Republic of Macedonia
Ministry of Environment and Physical Planning

Republic of Macedonia
Ministry of Local Self-Government

ASSESSING VITICULTURE VULNERABILITY IN THE VARDAR PLANNING REGION FOR THE DESIGN OF ADAPTION MEASURES TO CLIMATE CHANGE

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1. INTRODUCTION

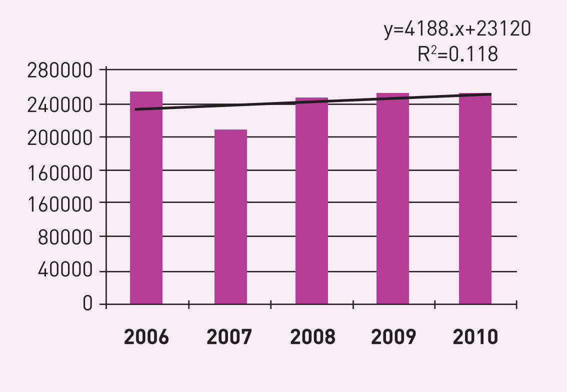
1.1. Features of the sector

Viticulture is one of the most important sectors of Macedonian agriculture, with wine being a significant export commodity. Viticulture, together with the wine production sector, contributes approximately 17–20% of agricultural GDP. Wine is the second most important product after tobacco in terms of the export value of agricultural commodities.

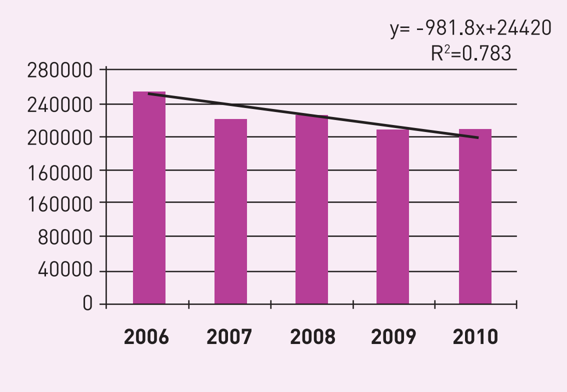
Vineyards in Macedonia have an unfavourable structure in terms of the age and size of the plantations (MAFWE, 2011). Over 60% of vineyards are more than 15 years old and plots are very small as a result of the long-term fragmentation of agricultural land through the country's tradition of inheritance, the lack of a land market and a long period of insufficient investments in this sector. This situation of small parcels and old plantations makes the viticulture sector vulnerable to the negative impact of climate change, especially due to the low capacity of farmers to apply effective measures for adaptation to climate change and the low efficiency of adaptive measures on small-sized plots.

The majority of vineyards are situated in the Vardar and South East Planning Region. According to its climatic characteristics, the Republic of Macedonia is classified as a single geographical wine-producing region (Bozinovic, Z., 2010). There are a total of 16 regions for the production of quality wine in the country: Skopsko, Velesko, Tikvesko, Gevgelisko-Valandovsko, Strumicko-Radovisko, Ovcepolsko, Kocansko-Vinicko, Kumanovsko, Kratovsko, Pijanecko, Prilepsko, Bitolsko, Prespansko, Ohridsko, Kicevsko and Tetovsko. The Povardarie Region includes Ovcepolsko, Velesko, Tikvesko, and Gevgelisko-Valandovsko.

Graph 1. Area under vineyards in ha



Graph 2. Wine grape production in tons



Vineyards comprise 4% of the total arable area. The area under vineyards has generally been decreasing since 2006. However, total grape production has been increasing in the same period. The total area of vineyards in 2010 was 20,700 ha, which was about 0.4% less than the previous year and 8% less than in 2008 (Graph 1). The production of wine grapes in 2010 was slightly lower than in 2009, while production increased by 2% in comparison with 2008 (Graph 2).

There are 86 officially registered cellars, with a total capacity for processing wine grapes of nearly 2,338,467 hl, two times greater than the annual production of wine grapes. The increase of the number of cellars from 28 in 2003 to 86 in 2010 (mainly small-to medium-sized) is a result of focusing on the production of high quality bottled wine, the control and traceability of wine production, and the introduction of more sophisticated production technology and marketing intended to make wines more competitive in domestic and foreign markets.

1.2. The impact of climate change on the viticulture sector

1.2.1. Grapevines and climate influence

Grapevines undergo morphological and physiological changes resulting from different stages of their vegetative and reproductive cycles. The duration of each phenological stage differs according to each grapevine variety, which is generally tied to the thermal conditions of each region (Mandelli et al. 2005). The prediction of stage evolution is of the utmost importance in planning viticulture activities and reaching winemaking decisions (Lopes et al. 2008). The length of the growing season for each variety is directly related to the mean temperature of the growing season (Jones, 2006). Additionally, the length of the growing season can also be linked to soil moisture, air temperature and crop-management practices (Webb et al., 2012). Climate strongly influences the development of vines in that it requires suitable temperatures, radiation intensities/duration, and water availability during its growth cycle, which ultimately influences yield and wine quality (Magalhaes 2008; Makra et al. 2009).

Air temperature is considered the most important factor in the overall growth and productivity of wine grapes (Jones and Alves 2012). Grapevine physiology and fruit metabolism and composition are highly influenced by the mean temperature during the growing season (Coombe 1987). Although this crop adapts well to environmental stresses, enduring extremely low temperatures for short time-periods during winter (Hidalgo 2002), negative temperatures during spring can severely damage the developing buds, leaves and shoots (Branas 1974). Wine grapes are also very sensitive to late frost and hail (Spellman 1999). However, winter chill is an important aspect in its growth development, as cold promotes bud dormancy (Kliewer and Soleiman 1972), initiating carbohydrate reserves for the following year (Bates et al. 2002; Field et al. 2009). In the same way, a 10°C basal temperature is required for the vine to break this dormancy and initiate its growing cycle (Amerine and Winkler 1944;

> Air temperature is considered the most important factor in the overall growth and productivity of wine grapes
>
> (Jones and Alves, 2012)

Winkler 1974). Extreme heat and heat waves may also permanently affect vine physiology and yield attributes (Kliewer 1977; Mullins et al. 1992), though some varieties may be more tolerant than others (Schaffer and Andersen 1994; Moutinho-Pereira et al. 2007). Grapevines grown under severe heat stress experience a significant decline in productivity due to stomata and mesophyll limitations in photosynthesis (Moutinho-Pereira et al. 2004), as well as injures under other physiological processes (Berry and Bjorkman 1980). Some studies argue that cool night temperatures in the period preceding the harvest (maturation/ripening), combined with high diurnal temperatures, stimulate the synthesis of anthocyanin and other phenolic compounds and are thus beneficial for high-quality wines (Kliewer and Torres 1972; Mori et al. 2005).

Annual precipitation and its seasonality are also critical factors influencing viticulture, as water stress can lead to a wide range of effects, largely dependent on the stage of development (Austin and Bondari 1988). For instance, proper soil moisture during budburst and shoot/inflorescence development is of foremost importance for vine growth development (Hardie and Martin 2000; Paranychianakis et al. 2004). Water stress at this stage may also cause small shoot growth, poor flower cluster and berry set development (Hardie and Considine 1976). In contrast, excessive humidity during these early stages overstimulates vegetative growth, which leads to denser canopies and a higher likelihood of disease problems in leaves and in inflorescences. From flowering to berry ripening, severe water stress results in low leaf area, limiting photosynthesis, flower abortion, and cluster abscission (During 1986). During this development stage, moderately dry and stable atmospheric conditions are considered favourable for high-quality wines (Jones and Davis 2000; Nemani et al. 2001; Ramos et al. 2008). Furthermore, slower leaf canopy development may lead to higher transpiration efficiency (Porter and Semenov 2005). During ripening, excessive humidity is unfavourable to maturation (Tonietto 1999) due to the promotion of sugar dilution (Reynolds and Naylor 1994). In contrast, moderate dryness at this stage seems to enhance quality (Storchi et al. 2005). Solar radiation is also a key factor affecting viticulture. Adequate radiant energy is required, especially during ripening (Manica and Pommer 2006). During maturation, sugar and phenolic contents are favoured by the occurrence of sunny days (Riou et al. 1994). Regions with less sunlight tend to surmount this limitation by adjusting training systems, optimizing solar exposure and canopy density. With more exposed leaves and grape clusters, stomata conductance and photosynthesis are favoured, though at the same time increasing water demands and boosting other problems, namely sunburns in leaves and clusters (Archer and Strauss 1990). Less exposed grape clusters, on the other hand, result in lower berry temperatures, but at the expense of reducing sugar and anthocyanin concentrations (Sparks and Larsen 1966; Smart et al. 1985). High canopy density can also reduce bud fertility, which is important for subsequent years (Morgan et al. 1985).

In most Mediterranean-like climatic regions, vineyards are subject to high radiation levels interacting with high temperatures and strong atmospheric and soil water deficits, which largely constrain grapevine productivity. Frequently, leaves display permanent photo inhibition and chlorosis, followed by necrosis, exposing the grape clusters, thus leading to low intrinsic water-use efficiency (WUE;

Moutinho-Pereira et al. 2004). Hence, low vigour tends to be associated with reduced berry weight, sugar content and yield. Other berry organoleptic properties, such as colour, flavour, and aroma components, are also inhibited by excessive solar radiance and severe dryness. This results in unbalanced wines, with high alcoholic content and excessively low acidity (Jones 2004). In this context, Mediterranean viticulture may be significantly challenged by climate change (Jones 2006).

1.2.2. Projections of Climate Change impact on viticulture

Climate change can potentially influence vine yield and quality (Kenny and Harrison 1992; Jones 2005). Recent temperature trends in viticulture regions show that mean temperatures in the growing-season increased globally by about 1.3°C in the period 1950–1999 and by 1.7°C in the period 1950–2004 in Europe (Jones et al. 2005a,b). For some European viticulture regions, in Italy, Germany, and France, studies already reported shortenings of the growing season and earlier phenological events (Chuine et al. 2004; Jones et al. 2005a; Dalla Marta et al.2010; Bock et al. 2011; Daux et al. 2011). Furthermore, changes in phenological events resulting in ripening during warmer periods can have negative impacts on wine quality (Webb et al. 2008). Higher temperatures during the growing season in north-east Slovenia promoted a significant decrease in the total acidity content of early-ripening varieties (Vrsic and Vodovnik, 2012). Climate change projections for the 21st century are expected to have important impacts on viticulture, as changes in temperature and precipitation patterns (Meehl et al. 2007) may significantly modify the current viticulture zoning in Europe (Malheiro et al. 2010). Recent climate change studies by Fraga et al. (2012) for Portugal, Neumann and Matzarakis (2011) for Germany, and Duchene and Schneider (2005) for Alsace in France, hint at an increase in the growing-season temperature. Santos et al. (2012a), using a multimodel ensemble for the Douro Valley (Portugal), demonstrated that springtime warming may lead to earlier budburst under a future warmer climate, which may affect wine quality. Additionally, future projections for this same region suggest higher grapevine yields (Santos et al. 2011) and wine productions (Gouveia et al. 2011), but also suggest increased risks of pests and diseases. Orduna (2010) argues that winemaking regions under extremely hot temperatures may lead to a significant increase in the risk of organoleptic degradation and wine spoilage. Under a future warmer climate, higher temperatures may inhibit the formation of anthocyanin (Buttrose et al. 1971), thus reducing grape colour (Downey et al. 2006) and increasing volatilization of aroma compounds (Bureau et al. 2000). Future changes in minimum temperatures during ripening in the Iberian Peninsula were also reported (Fraga et al. 2012; Malheiro et al. 2012), suggesting a decrease in wine quality. In future scenarios, a decrease in the suitability of the current winemaking regions in southern Europe might also be expected (Jones et al. 2005b; Stock et al. 2005; Fraga et al. 2012).

Southern European wine grapes are also expected to face adverse conditions due to severe dryness (Santos et al. 2003; Malheiro et al. 2010). These regions may become excessively dry for high-quality winemaking (Kenny and Harrison 1992), or even unsuitable for grapevine growth without sufficient

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irrigation (Koundouras et al. 1999). Malheiro et al. (2010) has stated that regions like Alentejo, Andalusia, Mancha, Sicily, Puglia, and Campania will suffer from water deficits. Santos et al. (2012b) also showed increased summer dryness in southern Europe. As an illustration, Alonso and O'Neill (2011) highlighted the negative impacts of climate change on Spanish viticulture, which may result in increased water demand due to irrigation. Camps and Ramos (2012) found a decrease in wine grape yield for northeastern Spain that can be attributed to water deficits. Ruml et al. (2012), in a study for Serbia, identified changes that may require additional vineyard irrigation. In addition to a lowering of wine quality expected in the future for some southern European winemaking regions, changes in the interannual variability and extremes may increase the irregularity of the yields (Schultz 2000; Jones et al. 2005a), with detrimental effects on the whole winemaking sector.

The negative effects of climate change in the agriculture sector are increasing. Recent analysis suggests that agriculture will be the most affected sector in Macedonia under the most likely climatic scenarios.

The sensitivity of the agricultural sector to climate has important implications in Macedonia. With a considerable proportion of the rural population dependent on agriculture for their livelihood, rural communities are particularly vulnerable to the risks posed by climate change. The vulnerability of the country's agricultural sector arises from two main causes: (i) the fact that agricultural production is performed in open spaces under the direct impact of various climatic phenomena, e.g. late frost, hail, torrential rainfalls, heat waves, etc.; and the fact that inputs in primary production, especially in perennial plantations (vineyards and orchards), have dramatically increased over the past few decades, due to which any negative impact of climate conditions will have strongly negative economic effects.

The Macedonian agricultural sector is characterized by a dual structure, i.e. corporate farms that cultivate larger pieces of land acquired through the privatization of formerly state-owned farms, and small family farms that cultivate about 80% of the country's agricultural land with an average landholding of 2.8 hectares divided into 6 non-contiguous plots. In terms of available resources and capital intensity, the family farming sector can be divided into three groups: (a) market producers; (b) semi-subsistence farms; and (c) subsistence farms.

By area, vineyards are the main perennial crop in Macedonia and occupy close to 21,000 ha. Most vineyard production is irrigated, although there is a substantial area under rain-fed production. The rain feed areas are highly dependent on the timing and quantity of rainfall, as well as associated extreme weather events like droughts and floods. The majority of the area under vineyards lies in the Vardar Planning Region. This region is also, however, the area most vulnerable to climate change (especially the central area of Veles - Sv.Nikole - Negotino).

Analysis has shown that this area is most vulnerable to water deficiencies during the summer season, resulting in significant moisture stress for summer and perennial crops. In an average year, evapotranspiration is higher than rainfall, resulting in crop water deficits of approximately 450mm (eastern and central areas).

One way of mitigating and coping with the negative effects of climate change in agricultural production is through the implementation of adaptation measures. Such measures should be carefully selected to ensure they are suitable for the crop concerned and applicable by the primary producers. The country's agricultural sector has low adaptability due to several key factors: (a) small primary producers with low annual income and insufficient capacity to implement adaptation measures, which in some cases can be costly to implement; (b) the prevalence of small plots, which prevents the effective implementation of adaptation measures; (c) insufficient financial support for farmers to cope with the negative impacts of climate change; (d) low awareness among the key players about climate change and its negative effects on agriculture; (e) weak networking and insufficient cooperation amongst scientific institutions; (f) insufficient capacities of the extension service and farmer associations for implementing know-how; (g) the lack of modern technologies of production and dissemination of research results to a broader audience; (h) insufficient experience in the implementation of modern approaches for assessing impacts and predicting future effects and trends.

The main goal of this study is to assess the vulnerability of the Vardar Planning Region to climate change, to identify appropriate adaptation measures and to model the impact of these measures on yield and gross biomass and calculate the financial effects of implementing such measures.

A preliminary analysis of the Strezevo irrigation area (Assessing the Economic Impact of Climate Change: National Case studies - AEICC) indicates that if water is not a limiting factor, adaptation through irrigation may be a cost-effective measure even without climate change. For other areas of the country, such estimations must be analysed on a case-by-case basis.

Both irrigated and rain-fed crops will have higher water requirements due to increased crop water demands, driven by higher temperatures, and reduced soil moisture availability due to less precipitation and runoff.

1.3. Description of the natural conditions in the Vardar Planning Region affecting the agricultural sector

1.3.1. Relief

The Republic of Macedonia can be divided into four geotectonic regions: the Serbian-Macedonian massif, the Povardarie area, the Pelagonia massif and the western Macedonia zone.

The Povardarie zone is in fact a large tectonic depression, which differs from the Serbian-Macedonian zone and the Pelagonia massif. Mountains located in the Povardarie zone include: Skopska Crna Gora, Krasta, Klepa, Nidze, Kozjak, and Kozuf. Valleys in the region include the Skopje valley, the Kumanovo, Ovce Pole, Tikves, Raecka valley, Valandovo, Gevgelija, Kocani and the Radovish valley.

> [Analysis has shown that this area is most vulnerable to water deficiencies during the summer season, resulting in significant moisture stress for summer crops]

The relief is the product of complex processes over a long period of time. The formation of the relief of Povardarie started with endogenic processes (tectonic and volcanic) and continued with exogenic morphogenetic processes, e.g. fluvial-denundational, fluvial-accumulative, lacustral and glacial.

The relief of the valleys in the Povardarie area is heterogenic. Morphologically, the relief features low altitude, vertical segmentation, mild inclination and different geological cover in comparison with the other three zones. Clastic stones are predominant.

The depression was originally part of a large sea. During this phase, paleogenic sediments were formed and tectonic movements formed the basic relief of the area, with high mountains and valleys situated in between. In the Miocene period, the valleys were filled with lakes. During this period, neogenic sediments were formed. During this "lake phase", the processes of abrasion and accumulation formed lake terraces which can be recognized today as small round-shaped hills. This hilly and undulated relief was additionally formed during the post "lacustral" phase through processes of erosion and accumulation. In this phase, two basic relief forms were formed in the valleys as a result of the influence of rivers and torrent flows: river terraces with recent alluvial sediments and hilly terrains with proluvial sediment.

The Povardarie region has specific hydrography, climatic conditions and vegetation which result in the formation of a specific soil cover, or the appearance of soil types typical of valleys e.g. alluvial, delluvial, chromic cambisols, and rendzinic soils. The last two soil types cover the hilly terrains and are most suitable for viticulture.

Climatic conditions

Macedonia has a highly diverse climate due to a mixture of influences from both continental and Mediterranean climates, as well as the complex geography of valleys and mountains throughout the country. The various microclimates of Macedonia have produced a highly diverse agricultural sector with a large range of crops grown. The climate ranges from alpine in the west and north-west of the country to Mediterranean in the southern districts of the River Vardar valley, and is characterized by cold winters, hot summers and a highly variable precipitation regime.

Four general circulation models (GCMs) presented in climate change scenarios for Macedonia, a combination of six different emission scenarios and four time-horizons have shown that Macedonia will become hotter and moderately drier as time passes, with substantial reductions in summer precipitation and more frequent and severe extreme events such as droughts and floods. The mean temperature for Macedonia will increase by 1.0°C by 2025 and by 1.9°C by 2050. For the same time horizons, mean precipitation is projected to decline by 3% and 5% respectively. Together, this will result in increased aridity. There is significant seasonal and spatial variation in impacts. The greatest warming is projected to occur in the mountainous north-west region of the country where only minimal reductions in precipitation are projected by 2050.

There are two general climatic types characteristic of the Povardarie Region according to its climatic parameters: the continental-sub Mediterranean climatic type which influences the Skopsko, Velesko, Tikvesko and Strumicko wine regions and the sub-Mediterranean climatic type which influences the Gevgelisko-Valandovsko region.

Unlike the other viticulture regions in the country, the climatic conditions in the Povardarie region are characterized by long and dry summers, with July and August characterized by heat waves and absolute maximum temperatures, and relatively mild winters. Absolute minimum temperatures below 0°C occur only during the winter period, unlike some other parts of the country where temperatures below 0°C are common in early spring and late autumn.

The monthly averages for air temperature over past decades in the Povardarie region have been 2–3°C higher than in the other regions of the country, with smaller temperature amplitudes. The Povardarie region has 33 more summer days than the other viticulture regions, and about 30-50 less frost days.

The annual sum of rainfalls is significantly lower, especially in the Tikves region. According to the aridity index, the Povardarie region is arid while the east region is semi humid and the west region is humid.

Soil conditions

Grapevines can sustain different soil conditions, including soils with low production capability. To achieve high yields and good quality, the soil should possess a certain level of quality which will enable its convenient growth, e.g., a deep and loose soil profile with appropriate aeration, water-holding capacity and a high nutrient content.

In the sub-Mediterranean zone and continental-sub-Mediterranean zone of the country, the most widespread soil types considered appropriate for viticulture are delluvial soils, rendzinic soils, chromic cambisols and, on small areas, vertisoils. Vine grape plantages can be very often found on regosols, but this soil type due to its shallow soil profile and low production capability, do not satisfy the needs of intensive vine production.

Generally speaking, the soils which are most suitable for viticulture production in the Povardarie region have a specific texture which is characterized by a low content of skeleton, except the chromic cambisols in some areas which have a higher content of skeleton. Sand is the dominant fraction of the fine earth in the investigated rendzinic soils, while in chromic cambisols clay is the dominant fraction of the fine earth. According to the classification of Sheffer and Schachtschabel, the investigated chromic cambisols are mostly loamy clay, while the investigated rendzinic soils are clayey loamy soils, since they have a lighter mechanical composition.

[The Povardarie region has 33 more summer days than the other viticulture regions, and about 30-50 less frost days.]

In terms of physical properties, the soils of the Povardarie region have favourable total porosity. It should be noted that the capacity for air of these soils is on a sufficient level which indicates that the soils are well-drained and suitable for viticulture production. In some cases, especially rendzinic soils, soils have low field water capacity and low quantity of available water. This indicates a possibility of water stress during the vegetative period. For this reason, irrigation is one of the most sensitive agro-technical operations in viticulture production.

The soils of the Povardarie region are very vulnerable to different types of land degradation. In conditions of heightened negative effects of climate change, soil erosion is one of the most dangerous and devastating types of land degradation. For this reason, special attention should be paid to this type of land degradation in viticulture production due to the fact that in many cases the producers apply some practices which intensify the process of soil erosion: e.g. the downslope orientation of vineyards, furrow irrigation, cultivation of the vineyards when the soil is not ready, i.e. too dry or too wet, for cultivation.

2. METHODOLOGY

2.1. BioMa

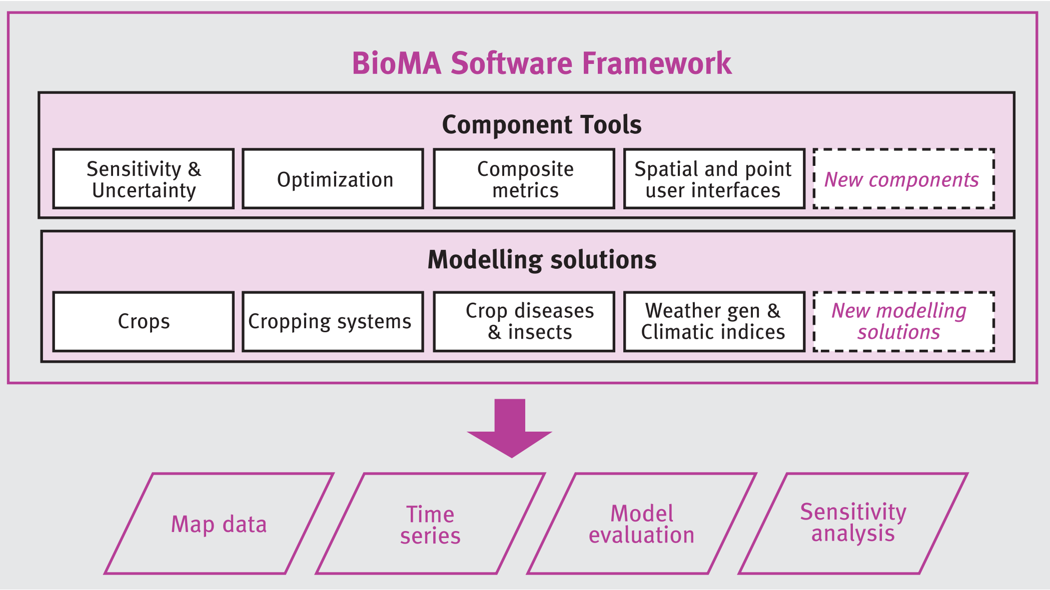
The Biophysical Model Application (BioMA) was developed by the Joint Research Centre (JRC) in Italy. BioMA is an extensible platform for running biophysical models on generic spatial units that enables the development of various simulations related to agriculture. Within this project a particular focus will be put on replication and upgrading the analyses already performed in other regions of the country with a focus on the areas most vulnerable to climate change.

The BioMa platform was used in practice for the first time since it was developed by the JRC scientists. The models used were successfully implemented and the results gained were in accordance with the data used for calibration and validation of the modelled data.

Simulations are carried out via modelling solutions, which are discrete simulation engines where different models are selected and integrated in order to carry out simulations for a specific goal. Each modelling solution makes use of extensible components. These features, such as extensibility, make the BioMA framework suitable for assessing the impact of climate change in the Republic of Macedonia because they have the advantage of allowing the customization of a model with country specific parameters (Figure 1).

The current version of BioMA includes diversified and alternate modelling solutions. For the purposes of this report the ClimIndices model that is implemented in BioMa was used for assessing the climate change vulnerability of the Vardar Planning Region. For assessment the impact of the adaptation measures to climate change was used the Cropsyst model that is developed by the Washington State University's Department of Biological Systems Engineering.

Figure 1: The macro-components of the BioMA software framework



2.1.1. ClimIndices

In order to make an appropriate adaptation strategy and to quantify the benefits of that adaptation strategy, there is a need to conduct a vulnerability assessment of the area of interest i.e. the Povardarie Region of Macedonia. For this purpose, agro-meteorological indicators were developed for the Vardar Planning Region with the ClimIndices model.

Table 1. Agro-meteorological indicators implemented in ClimIndices

Type	Indicator
Dates	Last spring air frost (day)
	First winter air frost (day)
	Last spring grass frost (day)
	First winter grass frost (day)
	Max. soil moisture deficit (day)
	Min. soil moisture deficit (day)
	Wettest week (day of midpoint)
	Start of growing season (day)
	End of growing season (day)
	End of field capacity (day)
	Return to field capacity (day)
Counts	Air frost days Indices
	Grass frost days
	Heat stress days
	Growing season range days
	Growing season days
	Dry days
	Wet days
	Dry soil days
Thermal sums	Accumulated air frost temperatures (°C-days)
	Accumulated heating (°C-days)
	Accumulated growing degree days (°C-days)
Water balance	Wettest week amount (mm)
	Excess winter rainfall (mm)
	Max. summer moisture deficit (mm)
	Min. summer moisture deficit (mm)
Waves	Longest heat wave (days)
	Longest cold spell (days)
	Longest dry spell (days)
	Longest wet spell (days)
Indices	Mean precipitation intensity (mm d-1)
	Rainfall seasonality index
	Modified Fournier index

Agro-meteorological indicators are based on climatic variables that have an impact on plant life (Table 1). They are used for various purposes, including the assessment of site suitability for crop growth, the geographical limits of crop land use in response to climate, and to provide synthetic estimates of weather anomalies/trends. ClimIndices calculates basic measures on an annual or monthly basis (mean air temperature, total precipitation, total incoming solar radiation, etc.) and agro-meteorological indicators in groups of six types:

- **Dates: the first/last occurrences of a phenomenon in a period of time**
- **Counts: the number of occurrences of a phenomenon**

[The water budget in the model includes precipitation, irrigation, runoff, interception, and water infiltration, water redistribution in the soil profile, crop transpiration, and evaporation.]

- **Thermal sums: degree-days above/below thresholds**
- **Water: the temporal sequence of changes of soil water**
- **Waves: the cyclical occurrence of phenomena**
- **Indices: metrics compared to standard values**

2.1.2. Usage of the CropSyst model for measuring the impact of the adaptation measures to climate change

CropSyst (Cropping Systems Simulation Model) is a multi-year, multi-crop, daily time-step crop growth simulation model which serves as an analytical tool to study the effect of cropping systems management on crop productivity and the environment.

With the model the crop yield projections are simulated per large land block fragments (25x25 km2). In one run, a uniform management regimen that are prepared in separate agro-management files representing BAU agro-management scenarios and scenarios with adaptation measures like irrigation, UV nets and an increase in planting altitude are applied to every fragment that represents a biophysically homogeneous unit area. Growth is described at the level of whole plant and organs. The crop parameters were described for two representative types of grape: wine grapes and juice grapes. Crop development is simulated based on the thermal time required to reach specific growth stages. The accumulation of thermal time may be accelerated by water stress. Thermal time may also be modulated by photoperiod and vernalization requirements whenever pertinent. Daily crop growth is expressed as biomass increase per unit ground area.

The model accounts for four limiting factors on crop growth: water, nitrogen, light, and temperature. For this purpose, CropSyst simulates the soil water budget, soil-plant nitrogen budget, crop phenology, crop canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water, and pesticide fate. These are affected by weather, soil characteristics, crop characteristics, and cropping system management. The weather data is obtained from the files provided by the Joint Research Centre in Ispra and is developed according to the IPCC SRES scenarios that contain various driving forces of climate change, including population growth and socio-economic development. In order to run the CropSyst model, these scenarios should be adapted to the resolution requirements of the model (25x25km). The source of climate data is the bias-corrected ENSEMBLE datasets composed by two realization of the A1B emission scenario: HADCM3 GCM nested with the HadRM3 RCM representing the so called “warm” scenario and ECHAM5, coupled with the HIRHAM5 RCM for the downscaling representing the so called “cold” scenario. The water budget in the model includes precipitation, irrigation, runoff, interception, and water infiltration, water redistribution in the soil profile, crop transpiration, and evaporation. Water redistribution in the soil is handled by a simple cascading approach or by a finite difference approach to determine soil water fluxes.

Soil data for running the model were collected from previous investigations in the Vardar Planning Region. For the purpose of this study, the most appropriate soil types for viticulture were selected: chromic cambisols and rendzinic soils from the Negotino and Kavadarci area. From each soil type the 3 most characteristic soil profiles were selected. It must be pointed out that the simulations limited to soil water are sensitive to basic soil parameters derived from texture and soil depth, as they determine the hydraulic characteristics.

3. VULNERABILITY ASSESSMENT OF THE AGRICULTURE SECTOR

For the purpose of analysing the climatic conditions of the Vardar Planning Region, a modelling approach was used for simulation of the climatic parameters for the period 1993–2057 with centered 2000. The whole territory of the country is divided in a grid of 53 squares. The main aim of these simulations was to predict future trends in the basic climatic parameters, i.e. temperature, rainfall; dates, e.g. the start of the growing season, the end of the growing season, last air frost and first air frost, etc.; counts: the growing season length, growing degree days, etc.; and indexes: aridity index, desertification index De Marthone, etc.

The main goal of this assessment was to predict the changes of all parameters for the period of 50 years by using the ClimIndices model. The target region is the Vardar Planning Region, which covers the central part of the country and which was identified as the regions most vulnerable to climate change by the previous analyses (II and III National Communication to the UNFCCC) .

The target crop is viticulture, which covers approximately 21,000 ha, mostly within the Vardar Planning Region. This crop was selected due to its high sensitivity to climate and soil conditions (temperature and water stress) and its importance as a basic material for production of high quality wines. In the recent period, table grape varieties are starting to become more attractive between primary producers. It should be noted that climatic conditions also have a high impact on these varieties, e.g. sunburns, decreasing yield, lower quality, etc.

3.1. Mean annual air temperature

Mean air temperatures are calculated for the period 1993–2057. The target region for the analysis was the Vardar Planning Region, which falls within 8 grids (62149, 62150, 63148, 63149, 63150, 64148, 64149 and 65149). Average yearly temperatures are simulated for each grid of 25 km^2.

From the simulated data it can be concluded that the Vardar Planning Region is significantly more vulnerable than the rest of the country, which is proven by the fact that the average temperature in the Vardar Planning Region is 1^{0}C higher than the rest of the country.

It should be noted that the negative influence of average air temperatures on agricultural production largely depends on other environmental conditions (rainfall, evapotranspiration, dryness, etc.). For this reason, the negative influences of increased air temperatures will differ in extent in different regions of the country.

More significant increasing of maximal annual air temperatures are expected in comparison to the average annual air temperatures. This is important information since the most recent investigation showed significant damage to grapes and reduction of quality as a result of high temperatures and strong solar radiation during the vegetative period. The cumulative increasing of maximal temperatures for the period 2000–2050 will be approximately 1.5°C on average.

3.2. Mean air temperature growing season

For each development stage, crops needs to gain a certain sum of active temperatures for the concerned vegetative stage. For this reason, temperatures in the growing season (>10 °) are very important for crop development. Significant changes in growing season temperatures may be expected to cause a certain shift in crop growing stages, meaning that some growing stages might occur earlier or later, which is also closely connected with certain crop management practices (plant protection and irrigation scheduling). This indicator is closely connected with Growing Degree Days. To this end, agricultural crops will need more water for their development, which is even at this moment a limiting factor for normal growth and is compensated for by irrigation. The average increases in air temperatures in the growing season for the Vardar Planning Region are 1.15°C and 1.24°C for the periods 2000–2025 and 2000–2050 respectively.

Such increasing of average temperatures during the growing season can have a serious impact on agricultural in the Vardar Planning Region, since the majority of the area is under intensive agriculture production: viticulture and orchards.

3.3. Growing Degree Days Yearly

Growing Degree Days is a temperature sum which represents a yearly sum of temperatures when average daily temperatures are higher than a base temperature for growth, (> 10° C).

The increase in GDD in the Vardar Planning Region for the period 2000–2050 is in the ranges of 350-440°C. The GDD sum in the Vardar Planning Region is approximately 400°C higher than the sum of GDD for the whole country (2630.75).

This leads to the conclusion that the Vardar Planning Region is much more vulnerable than the rest of the country and we can expect more emphasized differences in plant development phases for the next 40-year period. The growing period of all groups of crops with base temperature >10°C and higher will start earlier and the growing stages will be dramatically shifted in time.

The total difference in the average values of evapotranspiration for the Vardar Planning Region for the period 2000–2050 yields only 86 mm, while for the period 2025–2050 is low (at 159.56 mm).

3.4. Growing season length (GSL)

GSL gives a good indication of the future extent of impact of climate change on agriculture, in terms of changes in the dates of vegetative stages and the vegetation period as a whole, and changes in crop management: the selection of varieties, irrigation scheduling and plant protection plans.

From the data presented in Table 6 it can be seen that the GSL in the Vardar Planning Region will be shortened in a range by a maximum of 30 days up to a minimum of only 1 day. The shortening of the growing season is mainly the result of expected late air frosts and cold spells in early spring. This climatic phenomenon can have a serious impact on viticulture, due to which it is crucial to select appropriate micro locations for establishing vineyards. A possible reduction in rainfalls can also contribute to shortening the GSL.

3.5. Rainfalls

The Vardar Planning Region includes one of the most arid regions in the country: Veles-Sv. Nikole-Negotino. According to all climatic scenarios for the country, rainfalls will decrease. This climatic parameter is crucial for assessing vulnerability, since rainfalls (effective rain falls) are the only source for crop growth in areas not covered with irrigation systems.

Another important characteristic of annual rainfalls is the rainfall regime (i.e. the monthly distribution of rainfalls during the year and the growing season), the intensity of rainfalls and the number of rainfalls of high intensity. Rainfall regime and intensity is especially important in the Vardar Planning Region since the majority of the arable land is under intensive agriculture. Intensive rainfalls have a harmful effect on agricultural production. Large amounts of rainy water cannot be absorbed by the soil and a surface outflow appears. This surface runoff cause intensive soil erosion and damages agricultural crops. Floods are another negative effect of intensive rainfalls as they can threaten huge areas and compromise agricultural production. For all these reasons, appropriate land management is a crucial issue for the effective control of erosion processes.

Simulation of rainfalls is extremely difficult. This is because (a) the rainfall regime is influence by many factors and can vary significantly and very locally, and because (b) the Republic of Macedonia is under 3 different global rainfall regimes, despite being a small territory. The general trend for the period 2000–2050 is that annual rainfalls will decline significantly.

Similarly to the annual average rainfalls, rainfalls in the growing season show the same fluctuating pattern in their sums within the simulated period 2000–2050

3.6. Evapotranspiration

Water is a limiting factor in the country, especially in the Vardar Planning Region. Evapotranspiration represents the real quantity of water needed for a specific crop for particular regions (actual ETo). It is the best indicator for vulnerability assessment from all aspects. This is because if any water deficit appears, plants will be under stress and this will influence yield and yield quality.

Potential evapotranspiration was simulated using the basic climatological elements (air temperature, rainfalls, air moisture, wind speed, insolation, sun radiation).

Evapotranspiration exhibits very intensive changes during the modelled period. There are certain periods of increasing and decreasing of evapotranspiration, but there is an obvious trend of increasing over time. Changes of evapotranspiration mostly depend on changes in air temperature. The total difference in the average values of evapotranspiration for the Vardar Planning Region for the period 2000–2050 is not very significant and yields only 86 mm, while the difference is much higher for the period 2025–2050 (at 159.56 mm).

What is important to emphasize is that evapotranspiration in the Vardar Planning Region is much higher than the sums of rainfalls. For normal growth of agricultural crops, this difference is compensated for with irrigation. Better utilization of irrigation water and higher irrigation efficiency is imperative for solving this problem.

4. ADAPTATION AND MITIGATION MEASURES

Although the complex interrelationship between adaptation and mitigation measures are noteworthy, mitigation measures are mainly determined by international agreements and national public policies, while adaptation measures involve local entities and private actions (Klein et al. 2007). Mitigation measures are crucial, as long-term stabilization of CO2 concentrations may reduce damage to yield and quality (Easterling et al. 2007). Mitigation strategies, resulting in lower GHG concentrations, may reduce agricultural water requirements by about 40% when compared with unmitigated climate (Fischer et al. 2007). As for agricultural mitigation measures, tillage systems are of key importance, as they may slightly compensate for GHG emissions (Ugalde et al. 2007). No-till systems and minimum tillage are considered the best for this purpose, as no disturbance of the soil surface promotes carbon retention/sequestration (Kroodsma and Field 2006). In regions with very steep slopes, no-till systems may also significantly contribute to reducing soil erosion.

Short-term adaptation measures may be considered as the first protection strategy against climate change and should be focused on specific threats, aiming at optimizing production. These measures mostly imply changes in management practices (e.g., irrigation, sunscreens for leaf protection), while changes in oenological practices through technological advances may also have positive effects on wine quality.

Long-term adaptation measures mainly include varietal and land allocation changes, as some regions may become excessively warm and dry, while others consistently show high winemaking suitability (Malheiro et al. 2010). Changes to cooler sites, to higher altitudes, or coastal areas may also prove beneficial for future vineyards (changes in the vineyard microclimatic and mesoclimatic conditions).

4.1. The state of Viticulture in the Republic of Macedonia

Located at the meeting point of the continental climate and the Mediterranean climate, with over 270 sunny days, Macedonia is a place where viticulture will continue to be one of the leading agricultural branches. Vineyards stretch over a surface of around 25,000 hectares. However, in spite of Macedonia's convenient climatic conditions, in recent years a decrease in the land on which grapes are grown has been noticed. In 1990 Macedonia had vineyards of 40,000 hectares, but they have since dramatically decreased.

According to statistics, table and wine grapes were grown on 26,530 hectares in 2000, 27,111 hectares in 2001, 26,194 hectares in 2002, 25,692 hectares in 2003, 24,777 hectares in 2004, 25,044 hectares in 2005, and 21,000 ha in 2010.

The average annual production of grapes is around 230,000 tons. According to the official data, the average yield is 9–10 tons per hectare. Wine grapes are grown on about 20,000 hectares from a total of 25,000 and the annual yield is around 160,000- 170,000 tons of grapes, which is then used for production of 90–100 million litres of wine.

4.2. Climate Projections in Macedonia

Within the Second and Third National Communication to the UNFCCC, climate projections have been developed for the country. The general trends from these analyses indicate that Macedonia will become hotter and moderately drier as time passes, with substantial reductions in summer precipitation and more frequent and severe extreme events such as droughts and floods. This analysis was performed using four general circulation models (GCMs), a combination of six different emission scenarios and four time horizons. As demonstrated by the ensemble range for both temperature and precipitation in Table 2, there are significant differences in the extent of the potential changes between the four GCM models and associated emissions scenarios.

Table 2. Future Climate Projection for Macedonia compared to 1961–1990 period

Time Horizon	Temperature Projections		Precipitation Projections	
	Ensemble Averages^{0}C	Ensemble Ranges^{0}C	Ensemble Averages%	Ensemble Ranges%
2025	1	0.9 – 1.1	-3	-1 – -6
2050	1.9	1.6 – 2.1	-5	-2 – -7

The ensemble average projects that the mean temperature for Macedonia will increase by 1.0°C and 1.9°C by 2025 and 2050 respectively. For the same time horizons, mean precipitation is projected to decline by 3% and 5% respectively. Together, this will result in increased aridity.

There is also significant spatial variation. Because of the complex relief, vegetative cover and soil conditions of Macedonia, there will be important differences in the magnitude of climate changes at sub-national scale. The Second National Communication outlines these differences via localized empirical downscaling projections for the south-east, central and north-west parts of the country (Table 3), while the Third National Communication is focused only on the South-East region, with a special focus on estimation of the efficiency of adaptation measures.

In the south-east region, for example, summer precipitation is projected to decrease by 19% by 2100, while temperature will increase by 6°C.

Table 3. Future Sub-National Climate Projections for Macedonia Compared to 1961–1990 periods

Time Horizon	Mean Temperature Projections °C			Mean Precipitation Projections (%)		
	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

The greatest warming is projected to occur in the mountainous north-west region of the country – where only minimal reductions in precipitation are projected by 2050. The south-east and central regions of the country are projected to warm at a slightly slower pace, although precipitation will decline at a greater rate, especially in the second half of the century. The implications for agriculture become much clearer when seasonal and sub-national projections are combined. In the south-east region, for example, summer precipitation is projected to decrease by 19% by 2100, while temperature will increase by 6°C. Such extreme changes in temperature and precipitation will place tremendous strain on agricultural production, thus highlighting the importance of adaptation.

The agricultural zones that will be most sensitive by 2100 have been identified according to the results of climate scenarios at national and regional level. **The most vulnerable agricultural zone is the Vardar Planning Region, especially the area of the confluence of the Crna and Bregalnica rivers with the River Vardar. Winegrape is the most important crop in this region and is in the category of the crops most sensitive to climate change.** The expected reduction in yield is calculated using the FAO methodology "Yield Response to Crop Water Deficit." (Table 4)

Table 4. Expected yield reduction of grapes as a result of climate change (in %) if applicable

Region	Crop	2025	2050	2075	2100
Kavadarci	Grape	46	50	55	59

The obtaining results assume that crops would be grown without irrigation, from where yield decrease is so dramatic. Accordingly, the economic losses are calculated under the assumption that the country will be equally affected by climate change and not measures of adaptation will be applied.

Table 5. Estimated economic losses on vines caused by climate change

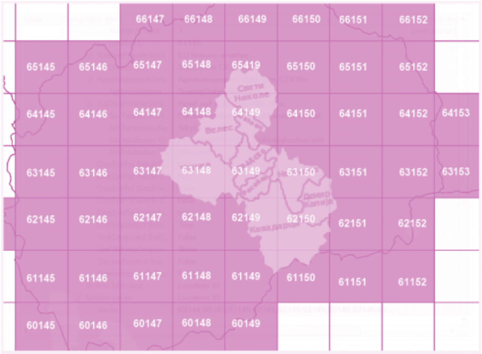
Year	Reduced production due to the climate change, in tons	Value of reduced production, in EUR
	Grape	Grape
2025	112.910	18.211.370
2050	122.729	19.794.968
2075	135.002	21.774.465
2100	144.820	23.358.062

The total direct economic damage would be more than 18 million in 2025 and would increase to almost 24 million in 2100.

4.3. Material and methods

For the purpose of our investigation, the territory of the country was divided into 53, 25x25 km grids. The grids codes of Vardar Planning Region are: 62149, 62150, 63148, 63149, 63150, 64148, 64149, and 65149, including the following municipalities: Kavadarci, Demir Kapija, Caska, Gradsko, Rosoman, Negotino, Veles, Lozovo and Sv. Nikole.

Map 1. Selected grids of Vardar Planning Region



GRID:	MUNICIPALITY:
62149	Kavadarci
62150	D. Kapija
63148	Caska
63149	Gradsko; Rosoman
63150	Negotino
64148	Veles
64149	Lozovo
65149	Sv. Nikole

The climate in this region is different as a result of the influence of the Continental climate (the annual quantity of rainfall is lower and aridness is increased), the pluviometric regime is changed and temperature is decreased, especially in winter. The annual quantity of rainfall in this area varies from 460–583 mm (on average 507 mm). The annual drought index varies between 19, 7 and 25, 4 (on average 22, 6) (Mitkova et al., 2009). Ristevski (1982) designates a BS-climate. The influence of both climates (Continental and Sub-Mediterranean) results in significantly diverse climate conditions. This provides the opportunity for the region to be divided into sub-regions, which is especially significant for wine-growing.

Climate change has a great influence on winegrape production in this region, where extreme climate factors very often occur: cold winters with low winter temperatures below –15^{0}C and very hot and dry summers with temperatures above 35^{0}C, as well as drought in July and August which significantly affects the quality of the wine grapes. There have been occurrences of simultaneously maturing varieties with different ripening periods. Harvesting is concentrated in a few weeks as opposed to previous periods when it was realized in two months. Noticeable is the uneven quality of grapes on a single vine: not mature, overripe, normally ripe and rotten. This confirms that the normal climate conditions will be change and the producers will not be able to cope with them through the use of standard agrotechnical and ampelotechnical measures.

The time horizons studied are 2025 and 2050, and the comparison is made against a baseline year – 2000, considered as representative of current conditions.

The base agro-management scenario (depending on the applying measure, SC 0 or SC 1), which will be used as a referent to which comparisons will be made, is without irrigation, applying agro-technical and ampelotechnical measures that correspond to traditional crop management in the study zones. In reality, of course, these measures vary within each region, but insufficient information was available to specify intra-regional variations. The additional agro-management scenarios, aimed at comparing changes in crop yield with changing climate in order to find the most suitable strategy, consist of different types, times and quantities of irrigation, the application of UV nets for reducing temperature and increases in the altitude of the vineyards, which according to many investigations may also prove beneficial for future vineyards.

4.4. Agro-management practices in vineyards to mitigate the effects of climate change

The main challenge for the preparation of this chapter were the conclusions presented in the Third National Communications to the UNFCCC, according to which the territory of the Republic of Macedonia will become hotter and moderately drier as time passes, with substantial reductions in summer precipitation and more frequent and severe extreme events such as droughts and floods. Such extreme changes in the temperature and precipitation will place tremendous strain on agricultural production, thus highlighting the importance of adaptation.

The agricultural zones most sensitive to climate change by 2100 have been identified according to the results of climate scenarios performed at national and regional level, The **Vardar Planning Region is singled out as the most vulnerable, especially the area of the confluence of the Crna and Bregalnica rivers with the River Vardar. Winegrape is the most important crop in this region and is in the category of the most sensitive crops to climate change.**

Furthermore, the study also suggests that if no adaptation measures are applied to mitigate climate changes which are inevitable, there will be a reduction in the grape yield of 46% in 2025, 50% in 2050, 55% in 2075 and 59% in 2100, respectively, with direct economic damage of more than €18 million in 2025 to almost €24 million in 2100.

Changes in temperature and precipitation (as well as the needs of water for irrigation) and the concentration of CO_2 are the most important climatic factors that have an effect on the grape yield and wine quality.

The Vardar Planning Region is singled out as the most vulnerable, especially the area of the confluence of the Crna and Bregalnica rivers with the River Vardar.

Wine grapes have four main development stages: budburst, flowering, veraison (berry softening and colour change, signalling the onset of rapid sugar importation) and maturity. (McIntyre et al. 1982). The timing and duration of these stages varies with the type of grape and climate (Jones and Davis, 2000). Matching development phases to climate is an important consideration in vineyard planning. As climates warm, grapes phenology will progress more swiftly and grapes will ripen earlier (Webb 2007b). Also, the rate of change in fruit composition is strongly influenced by temperature, with higher temperatures increasing the speed of sugar development, hastening acid degradation, and altering flavour compounds (Coombe and Iland 2004; Lund and Bohlmann 2006). Studies modelling the projected impact of climate changes on grape and wine quality indicate that for wine grapes that are currently able to ripen in a given climate, warming will reduce composition quality if no adaptation measures are implemented.

Most of Macedonian's vineyards are irrigated and rely on irrigation supply; therefore the largest impact of climate change is likely to be reduced water availability due to the lower rainfall in catchments and reduction of water for irrigation. Lower rainfalls are associated with proportionally larger reductions in stream-flow, which will substantially reduce available water in aquifers. When water is not available, yields will decline (Jackson et al. 2008) and vines can suffer long-term damage (Hardie and Considine, 1976). Therefore, maintaining well-watered vines is the main way to reduce heat stress. Improving water strategies is also essential for reducing costs and mitigating the impacts of droughts.

On the basis of the assumptions outlined above, the purpose of the simulations was to determine the effects on grape production of applying different amounts of irrigation water and different reductions in temperatures over a period of 50 years, as compared to not implementing any adaptation measures over the same period.

For the irrigation scenario we wanted to determine whether: 1. the amount of irrigation water used increases the yield of grapes; and 2. whether yield was affected by the volume of irrigation applied at particular stages in the development of the vine. Four scenarios were simulated, which are presented in Table 6.The same schedule for the amount and timing of irrigation was valid for both wine grapes and table grapes.

Table 6. Irrigation scenarios

IRRIGATION	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Development phases of grape	No Irrigation	Furrow [mm]	Drip Irrigation	Drip Irrigation
1.Before vegetation period	0	0	20	0
2.Before flowering	0	0	20	0
3.After flowering (mid June)	0	80	40	40
4.Mid July	0	80	40	40
5.Beginning of August	0	0	40	40
TOTAL (mm)	**0**	**160**	**160**	**120**

The agro-management adaptations with irrigation predicted 4 scenarios:

SC0: without irrigation

SC1: with furrow irrigation

SC2: with drip irrigation of 120 mm volume

SC3: with drip irrigation of 160 mm volume

The volume of irrigation was ranked from a minimum of 2 (SC 1) to a maximum of 5 (SC 2), depending on the type of irrigation (furrow: drip irrigation) and the development phase of the grape.

From the simulations involving irrigation, the following can be concluded:

Irrigation is necessary in intensive viticulture for maintaining plants for a long period as better as possible and for improving quality with a satisfactory yield. Without irrigation, vines face the threat of extinction. Despite their resistance, many vines in vineyards will gradually die, reducing the justification of profitable cultivation.

Air temperature influence was simulated in two ways: firstly, by covering the vineyards with UV nets to decrease temperature by 2^0C and 5 ^{0}C; and secondly, by the relocation of vineyards to higher altitudes of 250 m and 500 m.

The use of UV nets is regular practice in modern grape production. UV nets completely change the microclimate in vineyards by decreasing the temperature of the air and plants. This prevents the oc-

> The lowest yield at level 10 t/ha and the latest maturation (around August 19) results from the scenario involving a 500 m increase in altitude.

currence of diseases caused by precipitation, removes the risk from hail events, and reduces evapotranspiration.

In simulations of scenarios without UV nets, the yield of table grapes was around 30 t/ha. A certain displacement was observed in the beginning of the maturation of the grapes. Higher temperatures impact on the duration of the individual phenological stages of the crop, contributing to the rapid onset of ripening. In the case of wine grapes, the obtained yield in the scenario without UV net was 14 t/ha, with minimal differences at the beginning of maturation.

In simulations of scenarios using UV nets to decrease the temperature by 2 ^{0}C, the yield of table grapes in all three periods of investigation would be between 32 and 33 t/ha, while the period of beginning of maturation would become later. Compared to scenarios without UV nets, the differences in yield was around 2 to 3 t/ha, and the differences from the beginning of the period of maturation were from 7 to 10 days. For wine grapes, the obtaining yield in all three periods of investigation will be above 14 t/ha, while the period of beginning of maturation will start later, between 22 and 29 July.

The scenario in which UV nets are used to decrease temperature by 5 ^{0}C is characterized by a later beginning of the period of maturation of the table grapes. The achieved yield is around 30 t/ha. In the case of wine grape, a balanced beginning of maturation is noticed, which was not the case with table grapes. The achieved yield was at the level of 14 t/ha. Clearly, greater shading and lower temperatures do not lead to higher yields.

Comparing the simulations involving UV nets to those without UV nets, it may be concluded that the use of UV nets (to the certain level of shading which will cause a decrease in temperature of 2 ^{0}C), has a positive effect on the yields of both table grapes and wine grapes.

The relocation of vineyards is a long-term adaptation measure. Changes to cooler sites at higher altitudes may prove beneficial for future vineyards. By increasing altitude, temperatures decrease by a minimum of 0.5 ^{0}C per each 100 m. In our study three scenarios were modelled:

SC1: common altitude

SC2: altitude increased by 250 m

SC3: altitude increased by 500 m.

In all three scenarios, furrow irrigation was applied with a water volume of 160 mm split in two times – 80 mm in midle of June and 80 mm in midle of July.

Changing altitude to a certain level will significantly affect the volume of the yield and the time of maturity of table grapes. Increasing altitude by 250 m causes a delay in the maturation of the grapes of 15 days, while increasing altitude by 500m delays maturation by up to 30 days.

Increasing altitude by 250 m causes the highest yield. Increasing altitude by 500 m will reduce the yield and delay the time of ripening. The relocation of wine grape production to higher altitudes will significantly affect the yield and time of maturity. The lowest yield at level 10 t/ha and the latest maturation (around August 19) results from the scenario involving a 500 m increase in altitude. Early maturation between 8 and 15 July is in the variation with common altitude. The highest yield above 14 t/ha, will be obtained by increasing altitude by 250 m.

Increasing altitude thus contributes to achieving a higher yield, but only to a certain level. Relocating vineyards at altitudes 250 m higher than their current altitude proved to have the most positive effects. Increasing the altitude of grape production by more than 250 m carries the risk of delaying the start of the ripening of the grapes, delaying harvesting and reducing yields.

Some alternative adaptation measures and strategies not included in our investigation also deserve mention, such as: growing grape varieties with different thermal requirements and higher summer stress resistance; proper rootstock decisions; deficit irrigation strategies (e.g., regulated deficit irrigation – RDI; partial root drying – PRD; sustained deficit irrigation – SDI); and different tillage treatments.

5. CONCLUSION

Climate change has the potential to have a great impact on nearly every sector of agriculture, including viticulture. Grapevines are amongst the oldest cultivated plants, along with the process of making wine. The cultivated varieties and the overall wine style that a region produces is a result of average climatic conditions, while climate variability determines differences in vintage quality. Climatic changes, which influence both variability and average conditions, therefore have the potential to impact on growth, grape composition, wine style and the spatial distribution of grapevines. Without any adaptive measures to mitigate the changes caused by climatic influences, many of the regions where quality grapes are grown will be abandoned or reoriented to other types of farming.

From the simulations made in this study, the following conclusions can be drawn:

1. An increase in average annual temperatures for the analysed period (2000–2050) can be expected. The increase is especially significant for the period 2025–2050 and is in the range of 0.89–1.80C. The same pattern was observed for maximal annual air temperatures and for mean annual air temperatures (growing season), which are expected to increase by 10C and 1.240C respectively. Such an increase in average temperatures during the growing season can have a serious impact on agriculture in the Vardar Planning Region, since the majority of the area is under intensive agriculture production: viticulture and orchards.

2. The Growing Season Length in the Vardar Planning Region of Macedonia will be shortened by a maximum of 30 days.

3. The average sum of GDD (3022.73oC) for the Vardar Planning Region is higher by approximately 400oC than the sum of GDD for the whole country (2630.75). This leads to the conclusion that the Vardar Planning Region is much more vulnerable than the rest of the country and we can expect more emphasized differences in plant development phases in the next 40-year period.

4. The total difference in the average values of evapotranspiration for the period 2000–2050 is not very significant and yields only 86 mm while for the period 2025–2050 the difference is much higher at 159.56 mm (14%).

5. Without irrigation there will be a reduction in yields of table grapes from 26 tons in 2000 to 25 tons in 2025, and to 24 tons in 2050. Yields of wine grape will also be reduced, from almost 12 tons in 2000 to 11 tons in 2025 and to 10 tons in 2050.

6. With furrow irrigation, the average table grape yield would be approximately 30 t/ha, or there would be no differences in yield between the years (periods) of investigation (2000–2025, 2025–2050).

7. The average yield of wine grapes would be approximately 14 t/ha, with no differences in yield between the years (periods) of investigation.

8. Drip irrigation influences the size of the yield in table grape production. The yield is almost the same regardless of the quantity of water used for both scenarios (160 and 120mm). If compared with the non-irrigation scenario, the increase in yield is in the ranges of 22% and 26% for 2025 and 2050 respectively. The same conclusion applies to the wine grape.

9. Without irrigation, the yield of table grapes will decline from 26 t/ha in 2000 to 25 t/ha in 2025, i.e. less than 25 t/ha in 2050. Irrigation in all three scenarios contributes to a higher yield. Perhaps more attention should be given to the two scenarios with drip irrigation where the yield was at around of 32 t/ha. In cases where irrigation is not applied, the yield of wine grapes actually decreases, from 12 t/ha in 2000 to 11 t/ha in 2025, i.e. to 10 t/ha in 2050. Irrigation in all three scenarios contributes to higher yields, around 14 t/ha, whether furrow or drip irrigation is used. This may lead to the conclusion that despite the increase in temperature, which is real and should be expected in the Vardar Planning Region, timely and appropriate irrigation will mitigate the effects of high temperatures and will contribute to increased production. The quality of the grapes was not the subject of this study.

10. UV nets completely change the microclimate in the vineyards by decreasing the temperature of the air and the grapes, preventing the occurrence of diseases caused by precipitation, and removing the risk from hail events. Without UV nets, the yield of table grapes was around 30 t/ha. A certain shift was observed at the beginning of maturation of the grapes. In the case of wine grapes the yield without UV nets was 14 t/ha, with minimal differences at the beginning of maturation.

11. When simulation is made by using UV nets and decreasing temperature by 20C, the yield for table grapes in all three periods of investigation was between 32 and 33 t/ha, while the period of beginning of maturation became later. The difference in yield was around 2 to 3 t/ha, and the difference with regard to the beginning of the period of maturation from 7–10 days. For wine grapes, the obtaining yield in all three periods of investigation was above 14 t/ha, while the period of beginning of maturation started later, between 22 and 29 July.

12. The use of UV nets to decrease temperature by 5 0C is characterized by a later beginning of the period of maturation of table grapes. The achieved yield was around 30 t/ha. In the case of wine grapes there is noticed balanced beginning of maturation, which was not the case with table grapes. The achieved yield was at the level of 14 t/ha. Obviously, greater shading and lower temperatures do not lead to higher yields.

13. Comparing the situation when UV nets are not used to when they are used as an adaptation measure to mitigate climate change, we may conclude that the use of UV nets (that will cause a certain decrease in temperature) has a positive effect on the yield of table grapes and on the yield of wine grapes.

14. The change of altitude to a certain level will significantly affect the size of the yield and the time of maturity of table grapes. Increase in altitude causes a delay in the maturation of the grapes of 15 days. Increasing altitude by an extra 250 m will cause the highest yield. Increasing altitude by an extra 500 m compared to the altitude on which the grapes is growing now will reduce the yield and will delay the time of ripening.

ACTION (Adaptation measures to maximize economic benefits and minimize the impact of climate change per sector)	**EXPECTED RESULTS**	**TYPE** (Policy Legislation/ Capacity-building)	**STAKEHOLDERS** (Clear distinction of responsibilities among the relevant stakeholders)	**TIMEFRAME** (Short-term/long-term)	**FINANCING** (Financial means of implementing measures for the Region) In Euros	**CONSTRAINTS** (Identification of possible barriers and risks, including legal arrangements, institutional management, financial and technological aspects)	**COMMENTS**
1. Strengthening the Water User Associations (WUA) and Corporations, introducing structural changes.	Improved maintenance of irrigation schemes, prevention of water loss and more rationale use of water resources.	Policy/Legislation/ Capacity building	MAFWE, Water communities, local government	Short-term	1,000,000	Lack of finance and lack of awareness of the importance of this measure amongst key decision makers.	Organizations of farmers exist, but they need to be supported and strengthened in order to improve water management practices within farming society and increase public awareness of climate change.
2. Support to the water communities and changing the system of charging irrigation water (per m^3).	Improved capacities of water communities for water management and investment in irrigation schemes at local level.	Policy/ Legislation	MAFWE, water communities, local government	Short-term	No cost	Lack of awareness of the importance of this measure among key decision-makers. Need for preparedness to change the traditional system of charging for irrigation water based on area (per hectare), which encourages uncontrolled and irrational use of water.	Current levels of investment in irrigation schemes in the Vardar Planning Region are not satisfactory. Charging of water is problematic due to the financial difficulties of Water Communities.
3. Development of criteria and identification and delineation of localities with specific climatic and soil characteristics for certain varieties (*terroir*)	Improved zoning of vine and table grapes as a prerequisite for improved quality of production and resistance to the negative impact of CC	Legislation/ Capacity-building	MAFWE, IAS, FASF, NHS	Short-term	200,000		This action is under the Strategic objective of MAFWE (Strategic goal 1.1.3.).

4. Establishment of facilities for processing bio residues	Collection and processing of bio residues from vineyards in a form suitable for further use as biofuels. This will lead to better use of bioenergy and reduced CO_2 emissions.	Capacity-building	MAFWE, MOEPP, local government	Short-term	1,000,000	Low interest of primary producers.	Need for increasing public awareness by local government, NVO's and the scientific community.
5. Establishment of early warning system (network of meteorological stations) for improved pest control and water use efficiency	Continuous monitoring of climatic conditions. Implementing models for the prediction of diseases and optimization of irrigation scheduling through monitoring of current evapotranspiration.	Capacity-building	MAFWE, NHS	Short-term	500,000		Need for increasing public awareness by local government, NGO's and scientific community.
6. Supporting research and innovation for development and spreading new production systems and measures	Development and introduction of new/ additional adaptation measures (pruning as a tool for sunburn protection, use of calcium carbonate, etc.)	Capacity building/ Policy	MAFWE, Ministry of Education and Science (MES). IAS, FASF1	Short/ Medium term	2,000,000	The budget and financial means for R&D have been reduced. The research network is not developed and lacks innovations.	Financial support for R&D is at minimum level and has a decreasing trend. Researchers lack financial support for innovative research. Most of the research is not in line with CC trends and expectations.
7. Implementation of new training systems, especially in table grape varieties (protection against sunburn), and integrated viticulture production (optimization of pest control and fertilizer use efficiency)	Decreased damage to table grape varieties from sunburns and increased market value of the produced grapes.	Capacity building/ Policy	MAFWE, IAS, FASF	Short /Medium-term	1,000, 000	Low interest among primary producers due to lack of awareness. The government doesn't adopt the regulation for professional occupation and the vocational training, qualification and skills demanded.	This action is under the Strategic objective of MAFWE (Strategic goal 1.1.3.).

8. Support the establishment of facilities and logistics for the production of certified seedlings and varieties more resistant to climatic stress.	Sufficient production of high quality planting material as a prerequisite for renewal of the existing areas under vineyards. Decreasing the risk of introducing quarantine diseases and low quality planting material.	Legislation Capacity-building	MAFWE, IAS, FASF	Medium-term	2,000,000	Lack of finance, lack of awareness of the importance of this measure among key decision-makers.	There is no system for certified planting material. This action is under the Strategic objective of MAFWE (Strategic goal 3.1.1.).
9. Establishment of phenological fields in each sub-region of the Vardar Planning Region and long-term financing programme.	Permanent monitoring of the plant development stages vis-à-vis climatological parameters. Detection of any shifting of development stages in time, aiming at more efficient plant protection planning and irrigation scheduling	Capacity-building	MAFWE, IAS, FASF	Medium-term	1,000,000	Lack of finance, Insufficient awareness among the key decision- makers, Low interest among primary producers.	
10. Financial support for the implementation of modern adaptation measures, e.g. UV nets.	Decreased damage to table grape varieties from sunburns and increased market value of the produced grapes.	Capacity-building/ Policy	MAFWE (IPARD-Component V, Measure 103 –Improvement and upgrading of the existing vineyards according to EU standards); MAFWE -Programme for financial support of the agricultural sector.	Medium / Long-term	15,000,000	A system for subsidizing of these types of investments has not yet been introduced by the Government The financial sources and lending instruments are not available for the farmers.	This action is under the Strategic objective of MAFWE (Strategic goal 1.3.1.).
11. Financial support for the implementation of methods and techniques for increasing water-use efficiency, e.g. pressurized irrigation systems, control systems for efficient irrigation scheduling, etc.	Increased water- use efficiency through the implementation of modern irrigation and controlling systems.	Capacity-building/ Policy	MAFWE (IPARD-Component V, Measure 103 –Improvement and upgrading of the existing vineyards according to EU standards); MAFWE -Programme for financial support of the agricultural sector.	Medium / Long-term	11,500,000	Farmers do not have access to water resources. No system for subsidizing these types of investments has yet been introduced by the Government. The financial sources and lending instruments are not available for farmers. Lack of finance, Insufficient awareness among the key decision-makers, Low interest and know-how among primary producers.	Despite the introduction of modern irrigation systems, irrigation water is still not efficiently used. This action is under the Strategic objective of MAFWE (Strategic goal 1.3.1.).

12. Long-term investments in reconstruction and extension of dams and irrigation schemes.	Increased availability of irrigation water and increased area under irrigation schemes.	Capacity-building/ Policy	MAFWE, Water communities, local government	Long-term	Lack of input for estimation. Each case needs a feasibility study with a detailed budget.	Lack of finance, lack of awareness of the importance of this measure among key decision-makers. Insufficient cooperation between the central and local government and farmers NGO's.	The present capacities and condition of water reservoirs and irrigation schemes will not be sufficient to satisfy the future increased needs for irrigation water due to CC. For this reason, a systematic renewal of water reservoirs and irrigation schemes in the region is crucial.
13. Financial support for the relocation of vineyards to higher altitudes and for producing more appropriate/resistant varieties to frosts.	Newly established vineyards located at higher altitudes. Decreased negative impact of late spring frosts on vineyards	Capacity-building / Policy	MAFWE (IPARD-Component V, Measure 101-Renewal of the existing vineyards according to EU standards) Local government	Long-term	11,000,000	Possible lack of appropriate areas at higher altitudes. Extension of the existing irrigation schemes and additional costs for pumping water at higher altitudes (pumping stations). Additional investments for land preparation and foundation of the vineyards. Increased production costs as a result of higher altitude and increased transport costs. Lack of capacity and preparedness of local government for the management, parcelization and foundation of arable land at hilly/ higher altitude zones.	According to the Draft Strategy of viticulture and wine (2010–2015), more than 5000 ha of vineyards are located in the risk zones of late spring frosts and cold spell during the winter.

14. Financial support for intensification of the process of establishing new vineyards (only 2% of vineyards are renewed every year), for improvement of the age structure of vineyards.	Improved age structure of vineyards in the Vardar Planning Region	Capacity-building/ Policy	MAFWE (IPARD-Component V, Measure 101-Renewal of existing vineyards according to EU standards); MAFWE - Programme for financial support of the agricultural sector	Long-term	21,000,000	Lack of finance. No system for subsidizing these types of investments has yet been introduced by the Government.	Approximately 60% of the vineyards are older than 15 years. This action is under the Strategic objective of MAFWE (Strategic goal 1.1.1.).

Abbreviations:

MAFWE – Ministry of Agriculture and Water Economy
IAS – Institute of Agriculture, Skopje
FASF – Faculty of Agricultural Sciences and Food
NHS – National Hydro-meteorological Service
WUA – Water User associations
MES – Ministry of Education and Science

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