
Meadow and grasses	308	5.92	1200	5	-0.92
Watermelon and melon, ISA	51	0.98	0	0	-0.98
Potato and Onion, ISA	56	1.08	0	0	-1.08
Green pepper including industrial	213	4.09	8792	39	34.91
Tomato including industrial	33	0.63	0	0	-0.63
Vegetable include cabbage	159	3.05	1000	4	0.95
Cabbage	0	0	1000	4	4
Orchards and grape	208	3.99	208	1	-2.99
TOTAL	5208	100	22400	100	

The deviation, Δ (%) shows the percentile decrease (minus) or increase (plus) in 2050 in comparison to the current situation. It is evident that the most significant increase is for green pepper (34.91%). The increase in production area for 8,579 ha *(table 12)*, or approximately 163,000 t pepper, compared to the yearly production of 153,842 t pepper in 2011 (www, SSO, 2,

2011) implies that the production in the country will increase for more than double. Such drastic increase will cause severe market disruptions. Thus, in this situation Macedonia will benefit only if governmental policy for the country is specialization in high value crops and potential trade with other countries that have comparative advantage in other commodities. In any other circumstances, consumer surplus will drastically increase while producer surplus will decrease. In total, net welfare of the country will be negative since producer losses will be higher than consumer gains.

Detailed values of the net returns and allocated crop area in Strezevo under current circumstances are given in *Appendix 7*.

5.1.2 Economic results

5.1.2.1 Current and Base case scenario

The profit attained in the Base case scenario is 863,153,496 MKD/year. This is the maximal profit that can be potentially achieved with respect to the current conditions and constraints. In this case, profit maximization is constrained due to the limitation in area. Water is not a binding constraint.

The profit obtained in the current situation amounts to 110,118,568 MKD/year that refers to the actual value of the crop production on 5208 ha given the existing crop mix. The economic value of the current production (110,118,568 MKD/year) accounts 12,75 % of the potential profit (863,153,496 MKD/year) that could be attained if the production is extended on the total area and given the optimal crop mix (Base case scenario) as shown *in the table 13.*

As a result of not utilizing the entire area given the existing crop pattern (current scenario), the profit is reduced to 26% of profit that could be earned (423,532,954 MKD/year) if the crop production is extended on the area of 20,200 ha and keeping the existing crop mix. The lower profit earned given the current scenario on the total area (423,532,954 MKD/year) and the potential profit that could be attained on the same area given the optimal crop mix (863,153,496 MKD/year) is a result of the selection of less profitable crops.

Table 13: **Comparison of profit attained given the Current and Base case scenario**

	Profit attained (MKD/year)	Cultivated area (ha)	Cultivated area as % of the total area
Current scenario (5208 ha)	110,118,568.00	5208	26%
Current scenario extended to the total area (20200 ha)	423,532,954.00	20200	100%
Base case scenario (optimal crop mix)	863,153,496.00	20200 2200 (second crops)	100%

5.1.1.2 Cost of transition period

In general, reduction of cultivated area to 26% and not utilizing of the entire available area is considered as a “cost of a transition period” due to the country’s transformation from post-communist (state owned) to market driven economy. As a result of the transition process many market opportunities were lost and many of the existing processing firms were closed. In addition to this, certain policy issues regarding the management of water resources and maintenance of the irrigation system, accompanied with financial constraints of the hydro-meliorative system “Strezevo” were also crucial for poor maintenance of the infrastructure and reduction of the cultivated area. In addition, long tradition of the livestock production and existing agricultural practices influence to the selection of traditional crops with lower profitability. In that respect, the current value of agricultural production is only 12.75% of the value that could be potentially achieved. Hence, interpreting the process in economic terms, the “cost of a transition period” amounts to nearly $753 * 10^6$ MKD/yearly.

5.1.3 Sensitivity analysis

Having in mind that model includes integer variables; sensitivity analyses are not enabled by the Solver. Yet, the optimal solution for allocated area when the model includes integers and when integers are not defined as such is identical. Hence, the following analysis is based on the case when the model does not include integer variables, but due to identical results of the allocated area in both cases, the sensitivity analysis is considered as valid for this model.

Since the land is a restricting factor, the shadow price of land corresponds to 58,517 MKD/ha which implies that any additional unit of land results in a profit increase of 58,517 MKD. In fact, this is the maximum value that a farmer is willing to pay for one additional unit of land today. Opposite, decrease of 1 ha of land will cause reduction in the net profits of 58,517 MKD. As a comparison, currently the rent of 1 ha of state own agricultural land in Pelagonia region (“Pelagonia”-agricultural combinat) is 300 kg wheat/ha in MKD equivalent for lowland areas. Considering an average wheat price of 10 MKD/kg, the annual rent is 3000 MKD/ha (pers.comm. Gjorgievski K.). For mountainous areas the rent is far lower, 1000 MKD/ha per annum. Pelagonia as a mainly lowland area has around 12000 ha lowlands (state owned agricultural land) and nearly 6000 ha mountainous area. It is noticeably that the current prices for rent of agricultural state owned land is considerably less than the shadow price of land. Thus, renting of additional units of land is considered to be very profitable for farmers.

In respect of the relatively low rent price of land in comparison to the value of agricultural production in that region, one of the issues that should be raised is re-estimation of the value of agricultural land and improvement of the management of state owned agricultural land. However, despite of the economic value of the land, other aspect that should be taken into consideration is the social dimension of the state owned land and its contribution to the social policy of the country.

Table 14: Sensitivity report, Base case scenario, part I

		Final	Shadow	Constraint	Allowable	Allowable
Cell	Name	Value	Price	R.H. Side	Increase	Decrease
C128	Arable land (ha)	20200	58517.26	20200	200	800
C129	Water available (m3/year)	90323600	0	95000000	1E+30	4676400
C130	Feasible area for irrigation	20200	10443.74	20200	800	200

The allowable increase and decrease of arable land presents the limits of arable land for which the shadow price remains unchanged and the optimal solution is not altered. Thus, alteration of the constrained arable land between 19,400 ha and 20,400 ha will not cause any changes in the optimal solution. Similarly, feasible area for irrigation is also a binding constraint and its shadow price is 10,444 MKD for one extra ha of irrigation land. The allowable increase is 800 and allowable decrease 200 ha. This figure implies that the farmer is able to pay an additional 10,444 MKD/ha (given a rent of 58517,00 MKD) for land that can be irrigated instead of not irrigated. In addition, this indicator is closely linked to the costs related to rehabilitation of the irrigation system in the next years and transformation of non-irrigated to irrigated land.

Introduction of minimum requirements for orchards/grape, alfalfa and meadows, maize, winter wheat and barley, and vegetable cause a decrease of net profit in all cases. The most dramatic decrease is noticed if one extra unit of winter wheat and barley is cultivated, meaning that the net profit will be reduced for 56,973 MKD/year. The opposite refers for maximum requirements for barley, tobacco and meadow/grasses. For example, not cultivating of one additional ha of tobacco (upper limit for tobacco is set on 200 ha) results in profit decrease for 50,150 MKD/year (*see table 15*).

Table 15: Sensitivity report, Base case scenario, part II

		Final	Shadow	Constraint	Allowable	Allowable
Cell	**Name**	**Value**	**Price**	**R.H. Side**	**Increase**	**Decrease**
C163	Maximum area for wheat	2000	0	5000	1E+30	3000
C164	Maximum area for barley	1000	34619	1000	800	1000
C165	Maximum area for maize	3000	0	5000	1E+30	2000
C166	Maximum area for tobacco	200	50150	200	0	200
C170	Maximum area for alfalfa	2800	0	3000	1E+30	200
C172	Maximum area for meadow and grasses	1200	1611.74	1200	800	200
C173	Maximum area for orchards and grape	208	-22374	208	0	208
C174	Minimum alfalfa and meadows	4000	-55286	4000	200	2800
C175	Minimum maize silage	1200	0	1000	200	1E+30
C176	Minimum maize	3000	-50139	3000	2000	3000
C177	Minimum winter wheat and barley	3000	-56973	3000	3000	800
C178	Minimum vegetable	1000	-29308	1000	8792	1000

The allowed variations (increases and decreases) with respect to the allocated area per particular crop without changing the optimal solution are displayed in the *table 15*.

All crops represented in the optimal cropping pattern are cultivated as irrigated with full irrigation strategy, ISA (winter wheat, maize, tobacco, alfalfa, maize/second crop, green pepper, vegetables, cabbage/second crop and orchards/grape) or as rain-fed crops (barley and meadow/grasses). Deficit irrigation, ISB is not selected for any crop in the Base case scenario.

5.2 Climate change scenarios in 2050

There are three climate change scenarios for 2050 (Low, Medium, High). In all three scenarios, irrigation water requirements are increasing due to less favorable climate conditions. Respectively, available water for irrigation in the reservoir decreases from $92.72*10^6 m^3$; $89.57*10^6 m^3$ to $87.71*10^6 m^3$ in Low, Medium and High scenario respectively.

5.2.1 Crop area

The distribution of the cropping area varies slightly between all three scenarios. *Table 16* allows a comparison of the crop area for each crop grown in a given climate situation in all three scenarios in 2050.

Table 16: Area per crop in three climate scenarios in 2050 (ha)

2050	**LOW**	**MEDIUM**	**HIGH**
Winter Wheat, ISB	2000	2000	2000
Barley , rain-fed	1000	1000	1000
Maize , ISA	3000	3000	3000
Tobacco , ISA	200	200	200
Sunflower , rain-fed	0	383	500
Soybean , rain-fed	186	600	600
Alfalfa, ISB	2800	2800	2800
Maize for Silage, second crop, ISA	1000	1000	1000
Meadow and grasses, rain-fed	1200	1200	1200
Green Peppers incl. industrial, ISA	8606	7809	7173
Vegetables, ISA	1000	1000	1000
Orchards and Grape, ISA	208	208	208
Total cultivated area	21200	21200	20681
Feasible land (first crops)	20200	20200	19681
Second crops	1000	1000	1000

As shown in *table 16*, the areas with green pepper, rain-fed sunflower and rain-fed soybean vary. Green pepper as a very profitable crop, without restriction for maximum limit tends to increase as long as there is available water. Due to a higher amount of water available in Low case scenario, the planted area with green pepper is the highest in the Low case scenario and lowest in the High case scenario. On the other hand, the area planted with rain-fed crops (sunflower and soybean) increases, going from the Low case to the High case scenario.

The areas planted with winter wheat and barley, maize, maize for silage, vegetable and orchards are grown only to satisfy minimum area requirements. If the minimum requirements are excluded, these crops will not be selected by the system as the model maximizes profit. The existence of these crops is mainly due to food security, livestock needs and diversification of the production. Tobacco, which is a rather profitable crop, appears to be grown at the maximum allowable level. If the constraint for tobacco defined at 200 ha is extended, the area with tobacco increases. Compared to the Base case scenario, some crops such as sunflower and soybeans are introduced.

Since water is becoming a limited resource in 2050 (Low, Medium, High scenario), the irrigation strategies for wheat and alfalfa switch to less demanding ones (deficit irrigation, ISB). It is also evident a gradual increase in rain-fed sunflower and soybeans since water becomes scarce in 2050.

The feasible land of 20,200 ha is completely utilized in the Low and Medium case scenarios. However, it is not completely utilized given the High case scenario. The slack value for land (not utilized land) in 2050 High case scenario is 519 ha. Feasible area for irrigation is not completely utilized in all three scenarios (only in base case scenario is completely utilized) leaving some land not irrigated in the Medium and High case scenario.

5.2.2 Economic results

The diverse cropping area yields different profits in different scenario. The highest profit of 726,106,660 MKD/year is achieved in 2050 Low case scenario. The optimal production system given the Medium scenario in 2050 results in a reduced value of the objective function of 668,709,368 MKD, while the value of the objective function of 618,770,673 in High scenario is the most pessimistic.

If a comparison of the attained profit per unit cultivated area is made, the situation is following:

Table 17: Loss in net return in 2050 (%)

	Profit (MKD)	Cultivated area (ha)	Return (MKD/ha)	Loss in net return (%)
BASE	863153496	22400	38534	0
2050 LOW	726106660	21200	34250	11
2050 MEDIUM	668709368	21200	31543	18
2050 HIGH	618770673	20681	29920	22

As shown in the table above, the loss in net farm return caused by climate change will be 11% in the optimistic scenario (2050 Low), 18% in the realistic scenario (2050 Medium) and 22% in the pessimistic scenario (2050 High).

5.2.3 Sensitivity analysis

As stated in the base case scenario, sensitivity analysis when the model is applied without integer variables is also used for a discussion here. The fact that allocated area is identical when model includes integers and without integer variables, enables to consider sensitivity analysis as valid for this model.

Table 18: Sensitivity report, 2050 Low, I part

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
C128	Arable land (ha)	20200	2263	20200	414	186
C129	Water available (m3/year)	92720000	11.695	92720000	1029058	2295902
C130	Feasible area for irrigation	18814	0	20200	1E+30	1386

Table 19: Sensitivity report, 2050 Medium, I part

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
C128	Arable land (ha)	20200	1414	20200	117	383
C129	Water available (m3/year)	89570000	11.667	89570000	2148544	656456
C130	Feasible area for irrigation	18017	0	20200	1E+30	2183

Table 20: Sensitivity report, 2050 High, I part

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
C128	Arable land (ha)	19681	0	20200	1E+30	519
C129	Water available (m3/year)	87710000	11.668	87710000	2963976	40926576
C130	Feasible area for irrigation	17381	0	20200	1E+30	2819

Since the land is a restricting factor for Low and Medium case scenario, the shadow price of land is 2,263 MKD/ha and 1,414 MKD/ha respectively that correspond to the profit increase for one additional unit of land. Opposite, a decrease of 1 ha of land will yield reduction in the net profit by the same amount (*see tables 18 and 19*). The range of arable land for which the shadow price remains constant is between 20,014 ha and 20,614 ha for Low scenario *(table 18)* and between 19,817 ha and 20,317 ha for the Medium scenario *(table 19)*.

Considering the shadow price of land in the Base case scenario and 2050 climate scenarios, it is evident that there is a sharp fall in the value of land from 58,517.26 MKD/year in Base case scenario (*table 14*) to 1,414 MKD/year in 2050 High case scenario *(table 20)*. This is an indicator that the profitability of agricultural production will experience a drastic decline in 2050.

The optimal solutions to the cropping systems in all scenarios in 2050 result in consumption of all water available. The annual water availability is an effective constraint (binding) of the production system in all cases. Nevertheless, land is binding in the Low and Medium scenario, yet it is not binding in High case scenario given the excess of land of 519 ha. In line with the available area for cultivation, feasible area for irrigation is not a binding constraint in all scenarios. The value of the utilized irrigated area is 18,814; 18,017 and 17,381 ha respectively (Low, Medium, High).

The complete depletion of water resources results in a shadow price of water ranging between 11.70 to 11.67 MKD for one additional unit of water (m^3). This means that the value of the objective function decreases by approximately 12 MKD if the water volume is reduced for 1 m^3. Yet, the value of the objective function increases by 12 MKD if the volume of the available water is increased by $1m^3$. An interpretation from another perspective is that the shadow price actually corresponds to users' willingness to pay for an additional unit of water (opportunity cost). The shadow price is actually the price that farmers are willing to pay for a unit of water. If the water price is above shadow price than farmers are not willing to buy additional water since the cost of water exceed the marginal benefit.

The limits within which the shadow price for available water remains unchanged is between 90,42 and 93,75 (10^6 m^3) water for 2050 Low case scenario, 88.91 to 91.72 (10^6 m^3) for 2050 Medium case scenario and 46.78 to 90.67 (10^6 m^3) for 2050 High case scenario. The allowable increases and decreases per particular scenario are illustrated in the tables above (*see tables 18, 19 and 20*).

On the other hand, assurance of minimum area for several crops (orchards/grape; alfalfa and meadows; maize for silage; maize; winter wheat and barley; vegetable) that are less profitable but important for accomplishing food security and diversification of production in order to reduce risk, results in a decrease of profit (*see tables 21, 22 and 23*). For instance, defining a requirement for cultivation of one additional ha of maize corresponds to a decrease in profits by 42,303 to 42,437 MKD depending on the scenario. An additional ha of maize for silage decreases profits from 33,065 in the Low scenario to 34,305 MKD in the High scenario. Winter wheat and barley net profits decrease from 29,814 to 29,656 MKD, while vegetable net profits increase slightly from 34,646 to 34,734 MKD respectfully. The most severe decrease in profits is noticed for alfalfa and meadows in all three climate scenarios for 2050 (ranging from 55,372 to 56,409 MKD/year). In general, all defined minimum requirements such as for orchards/grape, alfalfa/meadows, maize for silage, maize and winter wheat/barley are binding constraints and do constrain the optimal value of attainable profit. It is evident that profits decrease more from the Low to the High case scenario as water requirements are more demanding and water is more scarce. Relaxation of each constraint for one additional ha of land implies increase in the objective function, or profit, equal to the corresponding shadow price given in *the tables 21, 22 and 23.*

In parallel, defining of the maximal limits for several crops (wheat, barley, maize, tobacco, sunflower, soybean, sugar beets, alfalfa, maize for silage and meadows/grasses) also constrain agricultural production. Thus, for highly profitable crops, such as tobacco that is limited on 200 ha, the opportunity cost has a positive value, implying that cultivation of one extra ha of tobacco above limits contributes to an increase of profit by 58,451 MKD in 2050 Low scenario and 58,640 MKD in 2050 High scenario *(see tables 21, 22 and 23)*. In this respect, the priority of water distribution is given to the most profitable crops.

In line with tobacco, an increase of the cultivated area of rain-fed meadow/grasses and barley will cause profits to grow in all scenarios. In this situation, economic implications to farmers for an additional unit of cultivated land of rain-fed meadow/grasses will increase profits from 55,002 to 56,853 MKD respectfully and between 30,374 to 31,152 MKD for rain-fed barley. It is evident that these crops although, not very profitable, with a net return of 8,201 MKD/ha for rain-fed barley and 4,843 MKD/ha for meadow/grasses (not irrigated) in comparison to 119,111 MKD/ha for highly profitable crops such as tobacco, have significant economic implications in the 2050 climate scenarios. The relatively high marginal benefit of not irrigated meadow/grasses (ranging between 55,002 MKD/ha in 2050 Low case scenario) and barley (ranging between 30,374 to 31,152 MKD), nearly as much as the marginal benefit of tobacco (58,452 MKD/ha in 2050 Low case scenario), is due to the water deficit and prioritization of rain-fed crops or crops with deficit irrigation. As water requirements become more demanding, the marginal benefit of rain-fed crops increases. Less significant increase in profits are obtained by extending the cultivated area of sunflowers and soybeans, both cultivated as rain-fed crops in 2050 Medium and High scenario *(tables 21, 22 and 23)*. In 2050 High case scenario, the profit increase for one additional unit of soybean is 1,233 MKD and 762 MKD for sunflower. However, these crops do not affect profitability in other scenarios when water requirements are less demanding (the shadow prices in other scenarios are zero).

The constraints for the maximum allowable areas for tobacco, meadow/grasses and barley in all three 2050 scenarios and rain-fed sunflower and soybean in 2050 Medium and High scenario, are binding. In this case, defining the maximum acreage constrains the objective function. Relaxation of the limits for one additional unit (ha) of these crops increases the value of the objective function equal to their shadow price. On the opposite, maximum allowable area for wheat, maize, sugar beets, alfalfa and maize for silage do not constrain agricultural production (shadow price is zero) because only minimum requirements are satisfied *(see tables 21, 22 and 23)*. Any relaxation of the defined limits will not cause any increase in the objective function.

Table 21: Sensitivity report, 2050 Low scenario, II part

		Final	**Shadow**	**Constraint**	**Allowable**	**Allowable**
Cell	**Name**	**Value**	**Price**	**R.H. Side**	**Increase**	**Decrease**
C163	Maximum area for wheat	2000	0	5000	1.E+30	3000
C164	Maximum area for barley	1000	30374	1000	417	930
C165	Maximum area for maize	3000	0	5000	1.E+30	2000
C166	Maximum area for tobacco	200	58452	200	0	200
C168	Maximum area for soybean	186	0	600	1.E+30	414
C170	Maximum area for alfalfa	2800	0	3000	1.E+30	200
C172	Maximum area for meadow and grasses	1200	55002	1200	209	200
C173	Minimum area for orchards and grape	208	-29248	208	0	208
C174	Minimum alfalfa and meadows	4000	-55372	4000	200	2800
C175	Minimum maize silage	1000	-33065	1000	644	289
C176	Minimum maize	3000	-42437	3000	1499	3000
C177	Minimum winter wheat and barley	3000	-29814	3000	335	747
C178	Minimum vegetable	1000	-34646	1000	5959	1000

Table 22: Sensitivity report, 2050 Medium scenario, II part

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
C163	Maximum area for wheat	2000	0	5000	1.E+30	3000
C164	Maximum area for barley	1000	30688	1000	849	259
C165	Maximum area for maize	3000	0	5000	1.E+30	2000
C166	Maximum area for tobacco	200	58507	200	0	200
C167	Maximum area for sunflower	383	0	500	1.E+30	117
C168	Maximum area for soybean	600	395	600	383	117
C170	Maximum area for alfalfa	2800	0	3000	1.E+30	200
C172	Maximum area for meadow and grasses	1200	55620	1200	427	131
C173	Minimum area for orchards and grape	208	-29611	208	0	208
C174	Minimum alfalfa and meadows	4000	-55793	4000	200	1130
C175	Minimum maize silage	1000	-33524	1000	182	596
C176	Minimum maize	3000	-42421	3000	2000	953
C177	Minimum winter wheat and barley	3000	-29820	3000	698	213
C178	Minimum vegetable	1000	-34675	1000	1692	1000

Table 23: Sensitivity report, 2050 High scenario, II part

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
C163	Maximum area for wheat	2000	0	5000	1.E+30	3000
C164	Maximum area for barley	1000	31152	1000	1000	1000
C165	Maximum area for maize	3000	0	5000	1.E+30	2000
C166	Maximum area for tobacco	200	58640	200	0	200
C167	Maximum area for sunflower	500	762	500	519	500
C168	Maximum area for soybean	600	1233	600	519	600
C170	Maximum area for alfalfa	2800	0	3000	1.E+30	200
C172	Maximum area for meadow and grasses	1200	56853	1200	574	200
C173	Minimum area for orchards and grape	208	-30403	208	0	208
C174	Minimum alfalfa and meadows	4000	-56409	4000	200	2800
C175	Minimum maize silage	1000	-34305	1000	1000	810
C176	Minimum maize	3000	-42303	3000	2000	3000
C177	Minimum winter wheat and barley	3000	-29656	3000	960	1000
C178	Minimum vegetable	1000	-34734	1000	6711	1000

In general, climate change will adversely affect agricultural production and profitability of agricultural production will decrease. The economic implications will be more severe moving from the 2050 Low case scenario to 2050 High case scenario. The increased water demand and the reduction of water resources will affect crop mix switching towards less demanding crops and crops with deficit irrigation. The marginal benefit of rain-fed crops increase as water is becoming more deficient and rain-fed crops with higher net returns will be prioritized.

6 Conclusions

This study aims to address how climate change in 2050 is likely to affect crop production in Pelagonia region and how this will influence farm profitability. The idea behind this study is to assess whether the water reservoir in 2050, if maintained properly, will be sufficient to satisfy irrigation requirements for the total area feasible for irrigation and which cropping patterns are economically rational. The accomplishment of the aim is discussed through the following questions:

- What is the optimal allocation of land that maximizes profit?
- What is the loss in net farm profit due to the climate change?
- What is the marginal value of additional units of water and land?

6.1 Selection of the model

In respect to the assessment of climate change to agricultural production some authors have considered complex integrated models that include different factors such as physical, biological and socio-economic components (Yin, 2003) or economic and technology effects, beside climate factors (Li et al., 2011). The model used in this study is based on agro-economic approach influenced by three main factors: climatic, agronomic and economic factors.

In order to find the optimal allocation of available resources, a linear model is applied. In particular, Simplex method of linear programming with integer variables is chosen as a suitable technique for satisfying the single objective and linear relationships of the current model offering the possibility for selection of a more favorable irrigation strategy. Lee&Olson (2006) have discussed linear programming as a very useful technique for resource allocation problem. Similar, Tran et. al. (2011) pointed out, linear programming together with non-linear and dynamic programming as the most common techniques for water management of the reservoir operation problems.

Given the absence of data required for a reliable estimation of price and cost projection in 2050, the model relies on the estimation of the present net returns assuming that the ratio between revenues and costs remains constant. This is fairly in line with USDA projections for 2050 according to which revenues increases by 23% and costs by 26% (*table 9*).

Perhaps, one of the most significant implications of the model is the possibility to introduce different irrigation strategies and to estimate their impact upon the total profitability of crop production. The option for selecting a more favorable irrigation strategy or choosing between irrigated and rain-fed production is enabled by the model. Certainly, it is highly dependent on the crops sensitivity to water deficit and net returns of the crop under the given circumstances of water limitation.

6.2 Findings of the study

This subchapter intends to address the aim of the study through answering the three main questions mentioned above.

6.2.1 Optimal allocation of land

The findings of the study show that due to climate divergences, the cropping patterns tend to change under the same constraints of land and agro-technical measures. The comparison between the Base case and 2050 sceneries illustrates the importance of crop selection in agricultural production. The optimal allocation of land in all scenarios (Base case and 2050 climate change scenarios) is presented in *table 24*.

Table 24: Optimal crop mix in the Base case scenario and 2050 climate scenarios

Crop	**BASE**	**2050 LOW**	**2050 MED**	**2050 HIGH**
Winter Wheat, ISA	2000	0	0	0
Winter Wheat, ISB	0	2000	2000	2000
Barley , ISA	0	0	0	0
Barley , ISB	0	0	0	0
Barley , rain-fed	1000	1000	1000	1000
Maize , ISA	3000	3000	3000	3000
Tobacco , ISA	200	200	200	200
Tobacco , ISB	0	0	0	0
Tobacco, rain-fed	0	0	0	0
Sunflower, ISA	0	0	0	0
Sunflower, ISB	0	0	0	0
Sunflower, rain-fed	0	0	383	500
Sunflower, second crop ISA	0	0	0	0
Soybean, ISA	0	0	0	0
Soybean, ISB	0	0	0	0
Soybean, rain-fed	0	186	600	600
Soybean, second crop ISA	0	0	0	0
Sugar beets, ISA	0	0	0	0
Sugar beets, ISB	0	0	0	0
Alfalfa, ISA	2800	0	0	0
Alfalfa, ISB	0	2800	2800	2800
Maize for Silage, ISA	0	0	0	0
Maize for Silage, ISB	0	0	0	0
Maize for Silage, second crop, ISA	1200	1000	1000	1000
Meadow and grasses, ISA	0	0	0	0
Meadow and grasses, ISB	0	0	0	0
Meadow and grasses, rain-fed	1200	1200	1200	1200
Watermelon/Melon, ISA	0	0	0	0
Potato and Onion, ISA	0	0	0	0
Potato, rain-fed	0	0	0	0
Green Peppers incl. industrial, ISA	8792	8606	7809	7173
Tomato incl. industrial, ISA	0	0	0	0
Vegetables, ISA	1000	1000	1000	1000
Cabbage, second crop, ISA	1000	0	0	0
Orchards and Grape, ISA	208	208	208	208
Orchards and Grape, ISB	0	0	0	0
Total cultivated area	22400	21200	21200	20681

An examination of the problem from the perspective of area constraints reveals that the area is a limiting factor for Base case scenario and 2050 Low and Medium scenarios. However, it is not a limiting factor in the 2050 High scenario. When water is not a binding constraint (**B**ase case scenario), the most profitable crops are grown (Frizzone et.al, 1997). This is fairly consistent with the result of this study where most profitable crops such as tobacco and green pepper are selected in the optimal solution. Due to the market restrictions or other agro-technical constraints, the production of some crops is limited to the certain limits. In that respect, tobacco as a highly profitable crop is produced to the upper limit of 200 ha. In addition, crops irrigated with the full irrigation strategy (ISA) are preferred as they yield higher returns. Presence of grain and fodder are due to existence of minimum constraints for ensuring food security and livestock production in the region. Hence, given the current climate conditions and land as a limiting factor, the production is constrained due to land restriction.

Looking from the perspective of water constraint, the results indicate that water availability is an expected bottleneck for potential increases in profits in 2050. As water is becoming a scarce resource, crops with lower water demand will be more favorable (Frizzone et.al 1997). Thus, considering water limitation, less profitable crops are expected be grown on a reduced area and/or with less irrigation while highly profitable crops are expected to be grown at their maximal limits (Frizzone et.al 1997).

The model results indicate the same situation, shifting from fully irrigated to deficit irrigated crops for less profitable crops (winter wheat and alfalfa) as water is becoming a binding constraint in 2050. At the same time, the area of highly profitable crops increases to the upper limits (tobacco). In addition, it is evident that introduction of low-profit crops such as sunflowers and soybeans without irrigation when water is more scarce resource is a feasible strategy (2050 Medium and High case scenario).

6.2.2 Loss in net farm profit due to the climate change

The expected climate change will cause negative economic implications upon the profitability of agricultural production. It is expected that economic implications will be more severe as temperatures increase and water is in higher demand. Thus, the profit decrease will be more evident moving from the 2050 Low case scenario to 2050 High case scenario. Compared to the Base case scenario, the total profits in 2050 will be reduced by 16 % in the optimistic scenario (2050 Low), 23% in the realistic (2050 Medium) to 28% in the most pessimistic scenario (2050 High).

Table 25: Profit decrease and loss in net return in 2050

	Profit (MKD)	Profit decrease (%)	Cultivated area (ha)	Return (MKD/ha)	Loss in net return (%)
BASE	863153496	100	22400	38534	0
2050 LOW	726106660	20	21200	34250	11
2050 MEDIUM	668709368	23	21200	31543	18
2050 HIGH	618770673	28	20681	29920	22

In parallel, the loss in net farm return caused by climate change will be 11% in the optimistic scenario (2050 Low), 18% in the realistic scenario (2050 Medium) and 22% in the pessimistic scenario (2050 High).

6.2.3 Marginal value of additional units of water and land

The available area for cultivation does constrain agricultural production in the Base case, the 2050 Low and 2050 Medium scenario. In this respect, farmers' profitability is curbed due to limitation in area. Thus, if farmers tend to maximize profit, they have to be ready to take opportunity cost of land and willing to pay utmost value of 58,517 MKD for one additional ha of land or additional 10,444 MKD/ha for having access to irrigated land. Paying a higher price will not be profitable anymore for farmers. Considering the current price of 3,000 MKD/ha for renting agricultural land (state owned) in Pelagonia region, it is obvious that the current rental rate is far below estimated economic value of land. However, the shadow price of land in 2050 experiences a drastic drop to even 1,414 MKD/year in the 2050 High case scenario which indicates that profitability of agricultural production and thus economic value of land will be decline drastically.

In respect to water availability, the agricultural productivity is restricted in all three 2050 scenarios (2050 Low, 2050 Medium, 2050 High) due to water limitation. In 2050, when water will become a scarce resource, a higher water price should be expected. Thus, water utilization will become one of the main issues in irrigated agriculture. Users, who are going to consume more water than necessary, have to be ready to pay a higher price for water, close to its shadow price. In that respect, the farmers might pay a price of slightly below 12 MKD/m3 for irrigation water which leads to the conclusion that the current water price of 3 MKD/ha might be underestimated.

Having in mind the huge discrepancies between shadow price of land and water and their market prices, both land and water resources seem to be valued far below their economic value. In that respect, consideration of new policies for more efficient management and sustainable utilization of natural resources in line with the social aspects of land and water have to be recommended.

6.3 Recommended measures

Generally, the agricultural sector is vulnerable towards future climate change. The climate change will adversely affect agricultural production, despite certain benefits, and therefore cause a decrease in farm profitability. The economic implications will be more severe as water is becoming scarcer. Considering a future climate challenges, the expected decrease in profits will amount to 16%, 23% and 28% respectively in the 2050 climate scenarios (Low, Medium, High).

Due to mitigation of the climate change consequences, it is highly recommendable application of adaptation and mitigation measures. In this regards, farmers are highly advised to shift towards more efficient adaptation strategies such as water efficient irrigation techniques, introduction of more resistant crop varieties, better suited cropping patterns, changing of the timing of field operations, diversification of farm enterprise and alike. The preliminary assessment for reducing the vulnerability of the agricultural sector (www, World Bank, 3, 2010) points out the importance of implementing adaptation measures on national level such as improved weather information systems and weather based crop programs, development of highly resistant crops, improved water use efficiency and risk management, improved watershed management and rehabilitation of the irrigation systems, appliance of new irrigation techniques and alike. UNDP report (www, UNDP, 1, 2011) points out similar adaptation techniques for Pelagonia region. Beside rehabilitation of the whole irrigation system, changing the cropping pattern with a larger share of less water demanding crops, introduction of new varieties that are more resistant to water deficit such as sorghum instead maize, application of water saving irrigation techniques such as drip irrigation where applicable and deficit irrigation for less sensitive crops are proposed measures for adaptation to climate changes in Macedonia, and in particular to Pelagonia region.

Taking into consideration the vulnerability of the risky and marginal agricultural production and its significant importance to the Country, a proactive approach for adaptation of Macedonian agriculture towards future climate change is needed. As findings of the model reveal, under more severe climate conditions; the production of less profitable bulky commodities (grain, cereals, and fodder or industrial crops) will not contribute to an increase in net returns. Hence, the production of these crops should be limited to the minimum level of satisfying basic needs and diversifying risk of agricultural production. For small countries like Macedonia, specialization in high value and less vulnerable crops such as tobacco, green pepper and vegetable will be more beneficial and might contribute to mitigating the adverse effects of climate change. By greater specialization of the country in products for which the country has comparative advantage (high value crops), production will be more efficient. Trade with other countries whose comparative advantages lie in other products could be valuable for both countries.

6.4 Comparison with other studies

6.4.1 Implications to agricultural production

The results of this study are well in line with similar problems examined on on-farm and national level by other authors. Similar adaptation measures are discussed and proposed by Kaiser (1991), Kaiser et al. (1993), and Deressa (2009). Kaiser (1991) claims that negative effects of climate change on agricultural production may be mitigated by adaptation strategies such as changing of crop calendar, crop mix and cultivars. The case farm in southern Minnesota reveals that yields will stay relatively stable (corn) or even increase (soybean and sorghum), and only in the most severe conditions they decrease. Further research by Kaiser et al. (1993) shows that adaptive strategies could much contribute to grain farmers from South Minnesota to effectively adapt to different climate change scenarios. Deressa et. al (2009) stresses out that adaptation strategies will be even more effective if they are adjusted to the particular agro-ecological zone.

6.4.2 Implications to trade

Apart of agro-technological measures, other authors have discussed macro and micro-economic components for combating negative effects of the climate change. Nelson et al. (2010) has discussed supply and demand of agricultural commodities in respect of the climate change. In line with this study, Nelson et al (2010) claims that trade flows might compensate disadvantages of the climate change. In such circumstances, the country should orient towards production of competitive commodities (crops) relies on climate conditions and resource endowments.

Similarly, Li et al. (2011) examines maize production at world level. Considering that climate change will alter competitive advantages of one region, but in turn might be abundant for other region, a greater specialization of the resource abundant country/region might offset the loss of competitive advantage of the other countries/regions. To mitigate negative effects to world maize supply as a result of changed competitive advantage of the major grain producers, freer trade between two countries based on special duties or without duties could avoid the risks of maize supply. As one of the proposed measures for buffering climate change in Macedonia, especially as a minor agricultural producer, specialization of the country in high value crops and potential trade with other compatible countries is a recommended strategy for the future. Similar results are provided in the recently published UNDP report (www, UNDP, 1, 2011, pp. 93-95) for Strezevo case study. The main findings are that five major crops that are the most vulnerable and the least valuable crops have to be replaced with other high value and less climate-sensitive crops. However, the suggested changes in the cropping patterns and orientation towards production of high value crops should be in line with market movements in order to prevent even greater income losses due to market failure or unstable prices. As a measure of prevention against risky agriculture, the model developed in this study defines minimum and maximum limits for certain crops in order to ensure food supplies of the main commodities and to diversify risk of agricultural enterprise. This is fairly in line with Kandulu (2011) who claims that diversification of agricultural production is an efficient strategy to reduce risk and fluctuations in net returns.

6.5 Epilogue

Despite several examined studies, this study introduces different approaches and assesses new aspects other than already discussed. Besides the possibility for selecting a more favorable irrigation strategy or choosing between irrigated and rain-fed production depending on the climate conditions in different scenarios, this study examines economic impact of climate change on agricultural production not only for a few main crops but also for high value crops cultivated in the region. In addition, cultivation of the secondary crops and their contribution to the total value of the agricultural production is also valuable. At total, 18 different crops or groups of crops, both irrigated and not irrigated, including second crops have been assessed in the study.

The findings of the study are not a solid base for drawing general conclusions about climate change and agriculture on a country level. However, the study depicts the implications of climate change in Pelagonia region and provides recommendations for further policy options and preparation of prevention programs.

7 Further research

This study has attempted to assess the potential effects of climate change on crop productivity in Pelagonia region in 2050. The major observation from the literature review is that different climate models use different data regarding climate change projections. The discrepancies between models are huge, varying in the value and even in the sign of foreseen climate changes on global level.

Thus, improvement of the climate models could lead to a higher accuracy and consistency of the data required. The calculations of crop water requirements are based on the Cropwat model which is an older simulation model. Estimation of crop water requirements by more sophisticated models like CERES, EPIC or WOFOST could provide even more accurate estimates of crop response to climate changes.

Furthermore, given the absence of data required for plausible estimation of prices and costs in 2050, the model relies on current price estimates. Perhaps, the significant improvement could be made if there are reliable long-term projections for crop net returns in 2050. Such reliable price and cost projections should reflect yields response not only to the projected climate change but also to the global changes in supply and demand. Estimations of price projections both for the main crops and for other important high value crops would be a valuable input for further research.

One important feature the model does not take into consideration is the effect of the technological improvements on agricultural production in the future climate change scenarios. More reliable estimates of the economic implications of climate change on agricultural production could be provided if this aspect is considered in future research. It is expected that technology improvement effects could substantially mitigate the adverse effects of climate change.

Finally, estimation of the effect of future climate change not only in relation to above mentioned factors, by also in relation to socio-economic factors such as population growth and income, economic development and other factors induced by climate change could substantially improve the model. Given these circumstances, the model could be developed on a larger spatial scale as well as on national/regional level.

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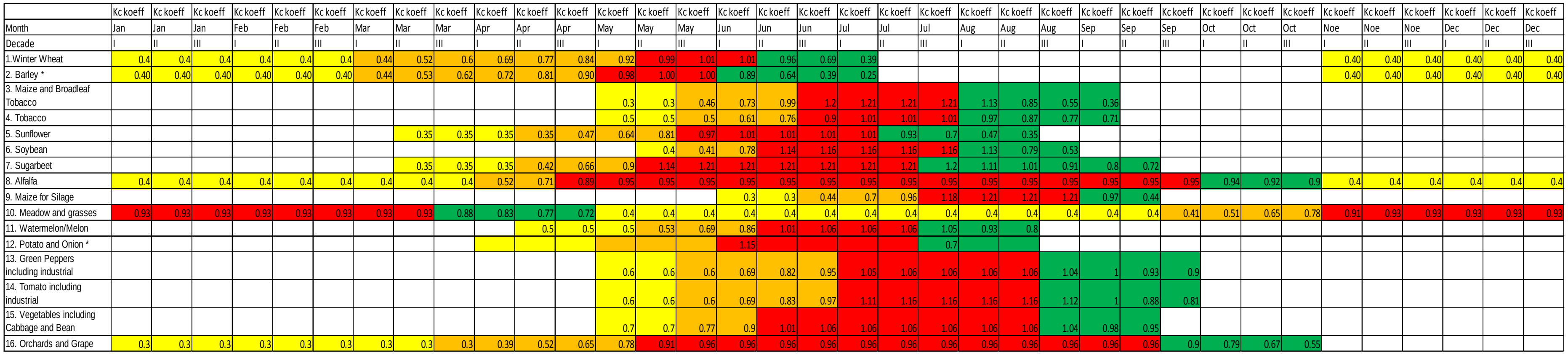
Appendix 1: Crop coefficient (kc) and crop growth stages



	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff	Kc koeff
Month	Jan	Jan	Jan	Feb	Feb	Feb	Mar	Mar	Mar	Apr	Apr	Apr	May	May	May	Jun	Jun	Jun	Jul	Jul	Jul	Aug	Aug	Aug	Sep	Sep	Sep	Oct	Oct	Oct	Noe	Noe	Noe	Dec	Dec	Dec
Decade	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
1.Winter Wheat	0.4	0.4	0.4	0.4	0.4	0.4	0.44	0.52	0.6	0.69	0.77	0.84	0.92	0.99	1.01	1.01	0.96	0.69	0.39												0.40	0.40	0.40	0.40	0.40	0.40
2. Barley *	0.40	0.40	0.40	0.40	0.40	0.40	0.44	0.53	0.62	0.72	0.81	0.90	0.98	1.00	1.00	0.89	0.64	0.39	0.25												0.40	0.40	0.40	0.40	0.40	0.40
3. Maize and Broadleaf Tobacco													0.3	0.3	0.46	0.73	0.99	1.2	1.21	1.21	1.21	1.13	0.85	0.55	0.36											
4. Tobacco													0.5	0.5	0.5	0.61	0.76	0.9	1.01	1.01	1.01	0.97	0.87	0.77	0.71											
5. Sunflower								0.35	0.35	0.35	0.35	0.47	0.64	0.81	0.97	1.01	1.01	1.01	1.01	0.93	0.7	0.47	0.35													
6. Soybean														0.4	0.41	0.78	1.14	1.16	1.16	1.16	1.16	1.13	0.79	0.53												
7. Sugarbeet								0.35	0.35	0.35	0.42	0.66	0.9	1.14	1.21	1.21	1.21	1.21	1.21	1.21	1.2	1.11	1.01	0.91	0.8	0.72										
8. Alfalfa	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.52	0.71	0.89	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.94	0.92	0.9	0.4	0.4	0.4	0.4	0.4	0.4
9. Maize for Silage																0.3	0.3	0.44	0.7	0.96	1.18	1.21	1.21	1.21	0.97	0.44										
10. Meadow and grasses	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.88	0.83	0.77	0.72	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.41	0.51	0.65	0.78	0.91	0.93	0.93	0.93	0.93	0.93
11. Watermelon/Melon											0.5	0.5	0.5	0.53	0.69	0.86	1.01	1.06	1.06	1.06	1.05	0.93	0.8													
12. Potato and Onion *																1.15					0.7															
13. Green Peppers including industrial													0.6	0.6	0.6	0.69	0.82	0.95	1.05	1.06	1.06	1.06	1.06	1.04	1	0.93	0.9									
14. Tomato including industrial													0.6	0.6	0.6	0.69	0.83	0.97	1.11	1.16	1.16	1.16	1.16	1.12	1	0.88	0.81									
15. Vegetables including Cabbage and Bean													0.7	0.7	0.77	0.9	1.01	1.06	1.06	1.06	1.06	1.06	1.06	1.04	0.98	0.95										
16. Orchards and Grape	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.39	0.52	0.65	0.78	0.91	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.9	0.79	0.67	0.55						

Source: Pejovska (2009)

Legend:

Initial/Vegetative	🟨
Development/Flowering	🟧
Middle/Yield formation	🟥
Late/Ripening	🟩

Appendix 2: Reference evapotranspiration, ETo

Month	ETo BASE	ETo 2050 LOW	ETo 2050 MEDIUM	ETo 2050 HIGH
January	0,49	0.54	0.55	0.56
February	0,85	0.95	0.97	0.99
March	1,61	1.75	1.77	1.8
April	2,60	2.8	2.82	2.87
May	3,55	3.78	3.79	3.85
June	4,76	5.07	5.11	5.16
July	5,08	5.39	5.43	5.49
August	4,43	4.72	4.76	4.81
September	3,01	3.19	3.21	3.24
October	1,70	1.81	1.82	1.84
November	0,86	0.93	0.93	0.94
December	0,52	0.57	0.58	0.59
Average	2,46	2.63	2.64	2.68

Appendix 3: Crop evapotranspiration, ETc

Appendix 3.1: Crop evapotranspiration (mm/month), BASE CASE

Etc/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Noe	Dec	Total (mm/year)
1. Etc winter wheat	5.88	10.20	25.12	59.80	103.66	126.62	19.81				10.32	6.24	367.64
2. Etc barley	5.88	10.20	25.60	63.18	105.79	91.39	12.70				10.32	6.24	331.30
3. Etc maize and broadleaf tobacco					37.63	138.99	184.40	112.08	10.84				483.94
4. Etc tobacco					53.25	108.05	153.92	115.62	21.37				452.22
5. Etc sunflower			11.27	30.42	85.91	144.23	134.11	36.33					442.27
6. Etc soybean					28.76	146.61	176.78	108.54					460.68
7. Etc sugar beet			11.27	37.18	115.38	172.79	183.90	134.23	45.75				700.49
8. Etc alfalfa	5.88	10.20	19.32	55.12	101.18	135.66	144.78	126.26	85.79	46.92	10.32	6.24	747.66
9. Etc maize for silage						49.50	144.27	160.81	42.44				397.03
10. Etc meadow and grasses	13.67	23.72	44.11	60.32	42.60	57.12	60.96	53.16	36.42	32.98	23.82	14.51	463.39
11. Etc melon				26.00	61.06	139.47	161.04	76.64					464.20
12. Etc potato and onion				26.00	67.81	151.84	166.62	102.78					515.05
13. Etc green peppers					63.90	117.10	161.04	139.99	85.18				567.20
14. Etc tomato					63.90	118.52	174.24	152.39	80.97				590.03
15. Etc vegetable					77.04	141.37	161.54	139.99	58.09				578.03
16. Etc orchards and grape	4.41	7.65	14.49	40.56	94.08	137.09	146.30	127.58	84.88	34.17			691.21

Appendix 3.2: Crop evapotranspiration (mm/month), 2050 LOW

Etc/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Noe	Dec	Total (mm/year)
1. Etc winter wheat	6.70	10.64	28.21	64.68	113.66	135.37	65.17	0.00	0.00	0.00	11.16	7.07	442.65
2. Etc barley	6.70	10.64	28.75	68.04	117.18	97.34	41.77	0.00	0.00	0.00	11.16	7.07	388.65
3. Etc maize and broadleaf tobacco	0.00	0.00	0.00	0.00	41.01	147.54	202.18	124.37	34.45	0.00	0.00	0.00	549.55
4. Etc tobacco	0.00	0.00	0.00	0.00	58.59	115.60	168.76	127.30	67.95	0.00	0.00	0.00	538.19
5. Etc sunflower	0.00	0.00	18.99	32.76	94.92	153.62	147.04	59.99	0.00	0.00	0.00	0.00	507.31
6. Etc soybean	0.00	0.00	0.00	0.00	46.87	156.66	193.82	119.98	0.00	0.00	0.00	0.00	517.34
7. Etc sugar beet	0.00	0.00	18.99	40.32	126.55	184.04	202.18	147.78	72.73	0.00	0.00	0.00	792.60
8. Etc alfalfa	6.70	10.64	21.70	59.64	111.32	144.50	158.74	139.00	90.92	51.62	11.16	7.07	813.00
9. Etc maize for silage	0.00	0.00	0.00	0.00	0.00	53.24	158.74	177.05	66.99	0.00	0.00	0.00	456.01
10. Etc meadow and grasses	15.57	24.74	49.37	64.68	46.87	60.84	66.84	58.53	38.28	36.47	25.95	16.43	504.56
11. Etc melon	0.00	0.00	0.00	42.00	66.79	149.06	177.12	125.84	0.00	0.00	0.00	0.00	560.80
12. Etc potato and onion	0.00	0.00	0.00	42.00	75.00	162.75	182.13	112.67	0.00	0.00	0.00	0.00	574.54
13. Etc green peppers	0.00	0.00	0.00	0.00	70.31	124.72	177.12	155.10	90.92	0.00	0.00	0.00	618.16
14. Etc tomato	0.00	0.00	0.00	0.00	70.31	126.24	193.82	169.73	86.13	0.00	0.00	0.00	646.24
15. Etc vegetable	0.00	0.00	0.00	0.00	82.03	150.58	177.12	155.10	91.87	0.00	0.00	0.00	656.69
16. Etc orchards and grape	5.02	7.98	16.28	43.68	103.12	146.02	160.41	140.47	90.92	37.59	0.00	0.00	751.47
Second crops:													
Etc maize for silage							120.30	153.64	114.84				388.78
Etc - vegetable cabbage							116.96	124.37	99.53	58.35			399.22

Appendix 3.3: Crop evapotranspiration (mm/month), 2050 MEDIUM

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Noe	Dec	Total (mm/year)
Etc winter wheat	6.82	10.86	28.53	65.14	113.97	136.44	65.65	0.00	0.00	0.00	11.16	7.19	445.76
Etc barley	6.82	10.86	29.08	68.53	117.49	98.11	42.08	0.00	0.00	0.00	11.16	7.19	391.33
Etc maize and broadleaf tobacco	0.00	0.00	0.00	0.00	41.12	148.70	203.68	125.43	34.67	0.00	0.00	0.00	553.60
Etc tobacco	0.00	0.00	0.00	0.00	58.75	116.51	170.01	128.38	68.37	0.00	0.00	0.00	542.02
Etc sunflower	0.00	0.00	19.20	32.99	95.17	154.83	148.13	60.50	0.00	0.00	0.00	0.00	510.83
Etc soybean	0.00	0.00	0.00	0.00	47.00	157.90	195.26	121.00	0.00	0.00	0.00	0.00	521.16
Etc sugar beet	0.00	0.00	19.20	40.61	126.89	185.49	203.68	149.04	73.19	0.00	0.00	0.00	798.10
Etc alfalfa	6.82	10.86	21.95	60.07	111.62	145.64	159.91	140.18	91.49	51.91	11.16	7.19	818.79
Etc maize for silage	0.00	0.00	0.00	0.00	0.00	53.66	159.91	178.55	67.41	0.00	0.00	0.00	459.53
Etc meadow and grasses	15.86	25.26	49.93	65.14	47.00	61.32	67.33	59.02	38.52	36.67	25.95	16.72	508.72
Etc melon	0.00	0.00	0.00	42.30	66.97	150.23	178.43	126.90	0.00	0.00	0.00	0.00	564.83
Etc potato and onion	0.00	0.00	0.00	42.30	75.19	164.03	183.48	113.62	0.00	0.00	0.00	0.00	578.63
Etc green peppers	0.00	0.00	0.00	0.00	70.49	125.71	178.43	156.41	91.49	0.00	0.00	0.00	622.53
Etc tomato	0.00	0.00	0.00	0.00	70.49	127.24	195.26	171.17	86.67	0.00	0.00	0.00	650.84
Etc vegetable	0.00	0.00	0.00	0.00	82.24	151.77	178.43	156.41	92.45	0.00	0.00	0.00	661.30
Etc orchards and grape	5.12	8.15	16.46	43.99	103.39	147.17	161.60	141.66	91.49	37.80	0.00	0.00	756.82
Second crops:													
Etc maize for silage							121.20	154.94	115.56				
Etc - vegetable cabbage							117.83	125.43	100.15	58.68			

Appendix 3.4: Crop evapotranspiration (mm/month), 2050 HIGH

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Noe	Dec	Total (mm/year)
Etc winter wheat	6.94	11.09	29.02	66.30	115.77	137.77	66.37	0.00	0.00	0.00	11.28	7.32	451.86
Etc barley	6.94	11.09	29.57	69.74	119.35	99.07	42.55	0.00	0.00	0.00	11.28	7.32	396.91
Etc maize and broadleaf tobacco	0.00	0.00	0.00	0.00	41.77	150.16	205.93	126.74	34.99	0.00	0.00	0.00	559.59
Etc tobacco	0.00	0.00	0.00	0.00	59.68	117.65	171.89	129.73	69.01	0.00	0.00	0.00	547.95
Etc sunflower	0.00	0.00	19.53	33.58	96.67	156.35	149.77	61.14	0.00	0.00	0.00	0.00	517.03
Etc soybean	0.00	0.00	0.00	0.00	47.74	159.44	197.42	122.27	0.00	0.00	0.00	0.00	526.87
Etc sugar beet	0.00	0.00	19.53	41.33	128.90	187.31	205.93	150.60	73.87	0.00	0.00	0.00	807.47
Etc alfalfa	6.94	11.09	22.32	61.13	113.38	147.06	161.68	141.65	92.34	52.48	11.28	7.32	828.67
Etc maize for silage	0.00	0.00	0.00	0.00	0.00	54.18	161.68	180.42	68.04	0.00	0.00	0.00	464.32
Etc meadow and grasses	16.14	25.78	50.78	66.30	47.74	61.92	68.08	59.64	38.88	37.08	26.23	17.01	515.57
Etc melon	0.00	0.00	0.00	43.05	68.03	151.70	180.40	128.23	0.00	0.00	0.00	0.00	571.42
Etc potato and onion	0.00	0.00	0.00	43.05	76.38	165.64	185.51	114.81	0.00	0.00	0.00	0.00	585.39
Etc green peppers	0.00	0.00	0.00	0.00	71.61	126.94	180.40	158.06	92.34	0.00	0.00	0.00	629.34
Etc tomato	0.00	0.00	0.00	0.00	71.61	128.48	197.42	172.97	87.48	0.00	0.00	0.00	657.96
Etc vegetable	0.00	0.00	0.00	0.00	83.55	153.25	180.40	158.06	93.31	0.00	0.00	0.00	668.57
Etc orchards and grape	5.21	8.32	16.74	44.77	105.03	148.61	163.38	143.15	92.34	38.22	0.00	0.00	765.76

Appendix 4: Irrigation water requirements (IWR)

Appendix 4.1: Irrigation water requirements, 2050 BASE

Appendix 4.1.1: Irrigation water requirements (mm/month) with FULL IRRIGATION, BASE CASE

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Noe	Dec	Total (mm/year)
1. Winter Wheat IWR (mm/month)	0.00	0.00	7.04	39.50	79.94	114.30	6.29	0.00	0.00	0.00	0.00	0.00	247.06
2. Barley IWR (mm/month)	0.00	0.00	7.52	42.88	82.07	79.07	0.00	0.00	0.00	0.00	0.00	0.00	211.54
3. Maize and Broadleaf Tobacco IWR (mm/month)	0.00	0.00	0.00	0.00	13.91	126.67	170.88	100.12	0.00	0.00	0.00	0.00	411.59
4. Tobacco IWR (mm/month)	0.00	0.00	0.00	0.00	29.53	95.73	140.40	103.66	6.89	0.00	0.00	0.00	376.22
5. Sunflower IWR (mm/month)	0.00	0.00	0.00	10.12	62.19	131.91	120.59	24.37	0.00	0.00	0.00	0.00	349.18
6. Soybean IWR (mm/month)	0.00	0.00	0.00	0.00	5.04	134.29	163.26	96.58	0.00	0.00	0.00	0.00	399.16
7. Sugar beet IWR (mm/month)	0.00	0.00	0.00	16.88	91.66	160.47	170.38	122.27	31.27	0.00	0.00	0.00	592.92
8. Alfalfa IWR (mm/month)	0.00	0.00	1.24	34.82	77.46	123.34	131.26	114.30	71.31	18.52	0.00	0.00	572.24
9. Maize for Silage IWR (mm/month)	0.00	0.00	0.00	0.00	0.00	37.18	130.75	148.85	27.96	0.00	0.00	0.00	344.75
10. Meadow and grasses IWR (mm/month)	0.00	1.92	26.03	40.02	18.88	44.80	47.44	41.20	21.94	4.58	0.00	0.00	246.81
11. Watermelon/Melon IWR (mm/month)	0.00	0.00	0.00	5.70	37.34	127.15	147.52	64.68	0.00	0.00	0.00	0.00	382.38
12. Potato and Onion IWR (mm/month)	0.00	0.00	0.00	5.70	44.09	139.52	153.10	90.82	0.00	0.00	0.00	0.00	433.23
13. Green Peppers including industrial IWR (mm/month)	0.00	0.00	0.00	0.00	40.18	104.78	147.52	128.03	70.70	0.00	0.00	0.00	491.20
14. Tomato including industrial IWR (mm/month)	0.00	0.00	0.00	0.00	40.18	106.20	160.72	140.43	66.49	0.00	0.00	0.00	514.03
15. Vegetables including Cabbage and Bean IWR (mm/month)	0.00	0.00	0.00	0.00	53.32	129.05	148.02	128.03	43.61	0.00	0.00	0.00	502.03
16. Orchards and Grape IWR (mm/month)	0.00	0.00	0.00	20.26	70.36	124.77	132.78	115.62	70.40	5.77	0.00	0.00	539.96
Second crops:													
IWR maize for silage second crop (mm/month)	0.00	0.00	0.00	0.00	0.00	0.00	107.68	142.98	101.08	0.00	0.00	0.00	351.74
IWR cabbage (mm/month)	0.00	0.00	0.00	0.00	0.00	0.00	104.31	113.47	85.67	30.28	0.00	0.00	333.73

Appendix 4.1.2: Irrigation water requirements (mm/month) with DEFICIT IRRIGATION, BASE CASE

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Noe	Dec	Total (mm/year)
IWR winter wheat (mm/month)	0.00	0.00	2.01	27.54	59.21	88.97	2.33	0.00	0.00	0.00	0.00	0.00	180.06
IWR barley (mm/month)	0.00	0.00	2.40	30.24	60.91	60.79	0.00	0.00	0.00	0.00	0.00	0.00	154.35
IWR tobacco (mm/month)	0.00	0.00	0.00	0.00	18.88	74.12	109.62	80.54	2.62	0.00	0.00	0.00	285.78
IWR sunflower (mm/month)	0.00	0.00	0.00	4.04	45.01	103.06	93.77	17.10	0.00	0.00	0.00	0.00	262.98
IWR soybean (mm/month)	0.00	0.00	0.00	0.00	0.00	104.97	127.91	74.87	0.00	0.00	0.00	0.00	307.74
IWR sugar beet (mm/month)	0.00	0.00	0.00	9.44	68.58	125.91	133.60	95.42	22.12	0.00	0.00	0.00	455.08
IWR alfalfa (mm/month)	0.00	0.00	0.00	23.80	57.22	96.21	102.30	89.04	54.15	9.14	0.00	0.00	431.86
IWR maize for silage (mm/month)	0.00	0.00	0.00	0.00	0.00	27.28	101.90	116.69	19.47	0.00	0.00	0.00	265.34
IWR meadow and grasses (mm/month)	0.00	0.00	17.21	27.96	10.36	33.38	35.25	30.57	14.66	0.00	0.00	0.00	169.38
IWR orchards and grape (mm/month)	0.00	0.00	0.00	12.15	51.54	97.35	103.52	90.11	53.43		0.00	0.00	408.09

Appendix 4.2: Irrigation water requirements, 2050 LOW

Appendix 4.2.1: Irrigation water requirements (mm/month) with FULL IRRIGATION, 2050 LOW

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Noe	Dec	Total (mm/year)
1. IWR winter wheat	0.00	0.00	10.69	44.99	90.61	126.62	55.41	0.00	0.00	0.00	0.00	0.00	328.32
2. IWR barley	0.00	0.00	11.23	48.35	94.13	88.59	32.01	0.00	0.00	0.00	0.00	0.00	274.32
3. IWR maize and broadleaf tobacco	0.00	0.00	0.00	0.00	17.96	138.79	192.42	115.92	20.46	0.00	0.00	0.00	485.55
4. IWR tobacco	0.00	0.00	0.00	0.00	35.54	106.85	159.00	118.85	53.96	0.00	0.00	0.00	474.19
5. IWR sunflower	0.00	0.00	0.00	13.07	71.87	144.87	137.28	51.54	0.00	0.00	0.00	0.00	418.63
6. IWR soybean	0.00	0.00	0.00	0.00	23.82	147.91	184.06	111.53	0.00	0.00	0.00	0.00	467.33
7. IWR sugar beet	0.00	0.00	0.00	20.63	103.50	175.29	192.42	139.33	58.74	0.00	0.00	0.00	689.92
8. IWR alfalfa	0.00	0.00	4.18	39.95	88.27	135.75	148.98	130.55	76.93	23.99	0.00	0.00	648.59
9. IWR maize for silage	0.00	0.00	0.00	0.00	0.00	44.49	148.98	168.60	53.00	0.00	0.00	0.00	415.06
10. IWR meadow and grasses	0.00	1.35	31.85	44.99	23.82	52.09	57.08	50.08	24.29	8.84	0.00	0.00	294.38
11. IWR watermelon/melon	0.00	0.00	0.00	22.31	43.74	140.31	167.36	117.39	0.00	0.00	0.00	0.00	491.10
12. IWR potato and onion	0.00	0.00	0.00	22.31	51.95	154.00	172.37	104.22	0.00	0.00	0.00	0.00	504.84
13. IWR green peppers	0.00	0.00	0.00	0.00	47.26	115.97	167.36	146.65	76.93	0.00	0.00	0.00	554.16
14. IWR tomato	0.00	0.00	0.00	0.00	47.26	117.49	184.06	161.28	72.14	0.00	0.00	0.00	582.24
15. IWR vegetable	0.00	0.00	0.00	0.00	58.98	141.83	167.36	146.65	77.88	0.00	0.00	0.00	592.69
16. IWR orchards and grape	0.00	0.00	0.00	23.99	80.07	137.27	150.65	132.02	76.93	9.96	0.00	0.00	610.88
Second crops:													
IWR maize for silage (mm/month)	0.00	0.00	0.00	0.00	0.00	0.00	110.54	145.19	100.85	0.00	0.00	0.00	356.58
IWR vegetable - cabbage (mm/month)	0.00	0.00	0.00	0.00	0.00	0.00	107.20	115.92	85.54	30.72	0.00	0.00	339.39

Appendix 4.2.2: Irrigation water requirements (mm/month) with DEFICIT IRRIGATION, 2050 LOW

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Noe	Dec	Total (mm/year)
2. IWR barley	0.00	0.00	5.48	34.74	70.69	69.13	23.66	0.00	0.00	0.00	0.00	0.00	203.70
4. IWR tobacco	0.00	0.00	0.00	0.00	23.82	83.73	125.25	93.39	40.37	0.00	0.00	0.00	366.55
5. IWR sunflower	0.00	0.00	0.00	6.52	52.88	114.15	107.87	39.54	0.00	0.00	0.00	0.00	320.96
6. IWR soybean	0.00	0.00	0.00	0.00	14.45	116.58	145.30	87.54	0.00	0.00	0.00	0.00	363.86
7. IWR sugar beet	0.00	0.00	0.00	12.57	78.19	138.48	151.98	109.78	44.20	0.00	0.00	0.00	535.20
8. IWR alfalfa	0.00	0.00	0.00	28.02	66.01	106.85	117.23	102.75	58.74	13.67	0.00	0.00	493.27
9. IWR maize for silage	0.00	0.00	0.00	0.00	0.00	33.84	117.23	133.19	39.60	0.00	0.00	0.00	323.86
10. IWR meadow and grasses	0.00	0.00	21.97	32.05	14.45	39.92	43.71	38.37	16.63	1.55	0.00	0.00	208.66
16. IWR orchards and grape	0.00	0.00	0.00	15.25	59.44	108.06	118.57	103.92	58.74	2.44	0.00	0.00	466.44
Second crops:													
IWR maize for silage	0.00	0.00	0.00	0.00	0.00	0.00	86.48	114.46	77.88	0.00	0.00	0.00	278.82

Appendix 4.3: Irrigation water requirements, 2050 MEDIUM

Appendix 4.3.1: Irrigation water requirements (mm/month) with FULL IRRIGATION, 2050 MEDIUM

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Noe	Dec	Total (mm/year)
1. IWR winter wheat	0.00	0.00	12.14	46.66	92.27	127.91	56.13	0.00	0.00	0.00	0.00	0.00	335.10
2. IWR barley	0.00	0.00	12.69	50.04	95.79	89.59	32.56	0.00	0.00	0.00	0.00	0.00	280.67
3. IWR maize and broadleaf tobacco	0.00	0.00	0.00	0.00	19.42	140.18	194.16	117.20	21.17	0.00	0.00	0.00	492.12
4. IWR tobacco	0.00	0.00	0.00	0.00	37.05	107.98	160.49	120.15	54.87	0.00	0.00	0.00	480.54
5. IWR sunflower	0.00	0.00	2.81	14.51	73.47	146.31	138.61	52.27	0.00	0.00	0.00	0.00	427.98
6. IWR soybean	0.00	0.00	0.00	0.00	25.30	149.37	185.74	112.77	0.00	0.00	0.00	0.00	473.19
7. IWR sugar beet	0.00	0.00	2.81	22.13	105.19	176.97	194.16	140.81	59.69	0.00	0.00	0.00	701.75
8. IWR alfalfa	0.00	0.00	5.55	41.58	89.92	137.11	150.39	131.96	77.98	25.04	0.00	0.00	659.54
9. IWR maize for silage	0.00	0.00	0.00	0.00	0.00	45.13	150.39	170.32	53.91	0.00	0.00	0.00	419.75
10. IWR meadow and grasses	0.00	3.14	33.54	46.66	25.30	52.79	57.81	50.80	25.02	9.81	0.00	0.00	304.87
11. IWR watermelon/melon	0.00	0.00	0.00	23.82	45.27	141.71	168.91	118.67	0.00	0.00	0.00	0.00	498.38
12. IWR potato and onion	0.00	0.00	0.00	23.82	53.50	155.51	173.96	105.39	0.00	0.00	0.00	0.00	512.17
13. IWR green peppers	0.00	0.00	0.00	0.00	48.80	117.18	168.91	148.19	77.98	0.00	0.00	0.00	561.06
14. IWR tomato	0.00	0.00	0.00	0.00	48.80	118.71	185.74	162.94	73.17	0.00	0.00	0.00	589.36
15. IWR vegetable	0.00	0.00	0.00	0.00	60.55	143.24	168.91	148.19	78.95	0.00	0.00	0.00	599.83
16. IWR orchards and grape	0.00	0.00	0.07	25.51	81.69	138.64	152.08	133.43	77.98	10.94	0.00	0.00	620.34
second crop													
IWR maize for silage	0.00	0.00	0.00	0.00	0.00	0.00	110.54	145.19	100.85	0.00	0.00	0.00	356.58
IWR vegetable - cabbage	0.00	0.00	0.00	0.00	0.00	0.00	107.20	115.92	85.54	30.72	0.00	0.00	339.39
Second crops:													
IWR maize for silage	0.00	0.00	0.00	0.00	0.00	0.00	111.68	146.71	102.06	0.00	0.00	0.00	360.45
IWR vegetable - cabbage	0.00	0.00	0.00	0.00	0.00	0.00	108.31	117.20	86.65	31.81	0.00	0.00	343.97

Appendix 4.3.2: Irrigation water requirements (mm/month) with DEFICIT IRRIGATION, 2050 MEDIUM

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Noe	Dec	Total (mm/year)
2. IWR barley	0.00	0.00	6.87	36.34	72.30	69.96	24.14	0.00	0.00	0.00	0.00	0.00	209.61
4. IWR tobacco	0.00	0.00	0.00	0.00	25.30	84.68	126.49	94.47	41.20	0.00	0.00	0.00	372.14
5. IWR sunflower	0.00	0.00	0.00	7.91	54.44	115.34	108.98	40.17	0.00	0.00	0.00	0.00	326.85
6. IWR soybean	0.00	0.00	0.00	0.00	15.90	117.79	146.69	88.57	0.00	0.00	0.00	0.00	368.95
7. IWR sugar beet	0.00	0.00	0.00	14.00	79.81	139.87	153.42	111.00	45.05	0.00	0.00	0.00	543.16
8. IWR alfalfa	0.00	0.00	1.16	29.57	67.60	107.98	118.41	103.92	59.69	14.66	0.00	0.00	502.99
9. IWR maize for silage	0.00	0.00	0.00	0.00	0.00	34.40	118.41	134.61	40.43	0.00	0.00	0.00	327.85
10. IWR meadow and grasses	0.00	0.00	23.55	33.63	15.90	40.53	44.34	38.99	17.32	2.47	0.00	0.00	216.74
16. IWR orchards and grape	0.00	0.00	0.00	16.71	61.02	109.21	119.76	105.10	59.69	3.38	0.00	0.00	474.86
Second crops:													
IWR maize for silage	0.00	0.00	0.00	0.00	0.00	0.00	87.44	115.72	78.95	0.00	0.00	0.00	282.11

Appendix 4.4: Irrigation water requirements, 2050 HIGH

Appendix 4.4.1: Irrigation water requirements (mm/month) with FULL IRRIGATION, 2050 HIGH

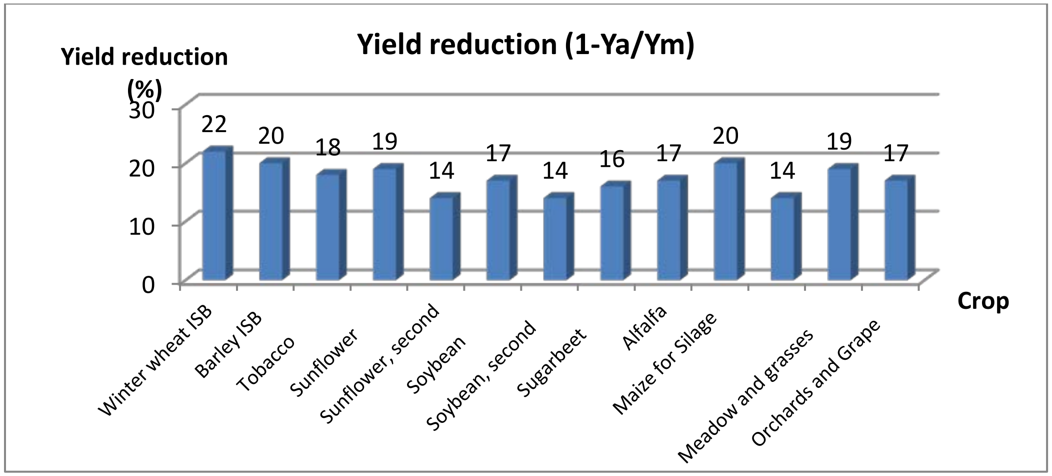
Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Noe	Dec	Total (mm/year)
1. IWR winter wheat	0.00	0.00	13.74	49.03	95.42	129.47	57.09	0.00	0.00	0.00	0.00	0.00	344.75
2. IWR barley	0.00	0.00	14.30	52.47	99.00	90.77	33.26	0.00	0.00	0.00	0.00	0.00	289.81
3. IWR maize and broadleaf tobacco	0.00	0.00	0.00	0.00	21.42	141.85	196.64	118.74	22.23	0.00	0.00	0.00	500.88
4. IWR tobacco	0.00	0.00	0.00	0.00	39.33	109.35	162.61	121.72	56.25	0.00	0.00	0.00	489.24
5. IWR sunflower	0.00	0.00	4.26	16.31	76.33	148.05	140.48	53.13	0.00	0.00	0.00	0.00	438.55
6. IWR soybean	0.00	0.00	0.00	0.00	27.39	151.14	188.13	114.26	0.00	0.00	0.00	0.00	480.93
7. IWR sugar beet	0.00	0.00	4.26	24.06	108.55	179.01	196.64	142.59	61.11	0.00	0.00	0.00	716.21
8. IWR alfalfa	0.00	0.00	7.05	43.86	93.03	138.76	152.39	133.65	79.57	26.76	0.00	0.00	675.08
9. IWR maize for silage	0.00	0.00	0.00	0.00	0.00	45.88	152.39	172.42	55.27	0.00	0.00	0.00	425.96
10. IWR meadow and grasses	0.00	4.30	35.51	49.03	27.39	53.62	58.79	51.64	26.11	11.36	0.00	0.00	317.74
11. IWR watermelon/melon	0.00	0.00	0.00	25.78	47.68	143.40	171.12	120.23	0.00	0.00	0.00	0.00	508.21
12. IWR potato and onion	0.00	0.00	0.00	25.78	56.04	157.33	176.22	106.81	0.00	0.00	0.00	0.00	522.18
13. IWR green peppers	0.00	0.00	0.00	0.00	51.26	118.63	171.12	150.05	79.57	0.00	0.00	0.00	570.63
14. IWR (mm/month)	0.00	0.00	0.00	0.00	51.26	120.18	188.13	164.96	74.71	0.00	0.00	0.00	599.25
15. IWR vegetable	0.00	0.00	0.00	0.00	63.20	144.95	171.12	150.05	80.55	0.00	0.00	0.00	609.86
16. IWR orchards and grape	0.00	0.00	1.47	27.50	84.68	140.31	154.10	135.14	79.57	12.50	0.00	0.00	635.27
Second crops:													
IWR maize for silage	0.00	0.00	0.00	0.00	0.00	0.00	113.25	148.56	103.87	0.00	0.00	0.00	365.68
IWR vegetable - cabbage	0.00	0.00	0.00	0.00	0.00	0.00	109.85	118.74	88.32	33.61	0.00	0.00	350.51

Appendix 4.4.2: Irrigation water requirements (mm/month) with DEFICIT IRRIGATION, 2050 HIGH

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Noe	Dec	Total (mm/year)
2. IWR barley	0.00	0.00	8.39	38.52	75.13	70.96	24.75	0.00	0.00	0.00	0.00	0.00	217.75
4. IWR tobacco	0.00	0.00	0.00	0.00	27.39	85.82	128.23	95.77	42.44	0.00	0.00	0.00	379.65
5. IWR sunflower	0.00	0.00	0.35	9.59	56.99	116.78	110.53	40.90	0.00	0.00	0.00	0.00	335.14
6. IWR soybean	0.00	0.00	0.00	0.00	17.84	119.25	148.65	89.81	0.00	0.00	0.00	0.00	375.56
7. IWR sugar beet	0.00	0.00	0.35	15.79	82.77	141.54	155.46	112.47	46.33	0.00	0.00	0.00	554.72
8. IWR alfalfa	0.00	0.00	2.58	31.63	70.36	109.35	120.06	105.32	61.11	16.27	0.00	0.00	516.67
9. IWR maize for silage	0.00	0.00	0.00	0.00	0.00	35.04	120.06	136.33	41.67	0.00	0.00	0.00	333.10
10. IWR meadow and grasses	0.00	0.00	25.35	35.77	17.84	41.23	45.17	39.71	18.34	3.95	0.00	0.00	227.36
16. IWR orchards and grape	0.00	0.00	0.00	18.55	63.67	110.58	121.42	106.51	61.11	4.86	0.00	0.00	486.70
Second crops:													
IWR maize for silage	0.00	0.00	0.00	0.00	0.00	0.00	88.74	117.25	80.55	0.00	0.00	0.00	286.53

Appendix 5: Yield reduction for deficit irrigation (ISB)

Crop	Relative yield Ya/Ym (%)	Yield reduction 1-Ya/Ym (%)
Winter wheat ISB	78	22
Barley ISB	80	20
Tobacco	82	18
Sunflower	81	19
Sunflower, second	86	14
Soybean	83	17
Soybean, second	86	14
Sugar beet	84	16
Alfalfa	83	17
Maize for Silage	80	20
Maize for Silage, second	86	14
Meadow and grasses	81	19
Orchards and Grape	83	17



Appendix 6: Calculation of gross margin and net return per crop

Appendix 6.1: Example of sunflower, irrigation strategy A (ISA)

		Quantity	Price	MKD/ha
Income				
Sunflower grain	kg	2500	16	40,000
Subsidies	ha	1	8000	8,000
Total incomes				48,000
Variable cost				
Seeds	kg	6	300	1,800
Fertilizer (NPK)	kg	300	21	6,300
Fertilizer (N)	kg	200	16	3,200
Crop chemical	kg/l	20	250	5,000
Fuel	l	80	61	4,880
Lubricants	l	4	150	600
Operator and hire labor	ha	1	2500	2,500
Other variable cost	ha	1	1500	1,500
Total variable cost				25,780
Fixed cost				
Insurance	ha	1	1200	1,200
Depreciations	ha	1	1000	1,000
Operating interest	ha	1	1221	1,221
Other fixed cost	ha	1	1000	1,000
Total fixed cost				4,421
Total costs excluding water (variable + fixed)				30,201
Gross margin				17,799
Water costs	m3	3033	3	9,099
Net return				8,700

Appendix 6.2: Example of sunflower, irrigation strategy B (ISB)

		Quantity	Price	MKD/ha
Income				
Sunflower grain	kg	2025	16	32,400
Subsidies	ha	1	8000	8,000
Total incomes				40,400
Variable cost				
Seeds	kg	6	300	1,800
Fertilizer (NPK)	kg	300	21	6,300
Fertilizer (N)	kg	200	16	3,200
Crop chemical	kg/l	20	250	5,000
Fuel	l	80	61	4,880
Lubricants	l	4	150	600
Operator and hire labor	ha	1	2500	2,500
Other variable cost	ha	1	1500	1,500
Total variable cost				25,780
Fixed cost				
Insurance	ha	1	972	972
Depreciations	ha	1	1000	1,000
Operating interest	ha	1	1157	1,157
Other fixed cost	ha	1	1000	1,000
Total fixed cost				4,129
Total costs excluding water (variable + fixed)				29,909
Gross margin				10,491
Water costs	m3	2426.4	3	7,279
Net return				3,212

Appendix 6.3: Example of sunflower, rain-fed

		Quantity	Price	MKD/ha
Income				
Sunflower grain	kg	1500	16	24,000
Subsidies	ha	1	8000	8,000
Total incomes				32,000
Variable cost				
Seeds	kg	6	300	1,800
Fertilizer (NPK)	kg	300	21	6,300
Fertilizer (N)	kg	100	16	1,600
Crop chemical	kg/l	20	250	5,000
Fuel	l	50	61	3,050
Lubricants	l	3	150	450
Operator and hire labor	ha	1	2500	2,500
Other variable cost	ha	1	1500	1,500
Total variable cost				22,200
Fixed cost				
Insurance	ha	1	720	720
Depreciations	ha	1	1000	1,000
Operating interest	ha	1	777	777
Other fixed cost	ha	1	1000	1,000
Total fixed cost				3,497
Total costs excluding water (variable + fixed)				25,697
Gross margin				6,303
Water costs	m3	0	3	0
Net return				6,303

Appendix 6.4: Example of sunflower, second crop

		Quantity	Price	MKD/ha
Income				
Sunflower grain	kg	1500	16	24,000
Subsidies	ha	1	8000	8,000
Total incomes				32,000
Variable cost				
Seeds	kg	6	300	1,800
Fertilizer (NPK)	kg	300	21	6,300
Fertilizer (N)	kg	100	16	1,600
Crop chemical	kg/l	20	250	5,000
Fuel	l	50	61	3,050
Lubricants	l	3	150	450
Operator and hire labor	ha	1	2500	2,500
Other variable cost	ha	1	1500	1,500
Total variable cost	(40%LESS)			13,320
Fixed cost				
Insurance	ha	1	720	720
Depreciations	ha	1	1000	1,000
Operating interest	ha	1	785	785
Other fixed cost	ha	1	1000	1,000
Total fixed cost				2,103
Total costs excluding water (variable + fixed)				15,423
Gross margin				16,577
Water costs	m3	3033	3	9,099
Net return				7,478

Appendix 7: Net returns and crop area in 2010

	ha	**%**	**Gross margin (MKD/ha)**	**Net return (MKD/ha)**
Winter wheat ISA	523	10.04%	19,401	15,153
Winter wheat, no irrigation		0.00%	6,021	6,021
Barley ISA	17	0.33%	18,536	14,288
Barley ISB	0	0.00%	9,836	6,437
Barley no irrigation		0.00%	8,201	8,201
Maize ISA	2016	38.72%	31,170	18,030
Tobacco oriental ISA	32	0.61%	130,397	124,044
Tobacco oriental ISB	0	0.00%	70,861	65,950
Tobacco oriental not irr		0.00%	40,501	40,501
Sunflower ISA	38	0.73%	17,799	8,700
Sunflower ISB	0	0.00%	10,491	3,212
Sunflower no irrigation		0.00%	6,303	6,303
Sunflower second crop, ISA		0.00%	16,577	7,478
Soybean ISA	183	3.51%	23,381	13,463
Soybean ISB	0	0.00%	14,546	6,611
Soybean no irrigation		0.00%	7,361	7,361
Soybean second crop		0.00%	17,899	7,981
Sugar beet ISA	103	1.98%	37,946	24,575
Sugar beet ISB	0	0.00%	18,639	7,942
Alfalfa ISA	841	16.15%	30,841	18,940
Alfalfa ISB	0	0.00%	19,382	9,861
Maize silage ISA	427	8.20%	25,423	16,903
Maize silage ISB	0	0.00%	11,903	9,527
Maize silage second crop, ISA		0.00%	19,337	10,817
Maize silage second crop, ISB		0.00%	11,231	9,527
Meadow and grass ISA	308	5.92%	15,330	9,192
Meadow and grass ISB	0	0.00%	6,527	1 ,616
Meadow and grass no irrigation		0.00%	4,843	4,843

Watermelon and melon, ISA	51	0.98%	44,288	34,568
Potato and Onion, ISA	56	1.08%	66,458	57,532
Potato, no irrigation		0.00%	18,665	18,665
Green pepper including industrial, ISA	213	4.09%	83,697	71,904
Tomato including industrial, ISA	33	0.63%	67,242	54,466
Vegetable include cabbage, ISA	159	3.05%	54,713	45,816
Cabbage, second crop, ISA		0.00%	48,525	44,721
Orchards and grape, ISA	207	3.98%	62,784	53,598
Orchards and grape, ISB		0.00%	10,931	(1,277)
TOTAL	5207	100.00%		

Appendix 8: Revenue and cost projections 2050

Appendix 8.1.1: USDA Agricultural projections to 2020

Year	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Corn - long term projections												
yield (bushes/acre)	164.70	154.30	162.00	164.00	166.00	168.00	170.00	172.00	174.00	176.00	178.00	180.00
price ($ /buchel)	3.55	5.20	4.80	4.30	4.10	4.10	4.10	4.15	4.20	4.25	4.25	4.25
Gross renevue ($/acre)	584.69	802.36	777.60	705.20	680.60	688.80	697.00	713.80	730.80	748.00	756.50	765.00
Variable costs of production ($/acre)	299.00	287.00	304.00	310.00	314.00	318.00	323.00	329.00	335.00	341.00	347.00	353.00
Net returns	285.69		473.60	395.20	366.60	370.80	374.00	384.80	395.80	407.00	409.50	412.00
Barley - long term projections												
yield (bushes/acre)	73.00	73.10	67.40	68.00	68.60	69.20	69.70	70.30	70.90	71.50	72.10	72.70
price ($ /buchel)	4.66	4.00	4.70	4.95	4.75	4.70	4.75	4.80	4.85	4.90	4.90	4.90
Gross renevue ($/acre)	340.18	292.40	316.78	336.60	325.85	325.24	331.08	337.44	343.87	350.35	353.29	356.23
Variable costs of production ($/acre)	143.00	141.00	149.00	152.00	155.00	157.00	160.00	163.00	166.00	169.00	172.00	175.00
Net returns		151.40	167.78	184.60	170.85	168.24	171.08	174.44	177.87	181.35	181.29	181.23
Wheat - long term projections												
yield (bushes/acre)	44.50	46.40	43.80	44.20	44.50	44.80	45.20	45.50	45.80	46.10	46.50	46.80
price ($ /buchel)	4.87	5.50	6.50	5.90	5.55	5.45	5.45	5.50	5.50	5.55	5.55	5.60
Gross renevue ($/acre)	216.72	255.20	284.70	260.78	246.98	244.16	246.34	250.25	251.90	255.86	258.08	262.08
Variable costs of production ($/acre)	129.00	125.00	133.00	136.00	138.00	140.00	142.00	145.00	148.00	151.00	154.00	157.00
Net returns		130.20	151.70	124.78	108.98	104.16	104.34	105.25	103.90	104.86	104.08	105.08
Soybeans - long term projections												
yield (bushes/acre)	44.00	43.90	43.50	44.00	44.40	44.90	45.30	45.80	46.20	46.70	47.10	47.60
price ($ /buchel)	9.59	11.45	11.20	10.55	10.25	10.20	10.25	10.25	10.30	10.30	10.35	10.35
Gross renevue ($/acre)	421.96	502.66	487.20	464.20	455.10	457.98	464.33	469.45	475.86	481.01	487.49	492.66
Variable costs of production ($/acre)	132.00	131.00	136.00	139.00	140.00	142.00	144.00	146.00	148.00	150.00	152.00	154.00
Net returns	289.96		351.20	325.20	315.10	315.98	320.33	323.45	327.86	331.01	335.49	338.66

Source: (www, USDA, 1, 2011)

Appendix 8.1.2: Example of extrapolated price projections for wheat according USDA for 2050

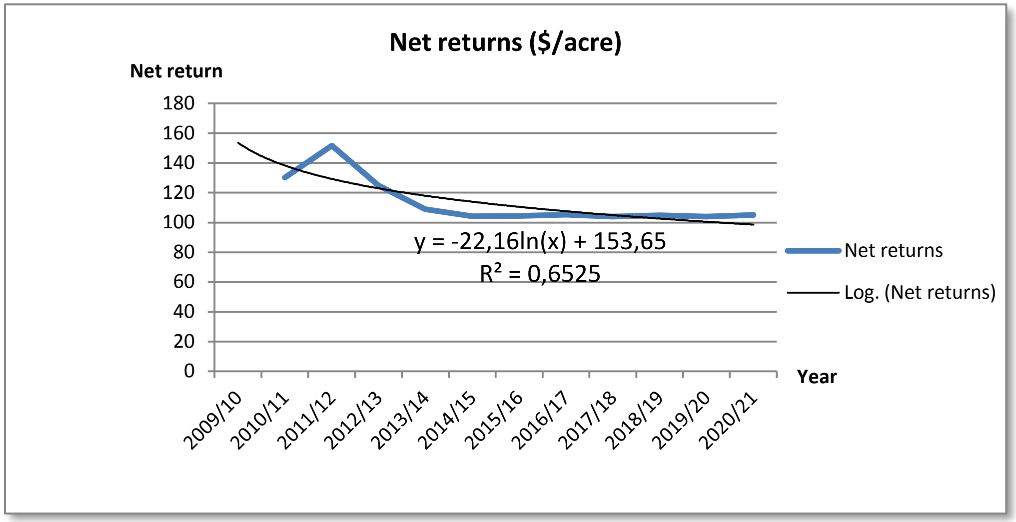


Figure 19: Net returns ($/acre) – wheat (2010-2020), according USDA

For 2050, the net revenue is:

y= -22.16*ln(30)+153.65= 78.28 ($/acre)

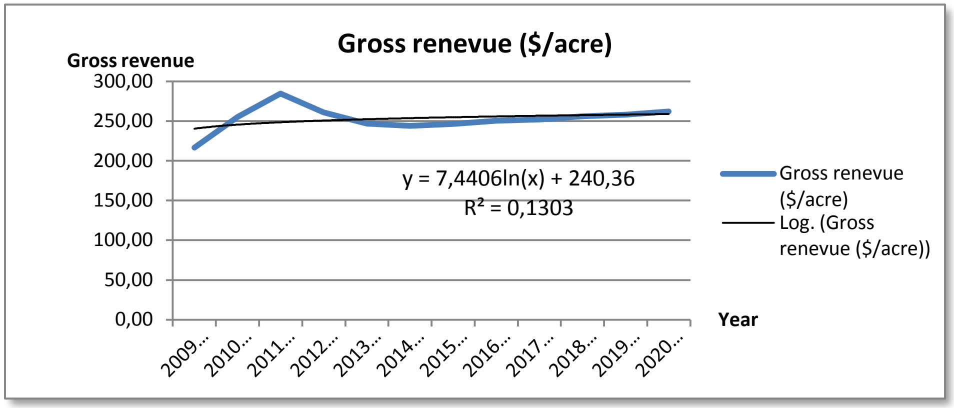


Figure 20: Gross revenue ($/acre) – wheat (2010-2020), according USDA

According the trendline curve, the projected value of the revenue in 2050 is:

y=7.4406*ln(30)+240.36=265.67 ($/acre)

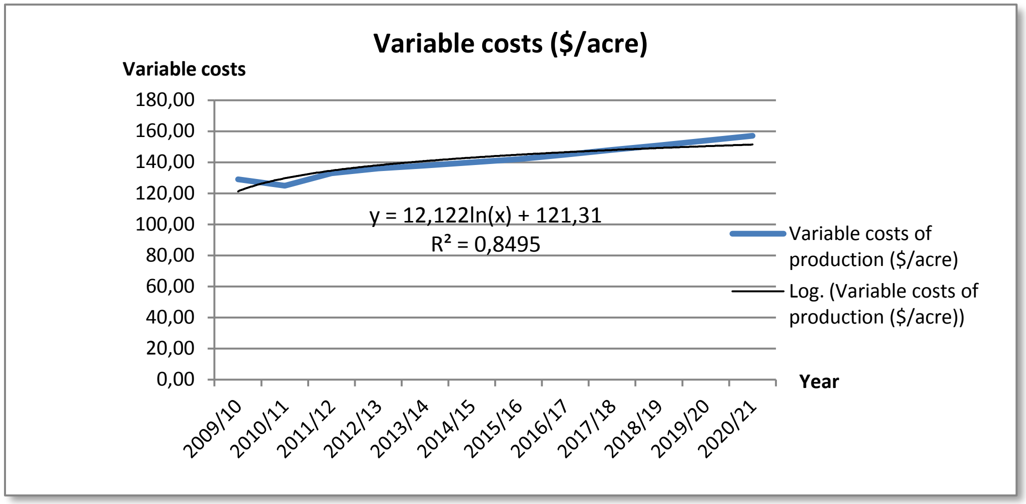


Figure 21: Variable costs ($/acre) – wheat (2010-2020), according USDA

The variable costs in 2050 are:

y=12.122*ln(30)+121.31=162.88 ($/acre)

Appendix 8.1.3: USDA extrapolated price projections to 2050

Item	**2009/10**	**2050**	**Δ**	**Δ (%)**
Corn - long term projections				
yield (bushes/acre)	164.70			
price ($ /buchel)	3.55	4.216162	0.187651	18.76512
Gross renevue ($/acre)	584.69	774.21	0.32	32.41
Variable costs of production ($/acre)	299.00	363.58	0.22	21.60
Net returns	285.69	440.2845	0.54	54.12
Barley - long term projections				
yield (bushes/acre)	73.00			
price ($ /buchel)	4.66			
Gross renevue ($/acre)	340.18	378.18	0.11	11.17
Variable costs of production ($/acre)	143.00	182.37	0.28	27.53
Net returns	197.18	193.0687	-0.02	-2.09
Wheat - long term projections				
yield (bushes/acre)	44.50			
price ($ /buchel)	4.87	5.714347	0.17	17.34
Gross renevue ($/acre)	216.72	265.67	0.23	22.59
Variable costs of production ($/acre)	129.00	162.88	0.26	26.26
Net returns	87.72	78.27947	-0.11	-10.76
Soybeans - long term projections				
yield (bushes/acre)	44.00			
price ($ /buchel)	9.59			
Gross renevue ($/acre)	421.96	493.51	0.17	16.96
Variable costs of production ($/acre)	132.00	159.23	0.21	20.63
Net returns	289.96	345.3825	0.19	19.11

Appendix 8.2.1: FAPRI Agricultural projections to 2020

Year	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
wheat											
yield	44.4	43.2	44	44.3	44.7	45	45.3	45.7	46.1	46.4	46.7
Farm price	4.92	4.58	4.74	4.81	4.9	4.9	4.99	5.04	5.05	5.11	5.06
Gross Market revenue	218.46	197.70	208.36	213.17	218.97	220.29	225.88	230.14	232.83	237.19	236.44
Variable expenses	108.07	108.60	114.30	118.01	121.04	124.38	129.02	132.23	134.52	136.85	138.92
Market net returns - whea	110.39	89.10	94.06	95.16	97.93	95.91	96.86	97.91	98.31	100.34	97.52
corn											
yield	165.20	159.70	161.90	164.00	166.10	168.30	170.50	172.80	175.00	177.00	178.90
Farm price	3.60	3.71	3.75	3.78	3.82	3.86	3.91	3.89	3.92	3.92	3.87
Gross Market revenue	593.94	592.69	606.89	619.62	635.15	649.50	666.27	672.66	685.08	693.10	692.41
Variable expenses	255.46	255.62	268.69	277.14	284.09	291.91	303.18	310.58	315.71	321.02	326.01
Market net returns	338.48	337.07	338.20	342.48	351.06	357.59	363.09	362.08	369.37	372.08	366.40
barley											
yield											
Farm price											
Gross Market revenue	325.92	262.17	275.97	285.89	291.56	295.99	300.59	301.99	305.57	307.86	307.32
Variable expenses	125.45	126.48	133.05	137.35	140.88	144.70	149.94	153.61	156.27	158.99	161.39
Market net returns	200.47	135.69	142.92	148.54	150.68	151.29	150.65	148.38	149.30	148.87	145.93
soybean											
yield											
Farm price											
Gross Market revenue	414.50	371.36	397.21	404.12	414.08	425.52	434.91	444.02	454.51	462.14	468.47
Variable expenses	121.72	125.24	130.94	135.43	139.20	143.08	147.35	150.72	153.48	156.25	158.60
Market net returns	292.78	246.12	266.27	268.69	274.88	282.44	287.56	293.30	301.03	305.89	309.87
sunflower											
yield											
Farm price											
Gross Market revenue	240.94	239.98	241.41	248.44	250.20	254.14	261.73	266.45	272.04	276.27	279.11
Variable expenses	101.78	104.73	109.49	113.25	116.40	119.64	123.22	126.03	128.34	130.66	132.66
Market net returns	139.16	135.25	131.92	135.19	133.80	134.50	138.51	140.42	143.70	145.61	146.45

Source: (www, FAPRI, 1, 2011)

Appendix 8.2.2: Example of extrapolated price projections for wheat according FAPRI for 2050

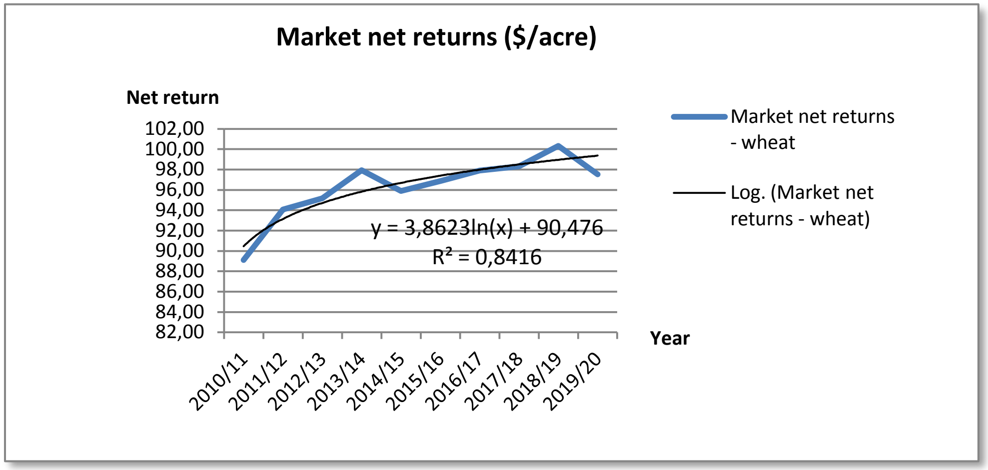


Figure 22: Market net returns ($/acre) – wheat (2010-2020), according FAPRI

Extrapolated net return for 2050 is calculated as:

$y_{(2050)}$=3.8623*ln(30)+90.476 = 103.61($/acre)

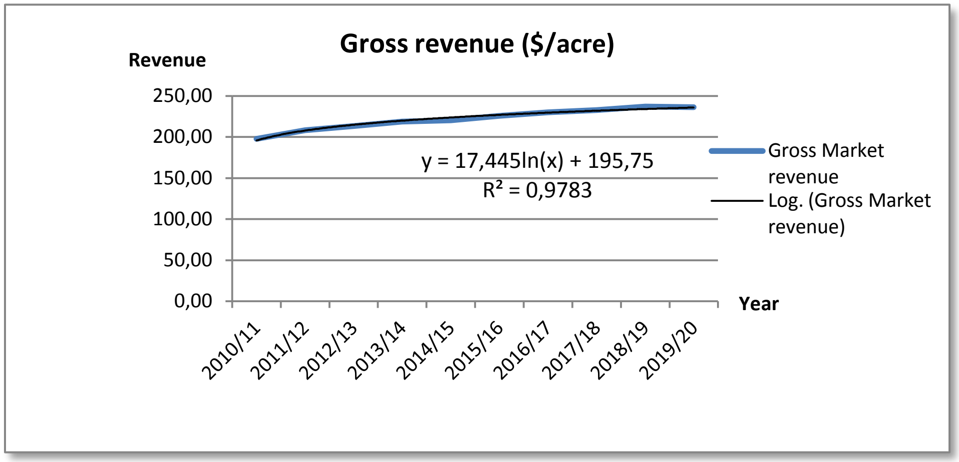


Figure 23: Gross revenues ($/acre) – wheat (2010-2020), according FAPRI

For 2050, the revenue is given as follows:

$y_{(2050)}$=17.445*ln(30)+195.75=255.08 ($/acre)

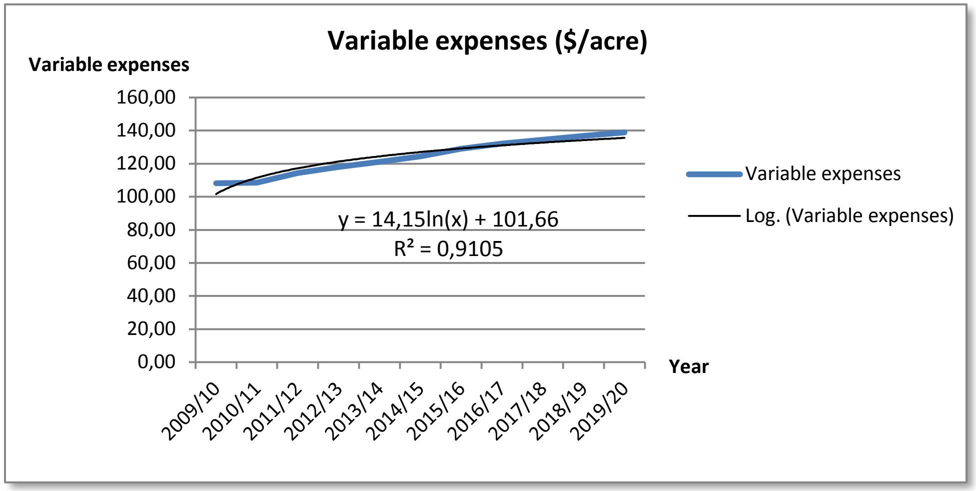


Figure 24: Variable expenses ($/acre) – wheat (2010-2020), according FAPRI

When extrapolated for 30 years forward (up to 2050), the variable expenses are:

$y_{(2050)}$=14.15*ln(30)+101.66=149.79 ($/acre)

Appendix 8.2.3: FAPRI extrapolated price projections to 2050

Item	2009/10	2050	Δ	Δ (%)
wheat				
yield	44.40			
Farm price	4.92	5.19	0.05	5.00
Gross Market revenue	218.46	255.08	0.17	16.76
Variable expenses	108.07	149.79	0.39	38.60
Market net returns	110.39	103.61	-0.06	-6.14
corn				
yield	165.20			
Farm price	3.60	4.06	0.13	12.82
Gross Market revenue	593.94	734.38	0.24	23.65
Variable expenses	255.46	350.67	0.37	37.27
Market net returns	338.48	383.71	0.13	13.36
barley				
yield				
Farm price				
Gross Market revenue	325.92	332.05	0.02	1.88
Variable expenses	125.45	174.05	0.39	38.74
Market net returns	200.47	129.75	-0.35	-35.28
soybean				
yield				
Farm price				
Gross Market revenue	414.50	483.47	0.17	16.64
Variable expenses	121.72	171.64	0.41	41.01
Market net returns	292.78	334.14	0.14	14.13
sunflower				
yield				
Farm price				
Gross Market revenue	240.94	288.81	0.20	19.87
Variable expenses	101.78	143.54	0.41	41.03
Market net returns	139.16	149.02	0.07	7.09

Appendix 9: Linear programming model

Appendix 9.1: Linear programming model for the Base case scenario

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56		
	Winter Wheat, ISA	Winter Wheat, ISB	Barley , ISA	Barley , ISB	Barley , no irr	Maize , ISA	Tobacco , ISA	Tobacco , ISB	Tobacco, not irr	Sunflower, ISA	Sunflower, ISB	Sunflower , no irr	Sunflower, second crop ISA	Soybean , ISA	Soybean , ISB	Soybean , no irr	Soybean, second crop ISA	Sugarbeet, ISA	Sugarbeet, ISB	Alfalfa, ISA	Alfalfa, ISB	Maize for Silage, ISA	Maize for Silage, ISB	Maize for Silage, second crop, ISA	Meadow and grasses, ISA	Meadow and grasses, ISB	Meadow and grasses, no irr	Watermelon/Melon, ISA	Potato and Onion, ISA	Potato, no irr	Green Peppers incl. industrial, ISA	Tomato incl. industrial, ISA	Vegetables, ISA	Cabbage, second crop, ISA	Orchards and Grape, ISA	Orchards and Grape, ISB	IX Winter wheat, ISA	IX Winter wheat, ISB	IX Barley , ISA	IX Barley , ISB	IX Tobacco , ISA	IX Tobacco , ISB	IX Sunflower, ISA	IX Sunflower, ISB	IX Soybean , ISA	IX Soybean , ISB	IX Sugarbeet, ISA	IX Sugarbeet, ISB	IX Alfalfa, ISA	IX Alfalfa, ISB	IX Maize for Silage, ISA	IX Maize for Silage, ISB	IX Meadow and grasses, ISA	IX Meadow and grasses, ISB	IX Orchards and Grape, ISA	IX Orchards and Grape, ISB	sign	value
Area (ha)	2000	0	0	0	1000	3000	200	0	0	0	0	0	0	0	0	0	0	0	0	2800	0	0	0	1200	0	0	1200	0	0	0	8792	0	1000	1000	208	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0		
Gross margin (MKD/ha)	19401	8731	18536	9836	8201	31170	130397	70861	40501	17799	10491	6303	16577	23381	14546	7361	17899	37946	18639	30841	19382	25423	11903	19337	15330	6527	4843	44288	66458	18665	83697	67242	54713	48525	62784	10931	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Water for irrigation (m3/ha)	2471	1801	2115	1543		4116	3762	2858		3492	2629	0	3003	3992	3077		3433	5929	4551	5722	4318	3447	2653	2964	2468	1694	0	3824	4332		4912	5140	5020	3373	5399	4081																						
Price for water (MKD/m3)	3	3	3	3		3	3	3		3	3		3	3	3		3	3	3	3	3	3	3	3	3	3		3	3		3	3	3	3	3	3																						
Water cost (MKD/ha)	7413	5403	6345	4629	0	12348	11286	8574	0	10476	7887	0	9009	11976	9231	0	10299	17787	13653	17166	12954	10341	7959	8893	7404	5082	0	11472	12996	0	14736	15420	15060	10119	16197	12243	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Net return (MKD/ha)	11988	3328	12191	5207	8201	18822	119111	62287	40501	7323	2604	6303	7568	11405	5315	7361	7600	20159	4986	13675	6428	15082	3944	10444	7926	1445	4843	32816	53462	18665	68961	51822	39653	38406	46587	-1312	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Profit max	863153496																																																									
Second crop after													barley				barley							wheat																																		
Constrains																																																										
Arable land (ha)	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1																					≤	20200
Feasible area for irrigation	1	1	1	1		1	1	1		1	1		1	1	1		1	1	1	1	1	1	1	1	1	1		1	1		1	1	1	1	1	1																					≤	20200
	2471	1801	2115	1543	0	4116	3762	2858	0	3492	2629	0	3003.12	3992	3077	0	3433.12	5929	4551	5722	4318	3447	2653	2964.42	2468	1694	0	3824	4332	0	4912	5140	5020	3373	5399	4081			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Irrigation strategy A for winter wheat	1																																				-5000																				≤	0
Irrigation strategy B for winter wheat		1																																				-5000																			≤	0
Irrigation strategy A for barley			1																																				-1000																		≤	0
Irrigation strategy B for barley				1																																				-1000																	≤	0
Irrigation strategy A for tobacco							1																																		-200																≤	0
Irrigation strategy B for tobacco								1																																		-200															≤	0
Irrigation strategy A for sunflower										1																																	-500														≤	0
Irrigation strategy B for sunflower											1																																	-500													≤	0
Irrigation strategy A for soybean														1																															-600												≤	0
Irrigation strategy B for soybean															1																															-600											≤	0
Irrigation strategy A for sugarbeet																		1																													-400										≤	0
Irrigation strategy B for sugarbeet																			1																													-400									≤	0
Irrigation strategy A for alfalfa																				1																													-3000								≤	0
Irrigation strategy B for alfalfa																					1																													-3000							≤	0
Irrigation strategy A for maize,silage																						1																													-1500						≤	0
Irrigation strategy B for maize,silage																							1																													-1500					≤	0
Irrigation strategy A for meadow,grasses																									1																												-1200				≤	0
Irrigation strategy B for meadow,grasses																										1																												-1200			≤	0
Irrigation strategy A for orchards,grape																																			1																				-208		=	0
Irrigation strategy B for orchards,grape																																				1																				-208	=	0
Selection of irrigation strategy for winter wheat																																					1	1																			≤	1
Selection of irrigation strategy for barley																																							1	1																	≤	1
Selection of irrigation strategy for tobacco																																									1	1															≤	1
Selection of irrigation strategy for sunflower																																											1	1													≤	1
Selection of irrigation strategy for soybean																																													1	1											≤	1
Selection of irrigation strategy for sugarbeet																																															1	1									≤	1
Selection of irrigation strategy for alfalfa																																																	1	1							≤	1
Selection of irrigation strategy for maize,sillage																																																			1	1					≤	1
Selection of irrigation strategy for meadow,grasses																																																					1	1			≤	1
Selection of irrigation strategy for orchards,grape																																																							1	1	≤	1
Second crops, sunflower+soybean+cabbage			-1	-1	-1								1				1																	1																							≤	0
Second crops, maize for silage	-1	-1																						1																																	≤	0
Maximum area for wheat	1	1																																																								≤	5000
Maximum area for barley			1	1	1																																																				≤	1000
Maximum area for maize						1																																																			≤	5000
Maximum area for tobbaco							1	1	1																																																≤	200
Maximum area for sunflower										1	1	1																																													≤	500
Maximum area for soybean														1	1	1																																									≤	600
Maximum area for sugarbeet																		1	1																																						≤	400
Maximum area for alfalfa																				1	1																																				≤	3000
Maximum area for maize for silage																						1	1																																		≤	1500
Maximum area for meadow and grasses																									1	1	1																														≤	1200
Area for orchards and grape																																			1	1																					=	208
Minimum alfalfa and meadows																				1	1				1	1	1																														≥	4000
Minimum maize sillage																						1	1	1																																	≥	1000
Minimum maize						1																																																			≥	3000
Minimum winter wheat and barley	1	1	1	1	1																																																				≥	3000
Minimum vegetable																																	1																								≥	1000
Non negativity constrains:																																																										
Winter Wheat, ISA	1																																																								≥	1
Winter Wheat, no irrig		1																																																							≥	1
Barley , ISA			1																																																						≥	1
Barley , ISB				1																																																					≥	1
Barley , no irr					1																																																				≥	1
Maize and Broadleaf Tobacco						1																																																			≥	1
Tobacco , ISA							1																																																		≥	1
Tobacco , ISB								1																																																	≥	1
Tobacco, not irr									1																																																≥	1
Sunflower, ISA										1																																															≥	1
Sunflower, ISB											1																																														≥	1
Sunflower , no irr												1																																													≥	1
Sunflower , second crop													1																																												≥	1
Soybean , ISA														1																																											≥	1
Soybean , ISB															1																																										≥	1
Soybean , no irr																1																																									≥	1
Soybean , second crop																	1																																								≥	1
Sugarbeet, ISA																		1																																							≥	1
Sugarbeet, ISB																			1																																						≥	1
Alfalfa, ISA																				1																																					≥	1
Alfalfa, ISB																					1																																				≥	1
Maize for Silage, ISA																						1																																			≥	1
Maize for Silage, ISB																							1																																		≥	1
Maize for Silage, second crop																								1																																	≥	1
Meadow and grasses, ISA																									1																																≥	1
Meadow and grasses, ISB																										1																															≥	1
Meadow and grasses, no irr																											1																														≥	1
Watermelon/Melon, ISA																												1																													≥	1
Potato and Onion, ISA																													1																												≥	1
Potato and Onion, no irr																														1																											≥	1
Green Peppers including industrial, ISA																															1																										≥	1
Tomato including industrial , ISA																																1																									≥	1
Vegetables including Cabbage and Bean, ISA																																	1																								≥	1
Cabbage, second crop, ISA																																		1																							≥	1
Orchards and Grape, ISA																																			1																						≥	1
Orchards and Grape, ISB																																				1																					≥	1

Appendix 9.2: Linear programming model for the Low case scenario

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
	Winter Wheat, ISA	Winter Wheat, ISB	Barley , ISA	Barley , ISB	Barley , no irr	Maize , ISA	Tobacco , ISA	Tobacco , ISB	Tobacco, not irr	Sunflower, ISA	Sunflower, ISB	Sunflower , no irr	Sunflower, second crop ISA	Soybean , ISA	Soybean , ISB	Soybean , no irr	Soybean, second crop ISA	Sugarbeet, ISA	Sugarbeet, ISB	Alfalfa, ISA	Alfalfa, ISB	Maize for Silage, ISA	Maize for Silage, ISB	Maize for Silage, second crop, ISA	Meadow and grasses, ISA	Meadow and grasses, ISB	Meadow and grasses, no irr	Watermelon/Melon, ISA	Potato and Onion, ISA	Potato, no irr	Green Peppers incl. industrial, ISA	Tomato incl. industrial, ISA	Vegetables, ISA	Cabbage, second crop, ISA	Orchards and Grape, ISA	Orchards and Grape, ISB	IX Winter wheat, ISA	IX Winter wheat, ISB	IX Barley , ISA	IX Barley , ISB	IX Tobacco , ISA	IX Tobacco , ISB	IX Sunflower, ISA	IX Sunflower, ISB	IX Soybean , ISA	IX Soybean , ISB	IX Sugarbeet, ISA	IX Sugarbeet, ISB	IX Alfalfa, ISA	IX Alfalfa, ISB	IX Maize for Silage, ISA	IX Maize for Silage, ISB	IX Meadow and grasses, ISA	IX Meadow and grasses, ISB	IX Orchards and Grape, ISA	IX Orchards and Grape, ISB	sign	value
Area (ha)	0	2000	0	0	1000	3000	200	0	0	0	0	0	0	0	0	186	0	0	0	0	2800	0	0	1000	0	0	1200	0	0	0	8606	0	1000	0	208	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0		
Gross margin (MKD/ha)	19401	8731	18536	9836	2823	31170	130397	70861	-8474	17799	10491	1988	16577	23381	14546	2263	17899	37946	18639	30841	19382	25423	11903	19337	15330	6527	1893	44288	66458	-19898	83697	67242	54713	48525	62784	10931	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Water for irrigation (m3/ha)	3283	2469	2743	2037		4855	4742	3665		4186	3209		3600	4673	3639		4018	6899	5352	6486	4933	4151	3238	3566	2944	2086		4911	5048		5542	5822	5927	3394	6109	4664																					
Price for water (MKD/m3)	3	3	3	3		3	3	3		3	3		3	3	3		3	3	3	3	3	3	3	3	3	3		3	3		3	3	3	3	3	3																					
Water cost (MKD/ha)	9849	7407	8230	6111	0	14565	14226	10995	0	12559	9627	0	10800	14020	10917	0	12054	20697	16056	19458	14799	12452	9714	10698	8831	6258	0	14733	15145	0	16625	17467	17781	10182	18326	13992	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Net profit (MKD/ha)	9552	1324	10306	3725	2823	16605	116171	59866	-8474	5240	864	1988	5777	9361	3629	2263	5845	17249	2583	11383	4583	12971	2189	8639	6499	269	1893	29555	51313	-19898	67072	49775	36932	38343	44458	-3061	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Profit max	726106660																																																								
Second crop after												barley				barley						wheat																																	
Constrains																																																									
Arable land (ha)	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1																				≤	20200
Feasible area for irrigation	1	1	1	1		1	1	1		1	1		1	1	1		1	1	1	1	1	1	1	1	1	1		1	1		1	1	1	1	1	1																				≤	20200
	3283	2469	2743	2037	0	4855	4742	3665	0	4186	3209	0	3600	4673	3639	0	4018	6899	5352	6486	4933	4151	3238	3566	2944	2086	0	4911	5048	0	5542	5822	5927	3394	6109	4664			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Irrigation strategy A for winter wheat	1																																			-5000																			≤	0
Irrigation strategy B for winter wheat		1																																			-5000																		≤	0
Irrigation strategy A for barley			1																																			-1000																	≤	0
Irrigation strategy B for barley				1																																			-1000																≤	0
Irrigation strategy A for tobacco							1																																	-200															≤	0
Irrigation strategy B for tobacco								1																																	-200														≤	0
Irrigation strategy A for sunflower										1																																-500													≤	0
Irrigation strategy B for sunflower											1																																-500												≤	0
Irrigation strategy A for soybean														1																														-600											≤	0
Irrigation strategy B for soybean															1																														-600										≤	0
Irrigation strategy A for sugarbeet																		1																												-400									≤	0
Irrigation strategy B for sugarbeet																			1																												-400								≤	0
Irrigation strategy A for alfalfa																				1																												-3000							≤	0
Irrigation strategy B for alfalfa																					1																												-3000						≤	0
Irrigation strategy A for maize,silage																						1																												-1500					≤	0
Irrigation strategy B for maize,silage																							1																												-1500				≤	0
Irrigation strategy A for meadow,grasses																									1																											-1200			≤	0
Irrigation strategy B for meadow,grasses																										1																											-1200		≤	0
Irrigation strategy A for orchards,grape																																			1																			-208		=	0
Irrigation strategy B for orchards,grape																																				1																			-208	=	0
Selection of irrigation strategy for winter wheat																																					1	1																		≤	1
Selection of irrigation strategy for barley																																							1	1																≤	1
Selection of irrigation strategy for tobacco																																									1	1														≤	1
Selection of irrigation strategy for sunflower																																											1	1												≤	1
Selection of irrigation strategy for soybean																																													1	1										≤	1
Selection of irrigation strategy for sugarbeet																																															1	1								≤	1
Selection of irrigation strategy for alfalfa																																																	1	1						≤	1
Selection of irrigation strategy for maize,sillage																																																			1	1				≤	1
Selection of irrigation strategy for meadow,grasses																																																					1	1		≤	1
Selection of irrigation strategy for orchards,grape																																																							1	1	≤	1
Second crops, sunflower+soybean+cabbage			-1	-1	-1								1				1																	1																							≤	0
Second crops, maize for silage	-1	-1																						1																																≤	0
Maximum area for wheat	1	1																																																						≤	5000
Maximum area for barley			1	1	1																																																			≤	1000
Maximum area for maize						1																																																		≤	5000
Maximum area for tobbaco							1	1	1																																															≤	200
Maximum area for sunflower										1	1	1																																												≤	500
Maximum area for soybean														1	1	1																																								≤	600
Maximum area for sugarbeet																		1	1																																					≤	400
Maximum area for alfalfa																				1	1																																			≤	3000
Maximum area for maize for silage																						1	1																																	≤	1500
Maximum area for meadow and grasses																									1	1	1																													≤	1200
Area for orchards and grape																																			1	1																				=	208
Minimum alfalfa and meadows																				1	1				1	1	1																													≥	4000
Minimum maize sillage																						1	1	1																																≥	1000
Minimum maize						1																																																		≥	3000
Minimum winter wheat and barley	1	1	1	1	1																																																			≥	3000
Minimum vegetable																																	1																							≥	1000
Non negativity constrains:																																																									
Winter Wheat, ISA	1																																																								≥	1
Winter Wheat, no irrig		1																																																							≥	1
Barley , ISA			1																																																						≥	1
Barley , ISB				1																																																					≥	1
Barley , no irr					1																																																				≥	1
Maize and Broadleaf Tobacco						1																																																		≥	1
Tobacco , ISA							1																																																	≥	1
Tobacco , ISB								1																																																≥	1
Tobacco, not irr									1																																															≥	1
Sunflower, ISA										1																																														≥	1
Sunflower, ISB											1																																													≥	1
Sunflower , no irr												1																																												≥	1
Sunflower , second crop													1																																											≥	1
Soybean , ISA														1																																										≥	1
Soybean , ISB															1																																									≥	1
Soybean , no irr																1																																								≥	1
Soybean , second crop																	1																																							≥	1
Sugarbeet, ISA																		1																																						≥	1
Sugarbeet, ISB																			1																																					≥	1
Alfalfa, ISA																				1																																				≥	1
Alfalfa, ISB																					1																																			≥	1
Maize for Silage, ISA																						1																																		≥	1
Maize for Silage, ISB																							1																																	≥	1
Maize for Silage, second crop																								1																																≥	1
Meadow and grasses, ISA																									1																															≥	1
Meadow and grasses, ISB																										1																														≥	1
Meadow and grasses, no irr																											1																													≥	1
Watermelon/Melon, ISA																												1																												≥	1
Potato and Onion, ISA																													1																											≥	1
Potato and Onion, no irr																														1																										≥	1
Green Peppers including industrial, ISA																															1																									≥	1
Tomato including industrial , ISA																																1																								≥	1
Vegetables including Cabbage and Bean, ISA																																	1																							≥	1
Cabbage, second crop, ISA																																		1																						≥	1
Orchards and Grape, ISA																																			1																					≥	1
Orchards and Grape, ISB																																				1																				≥	1

Appendix 9.3: Linear programming model for the Medium case scenario

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56		
	Winter Wheat, ISA	Winter Wheat, ISB	Barley , ISA	Barley , ISB	Barley , no irr	Maize , ISA	Tobacco , ISA	Tobacco , ISB	Tobacco, not irr	Sunflower, ISA	Sunflower, ISB	Sunflower , no irr	Sunflower, second crop ISA	Soybean , ISA	Soybean , ISB	Soybean , no irr	Soybean, second crop ISA	Sugarbeet, ISA	Sugarbeet, ISB	Alfalfa, ISA	Alfalfa, ISB	Maize for Silage, ISA	Maize for Silage, ISB	Maize for Silage, second crop, ISA	Meadow and grasses, ISA	Meadow and grasses, ISB	Meadow and grasses, no irr	Watermelon/Melon, ISA	Potato and Onion, ISA	Potato, no irr	Green Peppers incl. industrial, ISA	Tomato incl. industrial, ISA	Vegetables, ISA	Cabbage, second crop, ISA	Orchards and Grape, ISA	Orchards and Grape, ISB	IX Winter wheat, ISA	IX Winter wheat, ISB	IX Barley , ISA	IX Barley , ISB	IX Tobacco , ISA	IX Tobacco , ISB	IX Sunflower, ISA	IX Sunflower, ISB	IX Soybean , ISA	IX Soybean , ISB	IX Sugarbeet, ISA	IX Sugarbeet, ISB	IX Alfalfa, ISA	IX Alfalfa, ISB	IX Maize for Silage, ISA	IX Maize for Silage, ISB	IX Meadow and grasses, ISA	IX Meadow and grasses, ISB	IX Orchards and Grape, ISA	IX Orchards and Grape, ISB	sign	value
Area (ha)	0	2000	0	0	1000	3000	200	0	0	0	0	383	0	0	0	600	0	0	0	0	2800	0	0	1000	0	0	1200	0	0	0	7809	0	1000	0	208	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0		
Gross margin (MKD/ha)	19401	8731	18536	9836	2282	31170	130397	70861	-11607	17799	10491	1414	16577	23381	14546	1809	17899	37946	18639	30841	19382	25423	11903	19337	15330	6527	1241	44288	66458	-23856	83697	67242	54713	48525	62784	10931	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Water for irrigation (m3/ha)	3351	2532	2807	2096		4921	4805	3721		4279	3268		3681	4732	3689		4069	7017	5432	6595	5029	4197	3278	3604	3048	2167		4984	5122		5610	5894	5998	3439	6203	4748																					
Price for water (MKD/m3)	3	3	3	3		3	3	3		3	3		3	3	3		3	3	3	3	3	3	3	3	3	3		3	3		3	3	3	3	3	3																					
Water cost (MKD/ha)	10053	7596	8421	6288	0	14763	14415	11163	0	12837	9804	0	11043	14196	11067	0	12207	21051	16296	19785	15087	12591	9834	10812	9144	6501	0	14952	15366	0	16830	17682	17994	10317	18609	14244	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Net profit (MKD/ha)	9348	1135	10115	3548	2282	16407	115982	59698	-11607	4962	687	1414	5534	9185	3479	1809	5692	16895	2343	11056	4295	12832	2069	8525	6186	26	1241	29336	51092	-23856	66867	49560	36719	38208	44175	-3313	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Profit max	668709368																																																									
Second crop after													barley				barley							wheat																																	
Constrains																																																										
Arable land (ha)	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1																					≤	20200
Feasible area for irrigation	1	1	1	1		1	1	1		1	1		1	1	1		1	1	1	1	1	1	1	1	1	1		1	1		1	1	1	1	1	1																					≤	20200
	3351	2532	2807	2096	0	4921	4805	3721	0	4279	3268	0	3681	4732	3689	0	4069	7017	5432	6595	5029	4197	3278	3604	3048	2167	0	4984	5122	0	5610	5894	5998	3439	6203	4748			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Irrigation strategy A for winter wheat	1																																			-5000																			≤	0
Irrigation strategy B for winter wheat		1																																				-5000																		≤	0
Irrigation strategy A for barley			1																																				-1000																	≤	0
Irrigation strategy B for barley				1																																				-1000																≤	0
Irrigation strategy A for tobacco							1																																			-200															≤	0
Irrigation strategy B for tobacco								1																																			-200														≤	0
Irrigation strategy A for sunflower										1																																-500													≤	0
Irrigation strategy B for sunflower											1																																-500												≤	0
Irrigation strategy A for soybean														1																														-600											≤	0
Irrigation strategy B for soybean															1																														-600										≤	0
Irrigation strategy A for sugarbeet																		1																												-400									≤	0
Irrigation strategy B for sugarbeet																			1																												-400								≤	0
Irrigation strategy A for alfalfa																				1																												-3000							≤	0
Irrigation strategy B for alfalfa																					1																												-3000						≤	0
Irrigation strategy A for maize,silage																						1																												-1500					≤	0
Irrigation strategy B for maize,silage																							1																												-1500				≤	0
Irrigation strategy A for meadow,grasses																									1																											-1200			≤	0
Irrigation strategy B for meadow,grasses																										1																											-1200		≤	0
Irrigation strategy A for orchards,grape																																			1																					-208		=	0
Irrigation strategy B for orchards,grape																																				1																					-208	=	0
Selection of irrigation strategy for winter wheat																																					1	1																			≤	1
Selection of irrigation strategy for barley																																							1	1																	≤	1
Selection of irrigation strategy for tobacco																																									1	1															≤	1
Selection of irrigation strategy for sunflower																																											1	1													≤	1
Selection of irrigation strategy for soybean																																													1	1											≤	1
Selection of irrigation strategy for sugarbeet																																															1	1									≤	1
Selection of irrigation strategy for alfalfa																																																	1	1							≤	1
Selection of irrigation strategy for maize,sillage																																																			1	1					≤	1
Selection of irrigation strategy for meadow,grasses																																																					1	1			≤	1
Selection of irrigation strategy for orchards,grape																																																							1	1	≤	1
Second crops, sunflower+soybean+cabbage			-1	-1	-1								1				1																		1																								≤	0
Second crops, maize for silage	-1	-1																						1																																≤	0
Maximum area for wheat	1	1																																																						≤	3000
Maximum area for barley			1	1	1																																																				≤	1000
Maximum area for maize						1																																																		≤	5000
Maximum area for tobbaco							1	1	1																																															≤	200
Maximum area for sunflower										1	1	1																																												≤	500
Maximum area for soybean														1	1	1																																								≤	600
Maximum area for sugarbeet																		1	1																																					≤	400
Maximum area for alfalfa																				1	1																																			≤	3000
Maximum area for maize for silage																						1	1																																	≤	1500
Maximum area for meadow and grasses																									1	1	1																													≤	1200
Area for orchards and grape																																			1	1																					=	208
Minimum alfalfa and meadows																				1	1				1	1	1																													≥	4000
Minimum maize sillage																						1	1	1																																≥	1000
Minimum maize						1																																																		≥	4000
Minimum winter wheat and barley	1	1	1	1	1																																																				≥	2200
Minimum vegetable																																	1																								≥	1000
Non negativity constrains:																																																										
Winter Wheat, ISA	1																																																							≥	1
Winter Wheat, no irrig		1																																																						≥	1
Barley , ISA			1																																																					≥	1
Barley , ISB				1																																																				≥	1
Barley , no irr					1																																																			≥	1
Maize and Broadleaf Tobacco						1																																																		≥	1
Tobacco , ISA							1																																																	≥	1
Tobacco , ISB								1																																																≥	1
Tobacco, not irr									1																																															≥	1
Sunflower, ISA										1																																														≥	1
Sunflower, ISB											1																																													≥	1
Sunflower , no irr												1																																												≥	1
Sunflower , second crop													1																																											≥	1
Soybean , ISA														1																																										≥	1
Soybean , ISB															1																																									≥	1
Soybean , no irr																1																																								≥	1
Soybean , second crop																	1																																							≥	1
Sugarbeet, ISA																		1																																						≥	1
Sugarbeet, ISB																			1																																					≥	1
Alfalfa, ISA																				1																																				≥	1
Alfalfa, ISB																					1																																			≥	1
Maize for Silage, ISA																						1																																		≥	1
Maize for Silage, ISB																							1																																	≥	1
Maize for Silage, second crop																								1																																≥	1
Meadow and grasses, ISA																									1																															≥	1
Meadow and grasses, ISB																										1																														≥	1
Meadow and grasses, no irr																											1																													≥	1
Watermelon/Melon, ISA																												1																												≥	1
Potato and Onion, ISA																													1																											≥	1
Potato and Onion, no irr																														1																										≥	1
Green Peppers including industrial, ISA																															1																									≥	1
Tomato including industrial , ISA																																1																								≥	1
Vegetables including Cabbage and Bean, ISA																																	1																							≥	1
Cabbage, second crop, ISA																																		1																						≥	1
Orchards and Grape, ISA																																			1																					≥	1
Orchards and Grape, ISB																																				1																				≥	1

Appendix 9.4: Linear programming model for the High case scenario

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
	Winter Wheat, ISA	Winter Wheat, ISB	Barley , ISA	Barley , ISB	Barley , no irr	Maize , ISA	Tobacco , ISA	Tobacco , ISB	Tobacco, not irr	Sunflower, ISA	Sunflower, ISB	Sunflower , no irr	Sunflower, second crop ISA	Soybean , ISA	Soybean , ISB	Soybean , no irr	Soybean, second crop ISA	Sugarbeet, ISA	Sugarbeet, ISB	Alfalfa, ISA	Alfalfa, ISB	Maize for Silage, ISA	Maize for Silage, ISB	Maize for Silage, second crop, ISA	Meadow and grasses, ISA	Meadow and grasses, ISB	Meadow and grasses, no irr	Watermelon/Melon, ISA	Potato and Onion, ISA	Potato, no irr	Green Peppers incl. industrial, ISA	Tomato incl. industrial, ISA	Vegetables, ISA	Cabbage, second crop, ISA	Orchards and Grape, ISA	Orchards and Grape, ISB	IX Winter wheat, ISA	IX Winter wheat, ISB	IX Barley , ISA	IX Barley , ISB	IX Tobacco , ISA	IX Tobacco , ISB	IX Sunflower, ISA	IX Sunflower, ISB	IX Soybean , ISA	IX Soybean , ISB	IX Sugarbeet, ISA	IX Sugarbeet, ISB	IX Alfalfa, ISA	IX Alfalfa, ISB	IX Maize for Silage, ISA	IX Maize for Silage, ISB	IX Meadow and grasses, ISA	IX Meadow and grasses, ISB	IX Orchards and Grape, ISA	IX Orchards and Grape, ISB	sign	value
Area (ha)	0	2000	0	0	1000	3000	200	0	0	0	0	500	0	0	0	600	0	0	0	0	2800	0	0	1000	0	0	1200	0	0	0	7173	0	1000	0	208	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0		
Gross margin (MKD/ha)	19401	8731	18536	9836	1496	31170	130397	70861	-15895	17799	10491	762	16577	23381	14546	1233	17899	37946	18639	30841	19382	25423	11903	19337	15330	6527	444	44288	66458	-29245	83697	67242	54713	48525	62784	10931	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Water for irrigation (m3/ha)	3447	2617	2898	2177		5009	4892	3796		4385	3351		3771	4809	3755		4136	7162	5547	6751	5167	4259	3331	3657	3177	2274		5082	5222		5706	5992	6098	3505	6353	4867																						
Price for water (MKD/m3)	3	3	3	3		3	3	3		3	3		3	3	3		3	3	3	3	3	3	3	3	3	3		3	3		3	3	3	3	3	3																						
Water cost (MKD/ha)	10341	7851	8694	6531	0	15027	14676	11388	0	13155	10053	0	11313	14427	11265	0	12408	21486	16641	20253	15501	12777	9993	10971	9531	6822	0	15246	15666	0	17118	17976	18294	10515	19059	14601	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Net profit (MKD/ha)	9060	880	9842	3305	1496	16143	115721	59473	-15895	4644	438	762	5264	8954	3281	1233	5491	16460	1998	10588	3881	12646	1910	8366	5799	-295	444	29042	50792	-29245	66579	49266	36419	38010	43725	-3670	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Profit max	618770673																																																									
Second crop after													barley				barley							wheat																																		
Constrains																																																										
Arable land (ha)	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1																					≤	20200
Feasible area for irrigation	1	1	1	1		1	1	1		1	1		1	1	1		1	1	1	1	1	1	1	1	1	1		1	1		1	1	1	1	1	1																					≤	20200
	3447	2617	2898	2177	0	5009	4892	3796	0	4385	3351	0	3771	4809	3755	0	4136	7162	5547	6751	5167	4259	3331	3657	3177	2274	0	5082	5222	0	5706	5992	6098	3505	6353	4867			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Irrigation strategy A for winter wheat	1																																				-5000																				≤	0
Irrigation strategy B for winter wheat		1																																				-5000																			≤	0
Irrigation strategy A for barley			1																																				-1000																		≤	0
Irrigation strategy B for barley				1																																				-1000																	≤	0
Irrigation strategy A for tobacco							1																																		-200																≤	0
Irrigation strategy B for tobacco								1																																		-200															≤	0
Irrigation strategy A for sunflower										1																																	-500														≤	0
Irrigation strategy B for sunflower											1																																	-500													≤	0
Irrigation strategy A for soybean														1																															-600												≤	0
Irrigation strategy B for soybean															1																															-600											≤	0
Irrigation strategy A for sugarbeet																		1																														-400										≤	0
Irrigation strategy B for sugarbeet																			1																														-400									≤	0
Irrigation strategy A for alfalfa																				1																														-3000								≤	0
Irrigation strategy B for alfalfa																					1																														-3000							≤	0
Irrigation strategy A for maize,silage																						1																														-1500						≤	0
Irrigation strategy B for maize,silage																							1																														-1500					≤	0
Irrigation strategy A for meadow,grasses																									1																													-1200				≤	0
Irrigation strategy B for meadow,grasses																										1																													-1200			≤	0
Irrigation strategy A for orchards,grape																																			1																					-208		=	0
Irrigation strategy B for orchards,grape																																				1																					-208	=	0
Selection of irrigation strategy for winter wheat																																					1	1																			≤	1
Selection of irrigation strategy for barley																																							1	1																	≤	1
Selection of irrigation strategy for tobacco																																									1	1															≤	1
Selection of irrigation strategy for sunflower																																											1	1													≤	1
Selection of irrigation strategy for soybean																																													1	1											≤	1
Selection of irrigation strategy for sugarbeet																																															1	1									≤	1
Selection of irrigation strategy for alfalfa																																																	1	1							≤	1
Selection of irrigation strategy for maize,sillage																																																			1	1					≤	1
Selection of irrigation strategy for meadow,grasses																																																					1	1			≤	1
Selection of irrigation strategy for orchards,grape																																																							1	1	≤	1
Second crops, sunflower+soybean+cabbage			-1	-1	-1								1				1																	1																							≤	0
Second crops, maize for silage	-1	-1																						1																																	≤	0
Maximum area for wheat	1	1																																																							≤	5000
Maximum area for barley			1	1	1																																																				≤	1000
Maximum area for maize						1																																																			≤	5000
Maximum area for tobbaco							1	1	1																																																≤	200
Maximum area for sunflower										1	1	1																																													≤	500
Maximum area for soybean														1	1	1																																								≤	600
Maximum area for sugarbeet																		1	1																																						≤	400
Maximum area for alfalfa																				1	1																																				≤	3000
Maximum area for maize for silage																						1	1																																		≤	1500
Maximum area for meadow and grasses																									1	1	1																														≤	1200
Area for orchards and grape																																			1	1																					=	208
Minimum alfalfa and meadows																				1	1				1	1	1																														≥	4000
Minimum maize sillage																						1	1	1																																	≥	1000
Minimum maize						1																																																			≥	3000
Minimum winter wheat and barley	1	1	1	1	1																																																				≥	3000
Minimum vegetable																																	1																								≥	1000
Non negativity constrains:																																																										
Winter Wheat, ISA	1																																																								≥	1
Winter Wheat, no irrig		1																																																						≥	1
Barley , ISA			1																																																				≥	1
Barley , ISB				1																																																			≥	1
Barley , no irr					1																																																		≥	1
Maize and Broadleaf Tobacco						1																																																		≥	1
Tobacco , ISA							1																																																	≥	1
Tobacco , ISB								1																																																≥	1
Tobacco, not irr									1																																															≥	1
Sunflower, ISA										1																																														≥	1
Sunflower, ISB											1																																												≥	1
Sunflower , no irr												1																																											≥	1
Sunflower , second crop													1																																										≥	1
Soybean , ISA														1																																									≥	1
Soybean , ISB															1																																								≥	1
Soybean , no irr																1																																							≥	1
Soybean , second crop																	1																																						≥	1
Sugarbeet, ISA																		1																																					≥	1
Sugarbeet, ISB																			1																																				≥	1
Alfalfa, ISA																				1																																			≥	1
Alfalfa, ISB																					1																																		≥	1
Maize for Silage, ISA																						1																																	≥	1
Maize for Silage, ISB																							1																																≥	1
Maize for Silage, second crop																								1																															≥	1
Meadow and grasses, ISA																									1																														≥	1
Meadow and grasses, ISB																										1																													≥	1
Meadow and grasses, no irr																											1																												≥	1
Watermelon/Melon, ISA																												1																											≥	1
Potato and Onion, ISA																													1																										≥	1
Potato and Onion, no irr																														1																									≥	1
Green Peppers including industrial, ISA																															1																								≥	1
Tomato including industrial , ISA																																1																							≥	1
Vegetables including Cabbage and Bean, ISA																																	1																						≥	1
Cabbage, second crop, ISA																																		1																					≥	1
Orchards and Grape, ISA																																			1																						≥	1
Orchards and Grape, ISB																																				1																					≥	1