

# SECTORAL REPORT IN AGRICULTURE AND FORESTRY

PREPARED FOR THE DEVELOPMENT OF THE FOURTH NATIONAL PLAN  
ON CLIMATE CHANGE



Факултет за земјоделски науки и храна -Скопје



Земјоделски Институт-Скопје



ФАКУЛТЕТ ЗА  
ШУМАРСКИ НАУКИ,  
ПЕЈЗАЖНА АРХИТЕКТУРА  
И ЕКОИНЖЕНЕРИНГ  
ХАНС ЕМ



Skopje, December 2021

# Climate change vulnerability and adaptation agriculture, forestry and land use

For the Macedonian 4<sup>th</sup> National Communication on Climate Change

Skopje, December, 2021

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## Definitions

### RCP scenarios (GHG emissions scenarios)

A RCP is a greenhouse gas concentration (not emissions) trajectory adopted by the International Panel on Climate Changes ([IPCC](#)). The RCPs – originally RCP2.6, RCP4.5, RCP6, and RCP8.5 – are labelled after a possible range of radiative forcing values in the year 2100 (2.6, 4.5, 6, and 8.5 W/m<sup>2</sup> respectively). These scenarios represent possible changes in the concentrations of greenhouse gases in the atmosphere in the period 2000 -2100 (Figure 2).

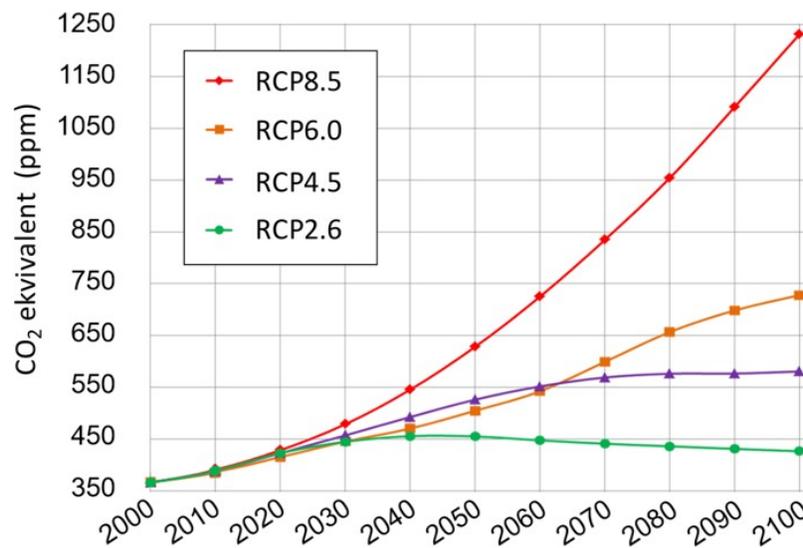


Figure 1. Future concentrations of greenhouse gases for four different scenarios (by Djurdjevic, 2020)

Scenarios RCP2.6 and RCP4.5 assume that, greenhouse gases concentrations will stabilize in the future, while under RCP6.0 and RCP8.5 scenarios, their concentrations will continue to increase, or follow trends observed in the past (Figure 2). Scenario RCP2.6 further assumes that, in the second half of this century, the concentration of greenhouse gases could will decline, requiring anthropogenic emissions to be net-zero at one point (van Vuuren et al. 2011).

### *Defining Agricultural Vulnerability to Climate Change*

Definitions of vulnerability with respect to climate change are quite varied (Polsky et al. 2007; IPCC 2012), though consensus has generally formed around the concept of “potential for loss” within a given system (Cutter et al. 2009). For this assessment, the IPCC’s 2015 definition has been adopted, which defines vulnerability as: “The propensity or predisposition to be adversely

affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt” (IPCC 2015).

IPCC (2015) further suggests that vulnerability can be characterized in two manners, as (1) “contextual, or current vulnerability” and (2) “outcome, or future vulnerability”. Current vulnerability is defined as: “A present inability to cope with external pressures or changes, such as changing climate conditions... a characteristic of social and ecological systems generated by multiple factors and processes” (IPCC 2015). Future vulnerability is defined as: “...the end point of a sequence of analyses beginning with projections of future emission trends, moving on to the development of climate scenarios, and concluding with biophysical impact studies and the identification of adaptive options. Any residual consequences that remain after adaptation has taken place define the levels of vulnerability” (IPCC 2015).

With respect to a managed system such as agriculture, the aforementioned definitions suggest that vulnerability can be thought of as being comprised of three categories of factors that influence the overall potential for impacts, or vulnerability (Figure 1):

- (1) The climate itself;
- (2) biophysical factors that influence how climatic conditions are translating into impacts; and
- (3) human, or management, factors that further mediate how climate influences agriculture, and abilities to adapt to changing conditions, including climate change and extreme weather.

As the climate changes and hazardous climate events and conditions occur in greater frequency, intensity and duration, the vulnerabilities in a given system can become more severe if sources of current vulnerability are not addressed. It is often recognized in climate change adaptation guidance that vulnerabilities can be addressed by increasing the adaptive capacity of a given system.

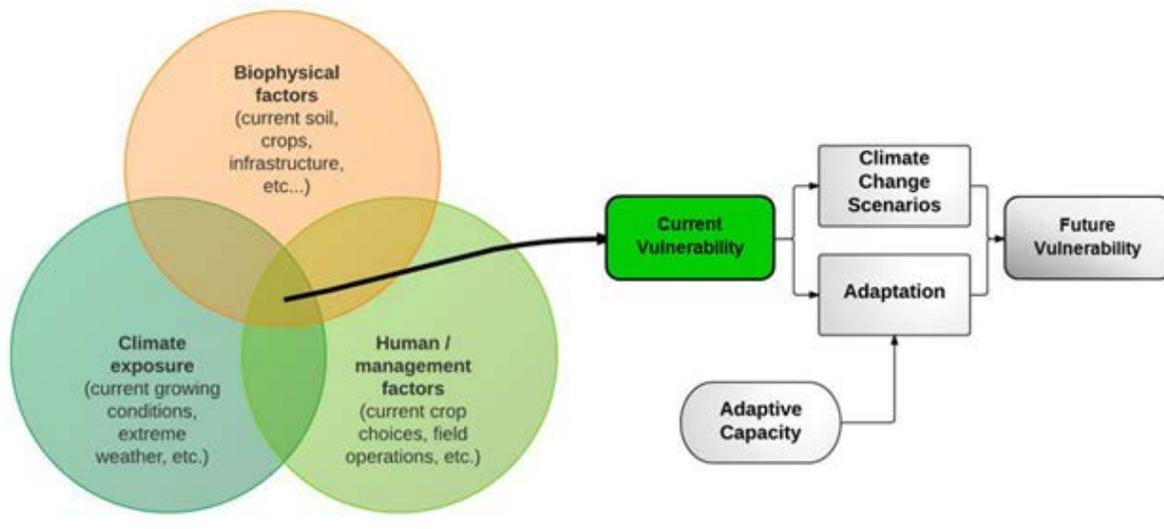


Figure 2.: Conceptual diagram illustrating the factors that contribute to current vulnerability, the role of adaptive capacity in influencing adaptation, in combination with climate change scenarios that ultimately influence future vulnerability for agricultural systems. (<https://climateconnections.ca/app/uploads/2012/03/Final-AgSystems-VA.pdf>)

Simplified Vulnerability explanation is presented on following figure.

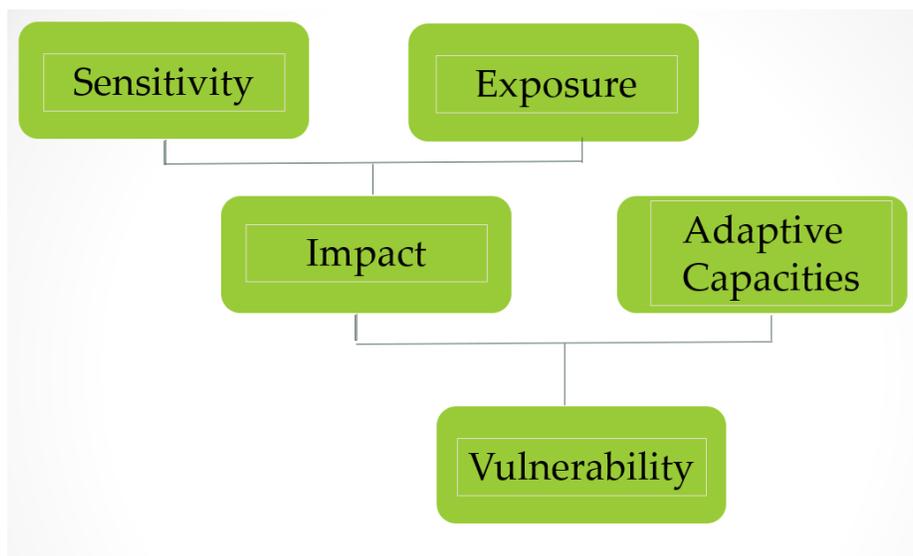


Figure 3. Simplified vulnerability graph

In general, agricultural vulnerability provides a useful theoretical framework, as it evaluates the possible susceptibility of crop yields, and assists in the appraisal of the trade-offs between climate-induced vulnerability of crop yields and farmer livelihoods [Berry et al., 2006]. Such an analysis aids the development of relevant adaptation strategies [Fellmann, 2012]. Different scholars identified a multitude of factors that influence agricultural vulnerability. In general, agricultural vulnerability is a variable condition generated by multiple environmental and social

processes, and would depend and differ on diverse contexts and circumstances [Berry et al., 2006]. A large body of literature is, however, based on climatic parameters (e.g., temperature, rainfall, precipitation), crops and agriculture production [Wu et al., 2017; Wilhelmi and Wilhite, 2002; Neset et al., 2019; Liang et al., 2019], while a smaller is based on other socio-economic factors, such as economic development, agricultural production, [Li et al., 2015], market prices, farmers welfare [Pathiraja et al., 2017], cultural settings: cumulatively all these elements affect the agricultural vulnerability, particularly in developing countries [Fischer et al., 1996].

### ***Adaptation of agricultural sector***

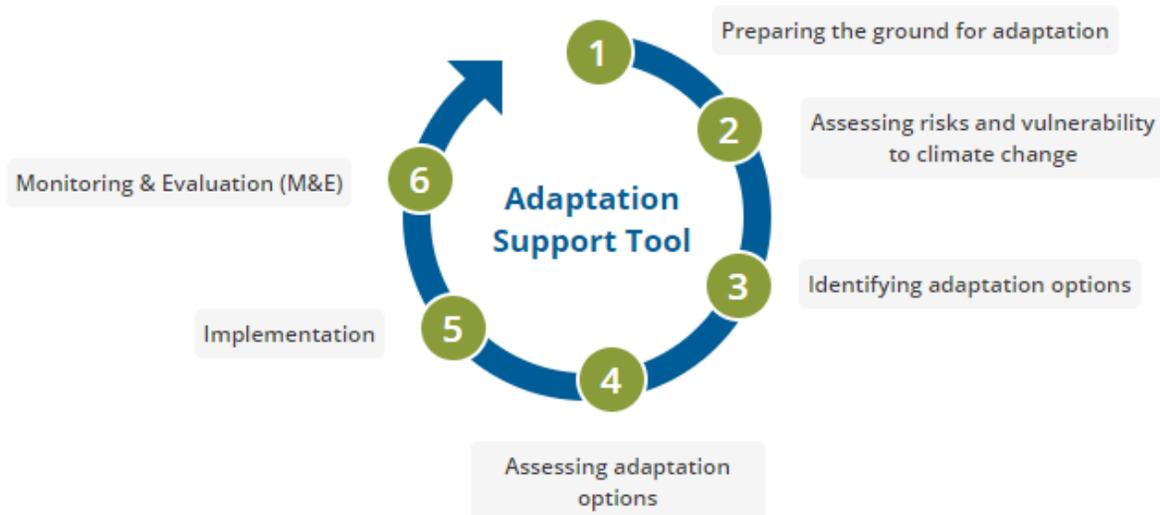
The European commission started their new strategic document entitled as Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change with the sentence “Climate change is happening today, so we have to build a more resilient tomorrow”.

The UNFCCC explain that adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change. In simple terms, countries and communities need to develop adaptation solution and implement action to respond to the impacts of climate change that are already happening, as well as prepare for future impacts. Therefore, adaption to climate change means taking action to prepare for and adjust to both the current effects of climate change and the predicted impacts in the future.

Adaptation to climate change is long-lasting and expensive process. Historically number of actions undertaken as positive considering existing knowledge bases in that time nowadays causes serious negative impacts. The simple example is using an organochloride insecticide (DDT) to fight malaria or in agriculture. Nevertheless, climate change is result of the industrialisation and increased use of fossil fuels. Therefore, actions that are not carefully analysed and assessed for their impact in much wider sense cannot be easily recommended, particularly not in agricultural sector that according FAO manage 37,6% of the land area of the World. Moreover, agriculture use 70% of the fresh water globally. Eventual errors in this sense can have serious consequences. The common understanding that farmers will simultaneously adopt to the climate change is potential risk that some actions can have negative impact on the very fragile natural resources as soil and freshwater are.

The EU portal for adaptation to climate change Climate ADAPT should serve as a major source of knowledge about adaptation. Their adaptation tool explains the whole process of adaptation in graphical form on the next figure. In agriculture this process can last with years, therefore the immediate star with building the capacities and knowledge base is required.

Figure 3. The climate change adaptation tool (from the portal Climate ADAPT)



Source: [AST Step 0 — Climate-ADAPT \(europa.eu\)](https://climate-adapt.europa.eu)

However, the tool is universal, but national circumstances are quite diverse, and each country, region, municipality and even smaller administrative units should start with activities for preparing the ground for adaptation.

## Status of implementation of the previous action plans related to climate change

The period after the development of the action plan for the agricultural sector within the TNC was characterized as quite intensive in term of achievements. The number of data gaps were filled, the digital soil map was published on the web page ([MASIS \(ukim.mk\)](http://MASIS.ukim.mk)), some agrometeorological services become public ([agrometeo.mk](http://agrometeo.mk)), the agro-ecological zoning was completed and made available for the public ([agroekologija.mk](http://agroekologija.mk)). These activities were conducted by MAFWE and supported by FAO. Moreover, USAID supported the project for Adaptation to climate change that was conducted by Rural Development network, and number of adaptation measures (more than 30) were tested with on farm experiment. Moreover, the last project was rising the public awareness about climate change in agriculture, with particular attention to youth (mainly addressing the high school in agriculture, but also number of other stakeholders from agricultural sector).

MAFWE developed the new strategy on agriculture and rural development (NSARD) for the period 2021-2027 and heavily increase the importance of climate change in the sector. The strategy defines the national policy objectives, types of policy interventions and measures for the development of agriculture and rural areas in the period 2021-2027. The strategic goal are:

- improving the competitiveness of the agri-food sector, economic sustainability and income of agricultural holdings,

- application of environmental practices in production that lead to mitigation and adaptation to climate change and
- ensuring sustainable development of rural areas.

Moreover, the strategy defines 9 specific goals. The second strategic goal clearly put climate change as one of the strategic priorities in the sector. There are 3 specific goals related to this strategic goal as follow:

- SG 4. Contributing to climate change mitigation and adaptation, as well as greater use of sustainable energy
- SG 5. Encouraging sustainable development and efficient management of natural resources such as water, soil and air
- SG 6. Contribute to the protection of biodiversity, improvement of ecosystem services and conservation of natural habitats and landscapes

The specific goal 4 (S4) define that climate change has a serious impact on Macedonian agriculture through reduced yields, the need for additional irrigation or drainage and increased incidence of atypical plant and animal diseases. In order to mitigate and adapt to climate change, practices that do not affect the climate will be stimulated by introducing them in cross-compliance requirements and with increased intensity of co-financing the necessary investments. The new IPARD program for the period 2021-2027 will provide an additionally higher percentage of public co-financing of investments aimed at mitigating and adapting to climate change. The projects to support the reduction of GHG emission will be represent with not less than 5% of the total number of projects financed through Measure 1 of the IPARD program (compared to 1.6% at the beginning of the period).

The negative impact of the climate change will be addressed through support for the procurement of protective equipment, efficient irrigation water uses systems, change of varieties appropriate to the future climate etc. Moreover, this goal defines that one of the main answers will be the realization of large investments in construction of the important irrigation and drainage infrastructure, for the rehabilitation of the existing and construction of new hydro systems for irrigation and drainage that should improve the regional availability of water during the irrigation periods, as well as flood protection. Moreover, the NSARD defines indicators and target values for the strategic period 2021-2027 for the total irrigated land and present value of 84 434 ha is targeted to more than 95 000 ha in year 2027.

The Rural development policy among other policies define Policies for natural resource management and mitigation of the impact of climate change. The high importance is paid to the water resource management and the long-term goal of investments in the water economy is to increase the irrigated area in the country to the level of installed capacity of 144,000 hectares and gradually expand the hydro systems to achieve the goal of irrigating the maximum possible irrigated area which is half of the arable

land, i.e. about 250,000 ha. These investments should have a direct impact on increasing yields and the physical volume of agricultural production and resilience to the impact of external climate risks.

Finally, all mitigation measures foreseen in the Third Biannual Update Report to UNFCCC are foreseen for the support by the system for support of agriculture. Also, number of adaptation measures already tested in the country will be supported. Therefore, MAFWE undertake the leadership in the agriculture and climate change issues, with respect to the all previous activities and planning documents, already completed number of important activities for alleviating issues frequently repeated previously as serious problems (particularly data gap). The present activities for improvement of the agro-meteorological services, designing of the number of climate smart agricultural practices with establishment of experimental and demonstration fields, preparation of the irrigation and drainage strategy and other will be completed soon, and further developed the knowledge and expertise in the sector thus reduce the adaptive deficit. Nevertheless, number of activities are pipelined that will further support reduction of the adaptive deficit (construction and rehabilitation of irrigation systems, increasing the awareness, building the capacities etc. MAFWE foreseen that progress will be achieved by implementing of the climate smart policies and using the available instruments for support of agriculture and others to boost implementation of the mitigation and adaptation activities.

The analyses of the implementation of the measures foreseen in the Adaptation plan prepared with the Third national plan for climate change show significant progress in some of the actions. However, in number of cases this progress is driven by external factors, external donor or just implemented as measures that was not treated as climate change adaptation. However, systematic approach in addressing climate change mitigation and adaptation by national institutions is essential tool for progress. The adaptation measures listed in the adaptation plan prepared with TNC and their realization is presented in table 1 of the Annex I. Here we will discuss only measures with some progress evidenced.

- The measure that foreseen the **establishing a national fund for testing of adaptive measures and introduction of drought resistant species** was not realized. However, the significant improvement in testing of adaptation measures was achieved by the USAID supported projects Adaptation to climate change. Number of adaptation measures (more than 30) were tested in the on-farm experiments and there is significant base of knowledge developed. As usually, all activities stopped with the project end.
- The measure that foreseen **subsidies for implementing adaptation measures for professional farmers** also has not any improvement compared with previous period. However, the National Strategy on Agriculture and Rural Development 2021-2027 foreseen support for adaptation and probably will started from year 2024.
- **Establishing of national network for long term monitoring of agro-climatic and agro-edaphic parameters as a prerequisite for efficient planning and implementation of the adaptive measures** is measure that was progressing during the period analyzed. The National hydrometeorological services established 3 agro-meteorological monitoring sites in Kocani, Strumica and Gradsko, by support of FAO project. The data is available on the web site [www.agometeo.mk](http://www.agometeo.mk).
- Significant achievement was achieved in realization of the measure for **development of criteria and identification of LUT and AEZ**. The Agroecological zones were developed with the support

of the FAO project. Moreover, the agro-ecological information system was developed. The data is available on <http://agroekologija.mk/>.

- The measure for establishment of 15-20 phenological fields and long-term financing was not realized. However, the National Hydrometeorological Service (UHMR) is running the network of phenological stations, but historical data is not readily available. Some data is available on [www.agrometeo.mk](http://www.agrometeo.mk).
- **Inclusion of climate change adaptation measures into rural development schemes** was not in focus during the period analyzed. However, the number of present measures in rural development can be associated to the climate change adaptation. Moreover, the NSARD for 2021-2027 foreseen intensification of the support for adaptation
- The measure for **increasing of the organic farming**, even though not treated as climate change adaptation measure achieved significant results. The area under organic production increased from 2280 to 3332 ha in the period from 2014 to 2019. For the same period, number of cattle in organic production increased by 136%, sheeps by 112%, goats by 83% and beehives for 47%.
- **Establishment of facilities for processing of bio residues for biofuels** was not considered as measure in agricultural sector. However the energy sector granted several concessions for using of biomass for electricity production and provide feeding tariff for the producers. Therefore, we can conclude that there is achievement in using the bio-residues for electricity production in Pelagonia and Polog Area.
- **Supporting the research and innovation for development and spreading the new production systems and measures.** Fund for Innovation supported several related activities, but no visible changes in the sector. The supported activities did not reach the end users because if products were developed, they were not properly promoted and never reach farmers. Moreover, the USAID support for the project of Adaptation of agriculture to climate change contributed significantly to this action. Nevertheless, the systematic support of these activities is required.
- **Financial support for implementation of modern adaptation measures e.g. UV nets, cover crops, sprinkler irrigation measure** is partially realized, The national program for support of agriculture supports the protective nets and drip irrigation.
- **Financial support for implementation of methods and techniques for increasing of water use efficiency, e.g. pressurized irrigation systems, control systems for efficient irrigation scheduling, etc.** Similar as previous, the investment in drip irrigation is supported, but not related to climate change. Moreover, there is not any progress in irrigation scheduling increasing of water use efficiency and water productivity etc.
- **Long term investments in reconstruction and extension of dams and irrigation schemes.** The measure was partially realized. The long-term support was not developed, but there is regular process of maintenance. Moreover, the Government realized the plan for support of irrigation, that will end in 2026 and number of activities are foreseen. Moreover, the several activities supported by international donors are in process of realization as rehabilitation of Irrigation in Southern Vardar Valley (KfW bank) and EU supported project (IPA) for construction of small irrigation systems
- **Financial support for intensification of the process of establishing of new vineyards (only 2% of vineyards are renewed every year),** for improvement of the age structure of vineyard. The

measure for support of the establishing the new vineyards is active for a longer period, but we cannot confirm that rate is higher than 2% annually.

## Status of Agriculture in Republic of North Macedonia

### *Current Situation of Agriculture*

**The agricultural sector in macroeconomic terms** in the past strategic period together with hunting, forestry and fishing has achieved a total increase in gross value added of 4.5%. The sector has a continuous annual increase in the value by 4.5% from 871.4 million euros in 2014 to 910.9 million in 2019, except in 2017 due to the impact of weather conditions. On the other hand, the relative share of the agricultural sector in the gross value added decreased from 10.2% to 8.1% due to the higher value added realized in the other more propulsive economic activities. Together with the processing industry (including beverages and tobacco), the share in the Gross Domestic Product (hereinafter GDP) reaches 12%, i.e. it is on the third place after the industry and services. Plant production dominates the value of agricultural production with an average share of 74.5% of the total value. The remaining 25.0% is livestock production, while a very small part (0.5%) is covered by agricultural services. Horticultural production with 38.35% has the largest share in the total value of agricultural production.

**Trade in agri-food product in the period 2014-2019**, the foreign trade exchange with agri-food products took place with a similar dynamic of development and within the previously established relations between exports and imports. Macedonian agricultural production and food industry recorded a continuous, gradual increase in competitiveness in foreign markets with an increase in the value of exports of agri-food products by 28%, from 486.2 million euros in 2014 to 624.5 million in 2019, while imports in the same period it increased by one percentage point more, from 649 million euros in 2014 to 837.2 in 2019. The most important partners for export (and import) of agricultural products are EU-28 countries and about half of the export and import of agricultural products is with these countries.

The average coverage of imports by exports for the period is 73% which results in an annual amount of negative trade balance of EUR 200 million. Primary agricultural products have on average 30 million euros of positive trade balance for the past period (300 million exports and 270 million imports). The most important export products are processed vegetable, tobacco, wine, lamb meat, while of the imported primary products, 23% are products for which the country does not have natural-climatic conditions for production. However, the country import chicken and beef meat, dairy products and number of other products the self-sufficiency is not achieved.

**Employment:** In terms of labor force, the share of the total active population employed in agriculture in 2019 is 13.9%. Out of a total of 111,033 people engaged in agriculture, 35%

(38,478) are unpaid family workers, 49% are self-employed and about 15% are full-time employees. About 17% (18,379) of the total agricultural workforce is employed on a part-time or seasonal basis. More than half of the total employees in agriculture are engaged in crop production, and the rest are engaged in mixed production and livestock breeding. Calculated through equivalent annual work units, the labor engaged in the agricultural holdings in the country is estimated at 151.5 thousand in 2018. 60% of them are paid equivalents, while the rest is the work of engaged members of family farming families, which again indicates the already established number of family farms.

One of the biggest problems in the country's agricultural sector is the aging workforce. According to the SSO structural survey from 2016, only 4% of agricultural holders are young under the age of 35 (or 7,254), 34% are between 35 and 54 (61,724) and the majority of 62% or 111,268 are older than 55 years.

**Food Security** as an issue is underreported and analyzed in national documents or in research/technical papers. However, some indications can be made based on available data from FAOSTAT. According to this source, the number of people undernourished (3-year average, period 2018-2020) is below 100 thousand and prevalence of undernourishment is 2.7%). However, there is significant improvement from three years average for 2000-2002 when the number of undernourished people was reported as 200 thousand, and prevalence was set to 7.5%. Number of moderately and severely food insecure people for the last reported 3 years average (2018-2020) is 300 thousand, an increase by 33% compared to previous reported period. For the same period prevalence of moderate and severe food insecurity rose from 14.4 to 17.3%. This data is based on FAO estimates and should be carefully elaborated for national circumstances, using the national data sources and knowledge. Moreover, FAO reported the average protein supply in g/day/capita and it is 82.7 g/day/capita and average dietary energy supply adequacy is 124% for the last 3 years average (2018-2020). Therefore, the food supply is adequate, but still there is some inequity in the distribution and access to food should be improved. Moreover, FAO reported that obesity is present in 22.4% of the adults in the country.

**Gender equity** in agricultural sector is presented by the National Statistical Office as Gender Statistic Indicators in the Republic of North Macedonia. The indicator used for presenting the gender equity is number of employed in the agricultural sector, and the last year presented is 2016. According this source total number of employees in the agricultural sector is slightly higher than 120 thousand persons, with only 44 738 women amounting to 37.2%, while men are participating with 62.8%. However, other statistics presented by the State Statistical Office (SSO) are gender sensitive and can be used for assessing the gender equity in the agricultural sector. The data from the last Farm Field Survey (2016) elaborate the number of engaged persons in the agricultural sector (household members and employees) and out of 441 929 totally engaged persons 187 156 are woman what is approximately 42.3%. Unfortunately, this indicator also shows that women are engaged in the sector with less rights (not all engaged enjoy same rights, therefore bigger percentage of men in the statistic of total engaged persons indicates that less

woman enjoy rights of employment in the sector), Moreover the State statistical office present decrease of woman in managing the farms, while in 2013 only 11% of the farms were managed by woman, in 2016 this percentage falls by 1%. Therefore, the assumption is that position of the woman in the agricultural sector will hardly improve in near future.

### ***Agricultural Land and Land use***

**In terms of land use** the territory of RN Macedonia is mostly mountainous (79%), and the rest are lowlands (19%) and natural lakes (2%). Agricultural land with 1.264 million ha (average for 2014-2020)<sup>20</sup> covers about half of the total area, while 44% is land under forests. About 59% of the agricultural land belongs to pastures and the rest with an area of 512 thousand hectares is cultivated land which is the basis for agricultural production. Most of the cultivated land or 80.6% (416 thousand ha) is occupied by arable land and gardens, perennial plantations - orchards and vineyards participate with about 7.8% (orchards 3.2% and vineyards 4.6%), and the remaining about 11.6% are meadows.

The property of the agricultural land is quite diverse. The majority of the pastures (more than 80%) are state owned and managed by the Public enterprise for pasture management. However, the majority of the arable land (60%) is private land and managed by small farm holders. State-owned agricultural land covers about 240 000 ha of arable land and about 570 000 hectares of pastures,

The arable land is categorized in eight classes according the quality. The first class, with best quality land cover only 15 375 ha or 2.24% of the total arable land. Second class is represented with 39 977 ha (5.82%); The third class covers 84 493 ha (12,28%). Therefore, only about 20% of the arable land is categorized in first 3 classes, and can be considered as fertile soil with good properties. The other classes are cover much higher part of the arable land (IV class 149 319 ha – 20.41%, V class 133 520 ha – 19.43%, VI class 118 156 ha – 17.19%, VII class 84 742 ha – 12.33%, VIII class 70 758 ha – 10.29%),

### ***Structure of agricultural sector***

Structure of agricultural holdings remains unfavorable and dual, consisting of a small number of large agricultural enterprises and a large, predominant number of very small family holdings with limited production capacity. Business entities, which are only 0.2% of the total number of agricultural holdings, have on average over 100 times larger engaged capacities per agricultural holding, i.e. 197 ha, in relation to the family holdings. According to the latest structural survey from 2016, 60.8% of agricultural holdings used less than 1 ha of agricultural land, while as much as 88% less than 3 hectares. Although the average land area and number of livestock units per agricultural holding has increased from 1.4 ha with 2.12 livestock units in 2007 to 1.8 ha in and 2.14 ha livestock units in 2016, structural changes are still taking place with insufficient

dynamics to ensure a more serious impact on the overall performance and competitiveness of the sector.

Additionally, small properties are on average fragmented into over five spatially spaced plots, with an average size of 0.24 ha on private land. Such a structure results in limited production results and, consequently, the abandonment of agricultural land, which reaches over one third of the total arable land.

The small and fragmented structure of the agriculture holdings has significant influence in establishing sustainable and efficient water use. Furthermore, the land-water nexus is inextricably tied to the implementation of modern technologies for water conservation and burdens the revitalization and investment in new irrigation and drainage systems with additional costs.

The most important crops by area sown are cereals with about 158 thousand hectares in 2019. The most important cereal crop is wheat (predominately winter wheat) with about 69 thousand hectares, followed by barley with 44 thousand hectares and maize with 34 thousand hectares. Rice is cultivated on 3481 ha. Moreover, the SSO reported the Rye and Oats with slightly above 3.5 thousand hectares. The most important industrial crop is Tobacco with 15 719 ha of sown area in 2019. The sunflower sown area is 4677 ha in same year. The other industrial crops are not reported by SSO. Alfalfa with 19,7 thousand hectares is the most important forage crop, followed by fodder maize on 8.4 thousand hectares and clover on almost 4 thousand hectares. Potatoes are sown on 12 496 ha, that makes them the most represented vegetable crop in the country. Other vegetables with significant area in the country are peppers on 9,4 thousand hectares, tomatoes on 5,5 thousand hectares, melons and water melons on 5,1 thousand hectares, cabbage on 4.6 thousand hectares and onion on 3,6 thousand hectares. Pulses are represented on 5,7 thousand hectares, and beans are the most important one with 4,5 thousand hectares. Fruit production is predominated by apples with close to 4,9 million trees in 2019, followed by plums (1,7 million trees), Sour Cherries (1,1 million trees and peaches (0,6 million trees). Viticulture is quite important activity in agricultural sector, the total number of vines is 88520 in 2019, and harvested area is 24 thousand hectares. The wine grape predominates over the table grapes.

The livestock production is with smaller scale compared to crop production, but very important in national agriculture. The number of cattle is about 218 thousand, pigs 136 thousand, Shipp 685 thousand goats 88 thousand, horses 9 thousand and poultry 1.562 million. Moreover, the number of bee-hives is 96 thousand.

### ***Challenges of Agricultural Sector***

There are number of challenges associated to agriculture. The small farm size, small economic size of the agricultural holdings, ageing of the population, depopulation of the rural areas,

unfavorable environmental condition (low fertile soil, dryness, water limited agriculture...), low level of education, very low level of operators with any form of education in agriculture, low level of know-how, weak competitiveness of the farms and the sector as a whole, etc. The climate change induced decrease of the productivity that combined with low adaptive capacities make sector more vulnerable and less competitive.

### ***Economic size of the agricultural holdings***

The economic size is used to characterize the agricultural holdings according the income from agricultural activities. There are 13 classes as presented in following table.

Table 1. Economic classes of agricultural holdings and limits of the income in EUR

Class	Limit in EUR	Class	Limit in EUR
<b>I</b>	up to 1 999	VIII	from 100 000 to 249 999
<b>II</b>	from 2 000 to 3 999	IX	from 250 000 to 499 999
<b>III</b>	from 4 000 to 7 999	X	from 500 000 to 749 999
<b>IV</b>	from 8 000 to 14 999	XI	from 750 000 to 999 999
<b>V</b>	from 15 000 to 24 999	XII	from 1 000 000 to 1 499 999
<b>VI</b>	from 25 000 to 49 999	XIII	from 1 500 000 to 2 999 999
<b>VII</b>	from 50 000 to 99 999	XIV	over 3 000 000

The distribution of the classes in North Macedonia is presented in following table. Moreover, the table presents some structural characteristics addressing the physical size of the holdings,

Table 2. Farms distribution by economic classes in North Macedonia

	<b>Total</b>	<b>I class</b>	<b>II class</b>	<b>III class</b>	<b>IV class</b>	<b>V class</b>	<b>VI class</b>	<b>VII-XIV class</b>
Number of holdings	<b>178125</b>	<b>89398</b>	<b>34754</b>	<b>29116</b>	<b>15046</b>	<b>5000</b>	<b>2830</b>	<b>751</b>
Value of the production in 1000 MKD	50756496	4885279	6173557	10022745	9999974	5724200	5692388	8258352
Area in ha	320738	47463	41445	58590	53992	28289	25933	64384
Total engaged workers (with family members)	441829	192429	87008	80030	47233	16545	10051	6174

Number of Livestock Units	381361	28229	37220	61985	78916	55305	65500	53554
Average farm size in ha	1.8	0.5	1.2	2	3.6	5.7	9.2	85.7
Average number of livestock units by farm	2.1	0.3	1.1	2.1	5.2	11.1	23.1	71.3
Average value of production by farm (1000 MKD)	284.9	54.6	177.6	344.2	664.6	1144.8	2011.8	10994.3
Average value of the production by ha (1000 MKD)	158.2	102.9	149	171.1	185.2	202.3	219.5	128.3

Source: Source: State Statistical Office: MAKSTAT, Agricultural Statistic

Majority of the farms (50.2%) are classified in the first class with economic size of less than 2000 EUR, however these farms contribute only with 9,6% in the total value of agricultural production. About 86% of the farms are classified in the first 3 class, and they contribute with 41.5 of the total value of the agricultural production. These farms are also physically small with maximal average size of 2ha for 3 class, and only 0,5ha for the first class. Such a small farms with low economic power, hardly survive and can not invest in the adaptive capacities building or in mitigation or adaptation measures. Nevertheless, these farms manage 46% of the utilized agricultural land, 33,4% of the livestock units and engage 81,6% of the work force in agriculture. Their vulnerability to the climate change is much higher compared to the larger scale farms, thus need higher support to become more adaptive to the climate change.

Moreover, the representatives of the farmers during the consultation workshop ephasised the lac of finances for investment in some modernization as one of the major obstacles related to climate change vulnerability and adaptation.

### ***Depopulation of rural areas and ageing of population***

The depopulation of the rural areas is one of the processes that heavily affect the agricultural sector. The process is long lasting, and become more prominent in the last period. The State statistical office reports migrations from villages to the cities and for the period 2014-2020 about 1564 people annually move from rural areas to the cities. Having in mind that number of municipalities in rural areas are very small (29 municipalities below 10 thousand inhabitatnts, 16 municipalities below 5000 inhabitants) this migration is significant and in sme cases heavily affect the rural areas.

Moreover, the process of aging of the population in the country is evident. The following table compare population age structure in 1991 with 2020.

Table 3. Age structure by classes for North Macedonia years 1991 and 2000

Year	Unit	Total	0-14 years	15-64 years	over 65 years
1991	Number	2033964	487952	1380296	165716
	Percent	100	24.0	67.9	8.1
2020	Number	2068808	333373	1430196	305239
	Percent	100	16.1	69.1	14.8

Source: State Statistical Office: MAKSTAT, population statistics

Number of children aged 0-14 decreased from 488 thousand to 333 thousand, or by more than 160 thousand persons (32%). In same time the population over 65 years increased by 84% (about 149 thousand). This process is more prominent in the rural areas and in number of cases there are inhabited places with no children or no young population.

The migrations and aging reduce the work force availability in rural areas, particularly skilled work force. The MAFWE is increasing support for the young farmers and number of measures are targeted to keep young population in rural areas. However, the interest is not sufficient, due to the number of reasons associated with the human welfare in rural areas (infrastructure, quality of life, quality of schools etc.)

Above mentioned processes of migration and ageing reduces the adaptive capacities, increase vulnerability of the agricultural sector, and seem that this process will keep in the future.

### ***Level of education in agricultural sector***

The level of education in the agricultural sector is very low

Table 4. Education of the people engaged in agricultural sector in 2016

	No education	Non-completed primary	Primary	Secondary in Agriculture	Other Secondary	Applied High education in Agriculture	Other applied high education	Bachelor in Agriculture	Another bachelor	Master, Doctorate in Agriculture	Other Master, Doctorate	Total
<b>Number</b>	10389	35735	152093	17549	187636	1017	7531	2770	23659	715	627	439721
<b>%</b>	2.4	8.1	34.6	4.0	42.7	0.2	1.7	0.6	5.4	0.2	0.1	100

Source: State Statistical office: Farms field survey, 2016

About 45% of the persons engaged in Agriculture are without education (2.4%), with non-completed primary education (8.1%) and with completed primary education (34.6%). About 46,7% have completed secondary education, but only 4% are with secondary education in agriculture. Only 0,6% are agricultural engineers and 0,2% have completed post-graduate education in agriculture. Including the 0,2 % of engaged persons that completed the applied high education in agriculture, only 5% of the engaged persons do have some formal education in agriculture (vocational, applied high education and university degree). The waste majority do not have any form of education in agriculture and probably applied local or inherited knowledge on agricultural activities. These practices are not sustainable and creates huge gap between situation in the sector and what modern and sustainable agriculture is.

The low level of education clearly reduces adaptative capacities to climate change and minimize chances for changing the situation in the sector just with technical measures. The first step has to be increasing the level ow knowledge and know-how and increase readiness to change practices among the workers engaged in agricultural sector. The process of capacity building should cover more than 400 thousand people. After the knowledge level will increase it will be easier to implement technical measures and sector will be ready for moving forward.

### ***Low interest for education***

There are nine higher education institutions in field of agricultural sciences, located in Skopje, Bitola, Shtip, Tetovo and Ohrid. The number of students is presented in following table.

Table 5. Number of students in Agricultural Sciences

School year	2014/15	2015/16	2016/17	2017/18	2018/19
Number	2118	1952	2275	1792	1496
percent	100	92.2	107.4	84.6	70.6

The results presented in the table, clearly show trend of decreasing interest for studying agricultural sciences and drop on the number of students by almost 30% in just 5-years period is almost alarming. The one of the reasons is lack of employment opportunities. Agricultural sector is not interested to employ experts, or if they are employing salaries offered are very low. The expertise in agricultural sector is not regulated, who ever want can do agricultural activities. Doing business that manage more than 50% of the country land territory, more than 60% of water used and is responsible for the welfare of the several hundreds of thousand animals without proper expertise is more than risky. Low expertise can jeopardize food security and food safety in the country, human health and welfare and can create severe environmental problems with deterioration of the land and water resources. Therefore, expertise in the agricultural sector

should be promoted and supported by changing of legal instruments and creating measures for support of the employment of agricultural experts and increasing knowledge.

### *Climate and climate change*

The well-known fact that temperature rise as result of GHG emission is associated with increased heat accumulation into the oceans and in to the terrestrial system. Due to increased energy accumulated into the whole system particularly oceans and atmosphere, the system became more dynamic, and some other effects are expected as increased evaporation, changes in the rainfalls by amount and their distribution by time and space, more frequent appearance of the extreme weather events as heath waves, drought spells, floods, changes in appearance of the frost in late spring and/or early autumn, and many other changes in the weather and responses to the agricultural crops and livestock sector to these changes .

Most of the agricultural activities are taking place in open fields, therefore agriculture is heavily exposed to above mentioned changes. That is one of the reasons why agriculture is considered as one of the most vulnerable sectors. However, there number of factors that make agriculture more vulnerable than other economic sectors, as low education of the agricultural producers, lower development of the economy in the rural areas, depopulation of the rural areas, aging of rural population, lower access to the finances etc.

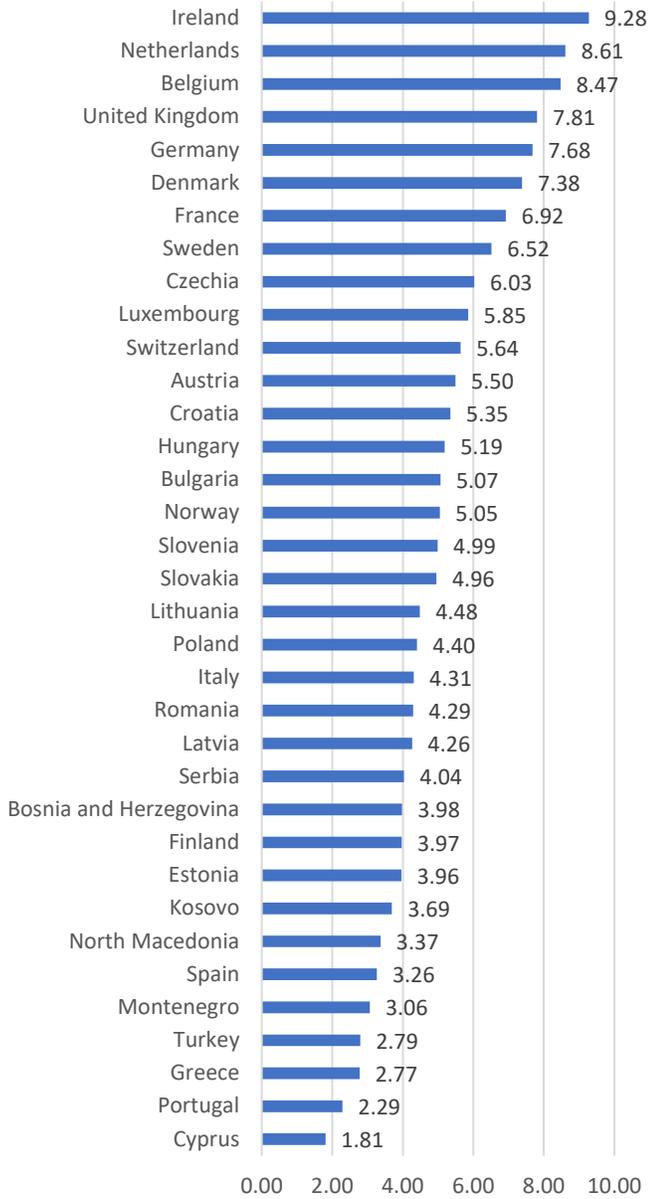
The National strategy on agriculture and rural development (NSARD) pointed out that the negative effects of climate change are expected to have a greater impact on agriculture than any other sector in the country, significantly reducing the yields of most crops. The analysis of the different climate change scenarios for the country shows that the average annual temperature will increase by 1.0 ° C by 2025 and 1.9 ° C by 2050, while the average rainfall is projected to decrease by 3% and 5% in the same time periods, which means a significant increase in dryness. This risk is further intensified by the relatively low productivity and lack of adjustable capacity also known as the "adaptation deficit" due to a number of structural factors.

The North Macedonian agriculture is limited by water and irrigation practices are applied by centuries. The World Bank report “Reducing the vulnerability of FYR Macedonia's agricultural systems to climate change” pointed out very low crop productivity in present climate with crop yields among lowest in Europe. The maize yield (usually irrigated crop in the country with C4 photosynthetic path, more tolerant to increased temperatures), and wheat (C3 crop, with higher sensitivity to heath stress) are by far lower than yields in most of the EU countries. North Macedonia average yield for the period 2014-2019, reported by Eurostat is 4.50 t/ha for maize and 3.37 t/ha for winter wheat. Moreover, these yields are ranked at position 28 out of 30 reported European countries for maize and 29 of 35 reported countries for winter wheat (Figure 1 and Figure 2). There are number of reasons for low level of adaptive capacities in the country, but these are mostly associated with low level of know-how, the research in agriculture is almost not existing, less than 5% of the employee in agricultural sector do have some education in agriculture etc.

Figure 4. Average yield of wheat in European countries in t/ha period 2014-2019

Figure 5. Average Yield of Maize in European countries in t/ha period 2014-2019

Average Yield of Wheat for 2014-2019 in European Countries in t/ha (Eurostat)



Average Yield of Maize for 2014-2019 in European Countries in t/ha (Eurostat)



The new research on CC effects in agricultural sector conducted for the 3 different Representative Concentration Pathways (RCPs) will strongly affect agricultural production whatever pathway will take place in the future. The expected temperature rise by the end of the century will be 1.5 °C for RCP 2.6, 2.5°C for RCP 4.5 and even 5.0 °C for RCP 8.5 (calculations over whole territory of the country).

Moreover, in same period, rainfalls will remain at the same level in case of RCP 2.6, but there will be significant decrease in other two RCPs by -20% (RCP4.5) and by -30% for RCP8.5. The summer rainfalls by the end of the century will decrease for -30% (RCP4.5) and -40% (RCP8.5). Therefore, North Macedonia will face hotter and dryer climate in the future, and amplitude of the change will be primarily related to the future concentration of GHG.

Moreover, crop will require more water for their normal growth, and Irrigation water requirement (IWR) will be even more pronounced by increased crop water requirement (CWR) and reduced rainfalls as major source of water for crop growth. The potential evapotranspiration (ETP) will increase even by more than 100 mm by the mid of the century.

The climate change will bring increased drought, longer drought periods and additional yield reduction caused by heat and drought stress. Moreover, the extreme weather events will be more frequent and the additionally reduction in the crop productivity is expected (by frost damages, hail damages, water logging and flood damages etc.). The risk of the movement of the crop/livestock pests and diseases northward will further complicate situation and increase need for the increasing the level of knowledge and know-how in the sector and accelerate the need for real time data driven decision making on the farm level.

The climate change will have strong adverse effect on agricultural sector, if no adaptation practices will take place. Number of national reports, policy documents and research point out that irrigation is considered as best available option for adaptation achieving the significant yield increase compared to “business as usual” scenario. However, irrigation is related to water availability and designing this measure the hydrological study for water availability in future climate is required. Moreover, there are significant opportunities to achieve significant water saving in agricultural sector and to maintain irrigation water available for all crops (reduce losses, increase water productivity etc.)

North Macedonian agriculture is limited by water and irrigation practices are applied by centuries. The problem is that agriculture in the country is not enough adapted even in present climate, therefore problems in future climate will be even alleviated. The World bank report entitled as “Reducing the vulnerability of FYR Macedonia's agricultural systems to climate change” pointed out many problems associated to the agricultural production in future climate. However, one of the most important problems is lack of adaptation deficit, explained that crop yields are among lowest in Europe. The following graphs compared yield of maize (as usually irrigated crop with C4 photosynthetic path, more tolerant to increased temperatures, and wheat, as C3 crop, with higher sensitivity to heat stress. Even though usual practices in the country are to irrigate maize and growing wheat in rainfed conditions in both cases the achieved yield is among the lowest in Europe. (Figure 1 and Figure 2)

However, not many improvements in building the adaptive capacities in the agricultural sector are noticed and yields are still among the lowest in Europe. The problem is mainly associated with know-how, the research in agriculture is almost not existing, more than 95% of the employee in agricultural sector do have some education in agriculture and many other factors create this extremely unfavorable situation.

## *Institutional and legal setup*

**The Ministry of Environment and Physical Planning (MoEPP)** is responsible for the environment protection including water, soil, biodiversity (in a broad sense) and climate change in the Republic of North Macedonia. It is responsible for the obligations taken from the conventions as: Convention on Biological Diversity, Cartagena Protocol on Biosafety to the Convention on Biological Diversity, Convention for the protection of the World's Cultural and Natural Heritage, Convention on International Trade in Endangered Species of Wild Fauna and Flora, European Landscape Convention, United Nations Framework Convention on Climate Change, Kyoto Protocol to the United Nations Framework Convention on Climate Change; United Nations Convention to Combat Desertification in Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa, International Convention on Plants Protection, International Treaty on Plant Genetic Resources for Food and Agriculture. Structural organization of the ministry is by departments. Climate change is within Department of Environment. Department for water is separate one that have significant importance for climate change adaptation in agriculture, because the agricultural production is water limited one. All activities of the Ministry are regulated with numerous Laws but related to agri-environment measures are laws for: water, nature protection, waste management, quality of ambient air and chemicals. In particular, many aspects for environment protection are requested implementation of agri-environmental measures including the mitigation of climate change measures, while issues related to agrobiodiversity protection and climate change adaptation are completely under Ministry of Agriculture Forestry and Water Economy.

**Ministry of Agriculture Forestry and Water Economy (MAFWE)** is directly responsible for agri-environmental measures implementation. This institution has a complex structure with 19 sectors and 62 divisions, out of which sectors associated to climate change are: Sector for agriculture; Sector of grapevine, wine and fruit production; Sector for livestock, Sector for analyzes of agricultural policy; Sector for marketing and quality of agricultural products and Sector for rural development. There are also other affiliated institutions related to agri-environmental and climate change measures as: Water Economy Directorate, Phyto-sanitary Directorate, Directorate for Seed and Seedlings (DSS), Agency for Food and Veterinary and State Inspectorate for Agriculture. MAFWE is responsible for sustainable preservation of forests, pastures, water and land used in agriculture, and agrobiodiversity protection. The Government of the Republic of N. Macedonia administers the agriculture, forests and forest lands in state ownership through the institutions presented below.

Agency for Financial Support in Agriculture and Rural Development (AFSARD)  
<http://www.ipardpa.gov.mk/>

The Agency for Financial Support in Agriculture and Rural Development is established by Law on Establishing an Agency for Financial Support in Agriculture and Rural Development in 2007. The purpose of AFSARD is successful implementation of the measures under agriculture policy and rural development policy in the Republic of North Macedonia. Hence, it provides efficient management of the funds under the both the Budget of Republic of Macedonia and the EU pre-accession assistance for rural development.

The competences of the Agency are the following:

- implementation of the measures for direct payment in agriculture;
- interventions in the agriculture products market;
- implementation of the production quotas;
- implementation of the rural development measures;

- implementation of the EU funds from the pre-accession assistance for rural development;
- implementation of the agriculture measures funded under the government assistance.

#### Activities of the Agency:

- receiving, recording and processing of applications for financial support;
- authorization of funds payment;
- organization of financial and accounting activities;
- internal audit;
- organization, implementation and coordination of the administrative and technical controls and on-the-spot controls;
- data collecting and processing;
- keeping databases and registers;
- preparation of reports and analyses.

#### **The Agency for Promotion of Agricultural Development (APAD)** <https://agencija.gov.mk/>

APAD was established by the Law on Establishment of the Agency for Promotion of Agricultural Development (Official Gazette of RM no. 3/98 of 22.01.1998). APAD aims to enable the transfer of knowledge and information, as well as their implementation in the agricultural holdings in order to improve the quality and quantity of agricultural production with economic justification, competitiveness of Macedonian markets in the EU and beyond, sustainable development of agriculture in rural areas, as well as support in the development and implementation of agrarian policy. APAD operates on the entire territory of the Republic of Macedonia, in 30 cities, grouped in eight regions with Headquarters in Bitola and 44 dispersed offices in rural areas.

#### **State inspectorate for Agriculture** <https://diz.gov.mk>

Until December 2013, the State Agriculture Inspectorate was a body within the Ministry of Agriculture, Forestry and Water Economy competent for the adoption of the Law on State Agriculture Inspectorate and bylaws arising therefrom. In December 2013, with the adoption of the Law Amending the Law on the State Agriculture Inspectorate (Official Gazette of the Republic of Macedonia No. 164/2013), the State Agriculture Inspectorate got the capacity of a legal entity. Their responsibility is inspection and supervision in the area of agriculture, rural development, fishery and aquaculture and enforcement of the legal setup in agricultural sector.

#### **State Inspectorate of Forestry and Hunting and State inspectorate for Agriculture**

<https://diz.gov.mk> as a body within the MAFWE, controls and supervises the enforcement of the Law on Forests, the Law on Hunting. and all other laws and legally binding acts in the field of agriculture, forestry and hunting. The Forestry Police, as a sector within the MAFWE, protects the forests in accordance with the Law on Forests.

#### **Public Enterprise National Forests (PENF)** [www.mkdsumi.com.mk](http://www.mkdsumi.com.mk)

The public enterprise for managing state forests was founded on the basis of Government Decision No. 3028/1 of December 15, 1997 (Official Gazette of FYRM No. 65/97). It began operations on July 1, 1998, as the legal successor to the former enterprises for forest management. In accordance with Article 7 of the Law on Forests, its core activities are: silviculture, protection and utilization of forests through the restoration, nurture, protection, afforestation and utilization of forests and forest land, and other activities for the maintenance

and improvement of forest functions.

**Public enterprise for pasture management** <http://jppasista.mk>

The Government of the Republic of Macedonia established the Public Enterprise for Pasture Management with mandate to manage state-owned pastures. The Public enterprise for pasture management operates state-owned pastures by preserving its area and increasing their value, to ensure a large growth of grass according to natural conditions. According their web site there are according their web site there are 3 subsidiaries in Tetovo, Gostivar and Bitola.

**Joint Stock Company Water Economy of Republic of North Macedonia (JSCWE)**  
<https://www.vodostopanstvo.mk>

JSCWE in state ownership was founded in accordance with the Law on Water Economy on 28 October 2015. The JSCWE uses, maintains, and manages the systems for irrigation and drainage as a whole including:

- Water supply for irrigation;
- Water supply to a communal water supply company for human consumption (drinking water and other needs);
- Water supply for industrial and technological (commercial) needs, including the production of electricity;
- Regulation of river beds;
- Drainage of land and withdrawal of discharged water.

In accordance with the Law on Waters, the JSCWE is responsible to ensure efficient operation of the system, to protect or provide security to the facilities belonging to the system, and to perform prevention and protection against floods, (with funds from the programs of the MEPP).

- builds and maintains facilities for protection and flood protection;
- builds and maintains facilities for preventing and protecting against erosion;
- builds and maintains objects for arranging rivers and vices; and
- performs other activities according to law.

JSCWE has its headquarters in Skopje, and twelve branch offices/subsidiaries responsible for performing water management activities in certain geographical areas, as presented below:

1. Subsidiary Radovishko Pole - Radovish
2. Subsidiary Crn Drim - Ohrid
3. Subsidiary Bregalnica - Kochani
4. Subsidiary Prilepsko Pole - Prilep
5. Subsidiary Tikvesh - Kavadarci
6. Subsidiary Kumanovsko-Lipkovsko Pole - Kumanovo
7. Subsidiary South Vardar - Gevgelija
8. Subsidiary Bitolsko Pole - Bitola
9. Subsidiary Polog - Gostivar
10. Subsidiary Berovo - Berovo
11. Subsidiary Strumichko Pole - Strumica
12. Subsidiary Skopsko Pole - Skopje

Furthermore, the following three Public Enterprises operate in the water economy sector outside the remits of the JSCWE:

1. Public Enterprise Strezhevo – Bitola,

2. Public Enterprise Hydrosystem Zletovica – Probishtip and
3. Public Enterprise Water Economy Lisiche – Veles

### **Faculty of Agricultural Sciences and Food** <http://www.fznh.ukim.edu.mk>

Faculty of Agricultural Sciences and Food was founded December 16, 1947 and is one of the founders of the University “Ss. Cyril and Methodius” in Skopje. During its long-lasting tradition, the Faculty has achieved fruitful educational, scientific and applied results, as well as active cooperation with domestic and foreign institutions in the related field. With regards to the academic staff, personnel, and equipment, the faculty is leading institution in the area of agriculture and food in Republic of Macedonia. Faculty imperative is to create academic profile capable of response to the needs of the contemporary agricultural production. There is 9 undergraduate study programs and 8 master study programs with number of options. Moreover, there are 6 doctoral study programs. The study programs cover, crop sciences, horticulture, agricultural economy, environmentally friendly agriculture, agricultural machinery, food technology and food quality and safety.

### **Hans Em faculty of Forest Sciences, Landscape Architecture and Environmental Engineering** [www.sf.ukim.edu.mk](http://www.sf.ukim.edu.mk)

Hans Em faculty of Forest Sciences, Landscape Architecture and Environmental Engineering in Skopje was established in 1947. Today, the faculty offers three undergraduate academic programs, 10 postgraduate academic programs, and doctoral studies with a tutoring system. The main mission of the faculty is education and the establishment of a highly educated and scientific staff in the field of forestry, landscape design, eco-engineering and eco-management.

### **Institute of Agriculture**

Is research institute associated to the Ss Cyril and Methodius University and offers education on master and doctoral level (postgraduate studies). Their role is to contribute to the development of the scientific base for advances of agricultural sector as whole.

### **National parks**

There are three legally established national parks in the Republic of N. Macedonia.

- Pelister National Park (<http://www.park-pelister.com/>) was established on November 30, 1948, mainly in order to protect the well-preserved forest of the endemic five-needle pine *Pinus peuce* (known as the Macedonian pine, or Molika). Today, the park covers an area of about 17,150 ha.
- Mavrovo National Park ([www.npmavrovo.org.mk](http://www.npmavrovo.org.mk)), which covers an area of 11,750 ha, was declared in 1949. In 1952 it was enlarged to its present size of 73,100 ha. Around 27,000 ha of the total area are forests. It is thought to comprise more than 1,000 types of higher plant forms, around 100 of which are extremely rare in the Balkans.
- Galichica National Park ([www.galichica.org.mk](http://www.galichica.org.mk)) is situated between Lake Ohrid and Lake Prespa and covers an area of 22,750 ha. It was declared in 1958. Nineteen different forest communities have been discovered on its territory, indicating that the vegetation in the park is very rich, including several extremely rare types of flora.

### **PEM MPA „Jasen“** [www.jasen.com.mk](http://www.jasen.com.mk)

The Jasen forest reserve was declared in 1958. It covers an area of 24,000 ha and stretches across the mountain massifs of Suva Gora, Suva Planina and Karadzica. This reserve falls into

the category of special nature reserve, protecting many species of flora and fauna and other natural rarities.

**Private forest owners** [www.naps.com.mk](http://www.naps.com.mk)

The National Society of Private Forest Owners (Nacionalno Zdruzenie na Sopstvenici na Privatni Sumi) was founded in 1997, although its current name was only adopted in 2010 (Official Gazette of FYRM No. 52 of April 16, 2010). It is a non-governmental and non-political organization, the main mission of which is the “protection of the individual and common interests of private forest owners without affecting the principles of sustainable forest management”. The society currently has a membership of around 1,500.

**The legal framework in agricultural sector** is set by Laws as: Law of agriculture and rural development, Law on quality of agricultural products, Law on agriculture and rural development, Law for plant health, Law on seeds and seedlings, Law on breeders rights, Law on livestock production, Law on pastures, Law on organic agricultural production, Law on quality of agricultural products, Law on agricultural land, Law on state agricultural inspectorate, Law for products in plant protection, Law for fertilizers, Law for water economy. Some of them are very general and not related to agri-environmental measures but other contained specialized chapters for them.

**The Law of agriculture and rural development** defines and gives a legal ground for implementing of the 5 main goals of the national agricultural policy, among which are: sustainable development of rural areas and optimal use of natural resources while respecting the principles for the protection of nature and environment. This Law defines all organizational forms for implementing of rural policy, like: Council for agriculture and rural development, Inter - ministerial group for rural development and the National Rural Network as a platform for establishing of partnership among the key stakeholders from rural areas in the process of planning and monitoring and implementing of the National program for rural development. In terms of rural development policy, this Law contains an detailed provisions and criterions for realization and implementation of the main priorities of rural development, like: a) increasing of the competition of the agricultural sector, b) protection and improvement of the environment and rural areas, c) improving the quality of life in rural areas and encouraging diversification of economic activities to increase employment opportunities in rural areas and d) encouraging local development of rural areas.

Financial support for achieving of the rural development priorities is defined in article 92 of the Law and is distributed as: a) non-refundable financial support for investments b) financial aid and c) direct payments to rural development. The non-refundable financial support can be used for non-material investments in a line with the national Program for agriculture and rural development, Direct payments are used to support the income generated from agriculture as compensation for losses incurred due to utilization of production potential for the application of agricultural production practices to protect the environment or due to increased costs for the application of higher standards of protection environment.

**The National Strategy for Agriculture and Rural Development** for the period 2021-2027 defines the national policy objectives, types of policy interventions and measures for the development of agriculture and rural areas in the period 2021-2027. The strategic goals are:

- improving the competitiveness of the agri-food sector, economic sustainability and income of agricultural holdings,
- application of environmental practices in production that lead to mitigation and adaptation to climate change and
- ensuring sustainable development of rural areas.

Moreover, the strategy defines 9 specific goals. The second strategic goal clearly put climate change as one of the strategic priorities in the sector. There are 3 specific goals related to this strategic goal as follow:

- SG 4. Contributing to climate change mitigation and adaptation, as well as greater use of sustainable energy
- SG 5. Encouraging sustainable development and efficient management of natural resources such as water, soil and air
- SG 6. Contribute to the protection of biodiversity, improvement of ecosystem services and conservation of natural habitats and landscapes

The specific goal 4 (S4) define that climate change has a serious impact on Macedonian agriculture through reduced yields, the need for additional irrigation or drainage and increased incidence of atypical plant and animal diseases. In order to mitigate and adapt to climate change, practices that do not affect the climate will be stimulated by introducing them in cross-compliance requirements and with increased intensity of co-financing the necessary investments. The new IPARD program for the period 2021-2027 will provide an additionally higher percentage of public co-financing of investments aimed at mitigating and adapting to climate change. Projects to support the reduction of GHG emission will represent at least 5% of the total number of projects financed through Measure 1 of the IPARD program (compared to 1.6% at the beginning of the period).

The negative impact of the changes will be addressed through support for the procurement of protective equipment, efficient water use systems, change of varieties appropriate to the future climate etc. Moreover, this goal defines that one of the main answers will be the realization of large capital investments for the rehabilitation of the existing and construction of new hydro systems for irrigation and drainage that should improve the regional availability of water during the irrigation periods, as well as flood protection. Moreover, the NASARD defines indicators and target values for the strategic period 2021-2027 for the total irrigated land and present value of 84 434 ha is targeted to more than 95 000 ha in year 2027.

The Rural development policy among other policies define Policies for natural resource management and mitigation of the impact of climate change. The high importance is paid to the water resource management and the long-term goal of investments in the water economy is to increase the irrigated area in the country to the level of installed capacity of 144,000 hectares and gradually expand the hydro systems to achieve the goal of irrigating the maximum possible irrigated area which is half of the arable land, i.e. about 250,000 ha. These investments should have a direct impact on increasing yields and the physical volume of agricultural production and resilience to the impact of external climate risks.

## Weather elements and their expected changes in context of agricultural production, land use and forestry

The expected climate change in North Macedonia are significant and cannot be neglected. The last research conducted by Djurdjevic in 2019 elaborated the 3 different scenarios for climate change. The scenarios are developed with respect of the expected GHG emissions, and using 3 different GHG scenarios: RCP2.6 (low), RCP4.5 (mid) and RCP8.5 (high). Therefore, the human behavior in the future period and achievements in reduction of GHG emissions highly influence future climate projections of essential climate variables, temperature and precipitation and derived climate indices are presented for territory of Macedonia. Analysis covers period from 2006 to 2100, and all changes were presented with respect to the reference period 1986-2005.

### *Temperature*

According to the results, it is expected that temperature increase will continue in the future. The amplitude of the increase, at the end of this century, primarily depend on the future GHG emissions, clearly indicating that future climate condition in the country will be determent by the success of international implementation of different polices related to the GHG emissions reduction. In case of *low* scenario, the annual mean temperature increase by the end of the century will be 1,5 °C, and in case of *mid* and high scenarios increase will be 2,5 °C and 5 °C respectively. In some part of the country temperature increase is even above 5 °C in case of *high* scenario. For the middle of the century the differences between temperature increase for different scenarios are much smaller, which is not surprising, since that GHG concentrations for that period are much closer to each other. The expected temperature increase for the middle of the century are 1 °C, 2 °C and 2.5 °C for *low*, *mid* and *high* scenario respectively. For the near future (period 2016-2035) for all three scenarios expected increase of temperature is about 1 °C. Analyzing temperature changes for different seasons, in case for *mid* and *high* scenario, the season with highest temperature increase is summer (Jun-July-August), and by the end of the century temperature increase (for *high* scenario) is above 5.5 °C in some parts of the country. In case of *low* scenario there is no substantial differences between different seasons. Analyzing changes in future daily minimum and maximum temperatures similar patterns were found. To some extent higher increase in daily maximum temperature were found in comparison to daily mean and minimum temperature. For summer season, increase in daily maximum temperature for the end of the century is above 5 °C for the whole country, which can be considered most significant change found in temperature analyses.

Figure 6. Average annual air temperature in North Macedonia, year 1979-2019 in °C

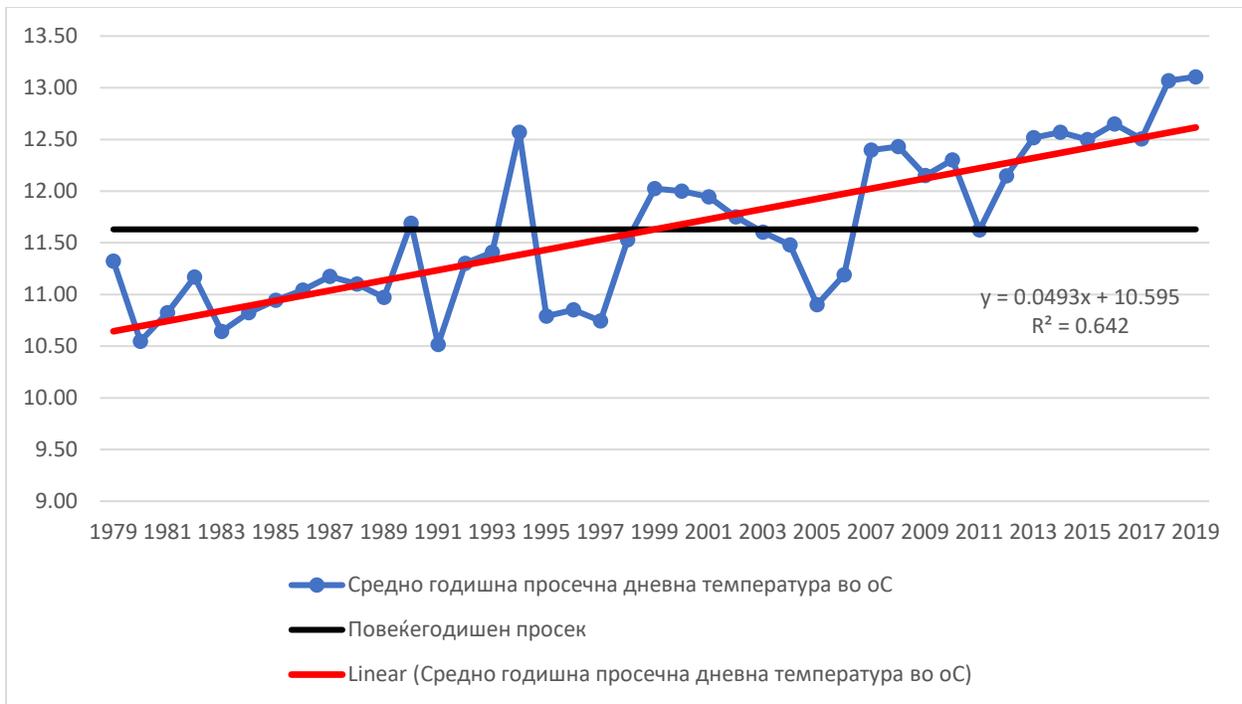
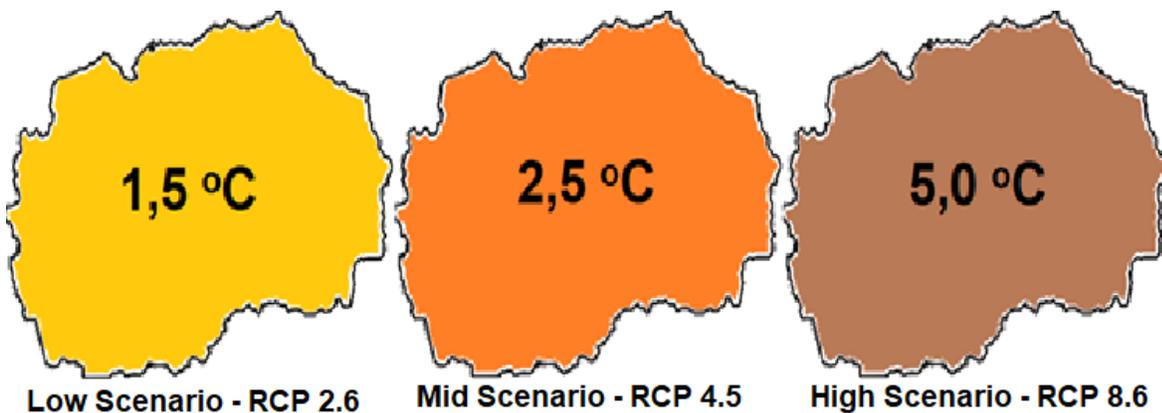


Figure 7. Expected changes in annual air temperature by the end of the century, for scenarios RCP2.6, RCP4.5 and RCP8.5 in respect to the period 1986-2005



### Precipitation

Analysis of precipitation shows more complex patterns of change in comparison to temperature. In case of *low* scenario, there is no clear signal of precipitation change in the future, except precipitation increase of September-October-November season. For other two scenarios, annual precipitation decrease is expected, mainly driven by significant decrease in summer precipitation. For *mid* scenario annual precipitation decrease is up to -20% with decrease for summer precipitation of -30%, and for *high* scenario decrease in annual

precipitation is up to -30%, and -40% for summer precipitation, by the end of the century. Also, spring season (March-April-May) shows consistent pattern of precipitation decrease over the century, but with smaller amplitude. For the middle of the century both scenarios also show decrease in summer precipitation, up to -30% in both.

Figure 8. Annual precipitation in North Macedonia, year 1979-2019 in mm

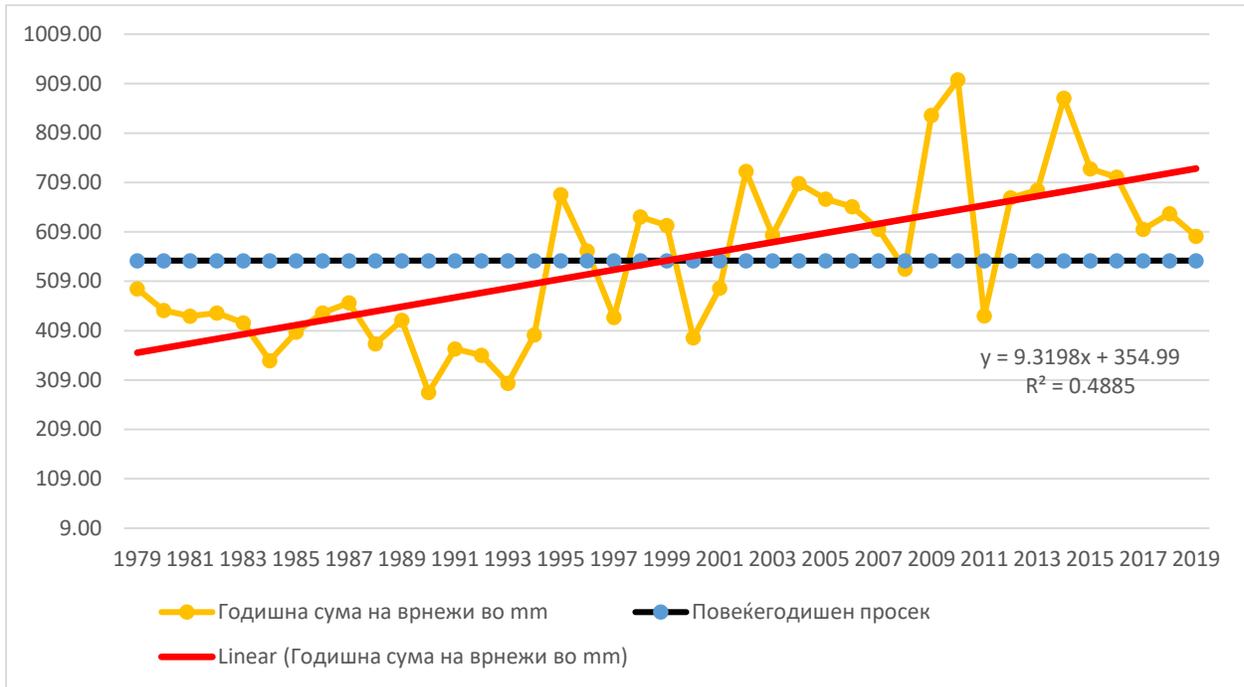


Figure 9. Expected changes in annual precipitation by the end of the century, for scenarios RCP2.6, RCP4.5 and RCP8.5 in respect to the period 1986-2005

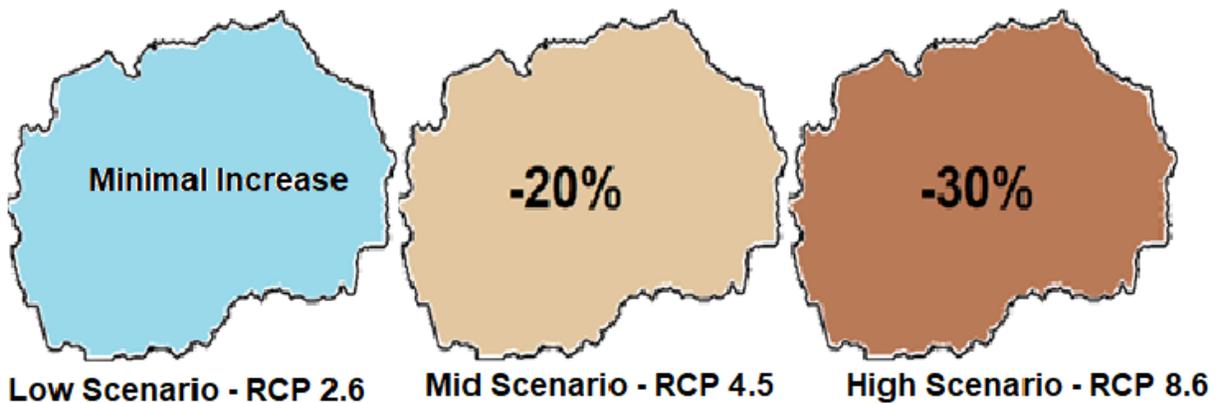
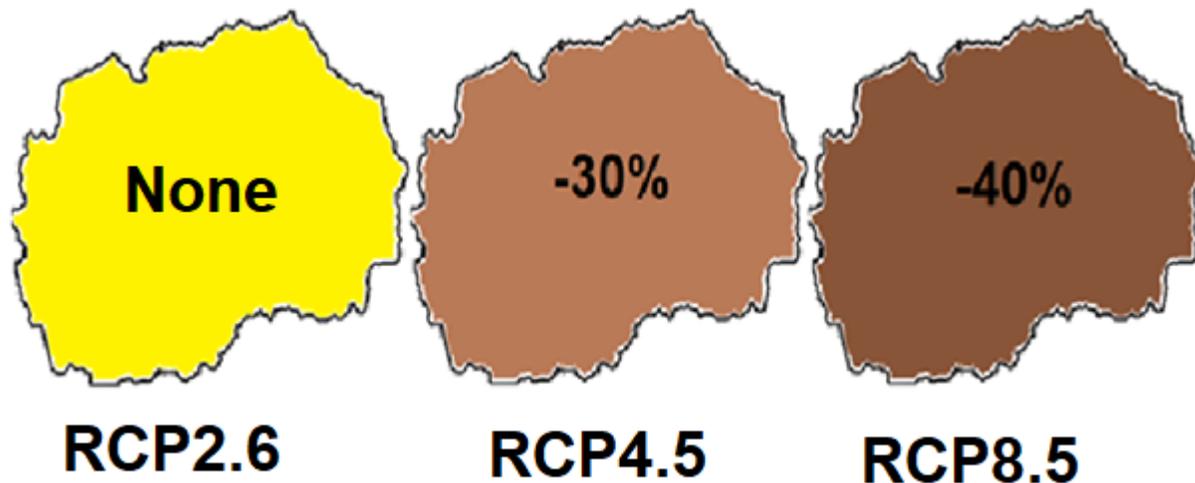


Figure 10. Expected changes in summer precipitation by the end of the century, for scenarios RCP2.6, RCP4.5 and RCP8.5 in respect to the period 1986-2005



According to the results North Macedonia will face hotter and dryer climate in the future, and amplitude of the change will be primarily related to the future concentration of GHG.

#### *Extreme weather constraining agricultural production*

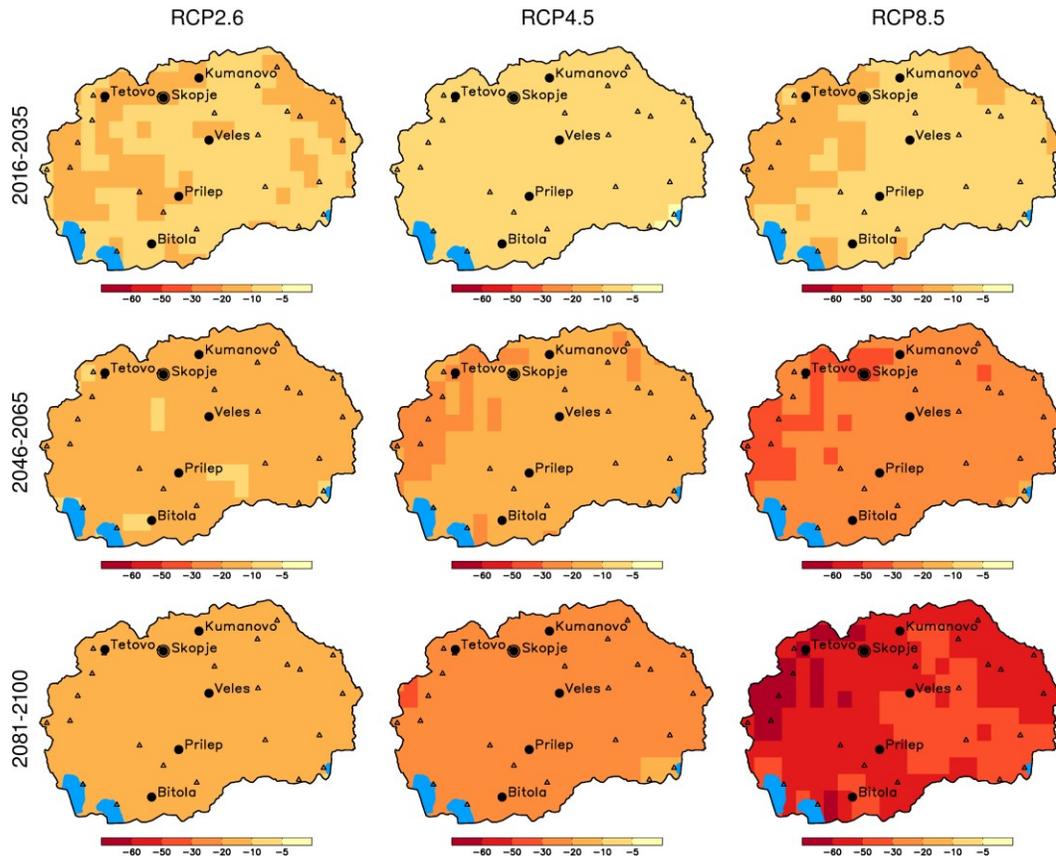
Thru the analysis of different climate indices, future change in meteorological and climatological extremes were accessed. In the future the decrease in cold and increase in hot extremes is expected. Similar to the temperature analysis differences between scenarios are pronounced for the end of the century (period 2081-2100), and for the near future (period 2016-2035) there is almost no difference between them. For the middle of the century (period 2036-2065) changes of *mid* and *high* scenarios are much more similar in comparison to *low* scenario.

#### Cold extremes

For the near future expected decrease in frost days is between -20 and -30 days. For the end of the century decrease for *low* scenario will remain the same, and for *high* scenario decrease is between -50 and -60 days. For the middle of the century change is between these upper and lower bounds of *low* and *high* scenarios. The change in ice days is very similar to the change of frost days, except that amplitude of change is smaller, for near future change is from -2 to -5 days, and for the end of the century it is up to -20 days for *high* scenario. According to the

results, the cold waves will be shorter in the future, and for the *high* scenario disappearance of cold waves is possible.

Figure 11. Expected changes in number of icing days with maximal temperature below 0°C, for scenarios RCP2.6, RCP4.5 and RCP8.5 for three future periods (2016 - 2035 year, 2046 - 2065 year and in 2081 - 2100 year) in respect to the period 1986-2005



### Hot extremes

Hot extremes are expected to increase in the future. The increase in summer days for the near future between 20 and 30 days. For the end of the century for *low* scenario change will remain the same but for *high* scenario increase will be between 50 and 60 days, over the majority of the country. Increase in tropical night are mainly projected to the low altitude areas. For the near future change is between 5 to 20 days. For the end of the century significant increase is expected in the case of *high* scenarios, and in low altitude areas increase of more than 60 days can be expected. Finally, it can be expected increase in duration and frequency of heat waves over whole territory. For the near future the change in frequency has values from 1 to 3 more events in 20-year period for all scenarios. By the end of the century, in case of *high* scenario this

change can increase up to 40 more events in 20-year period in western and eastern part of the country. The change in duration for the end of the century is projected to increase up to 25 more days, in case of *high* scenario.

Figure 12. Expected changes in number of summer days with maximal temperature higher than 25 °C, for scenarios RCP2.6, RCP4.5 and RCP8.5, for three future periods (2016 -2035 year, 2046 - 2065 year and 2081 - 2100 year) in respect to the period 1986-2005

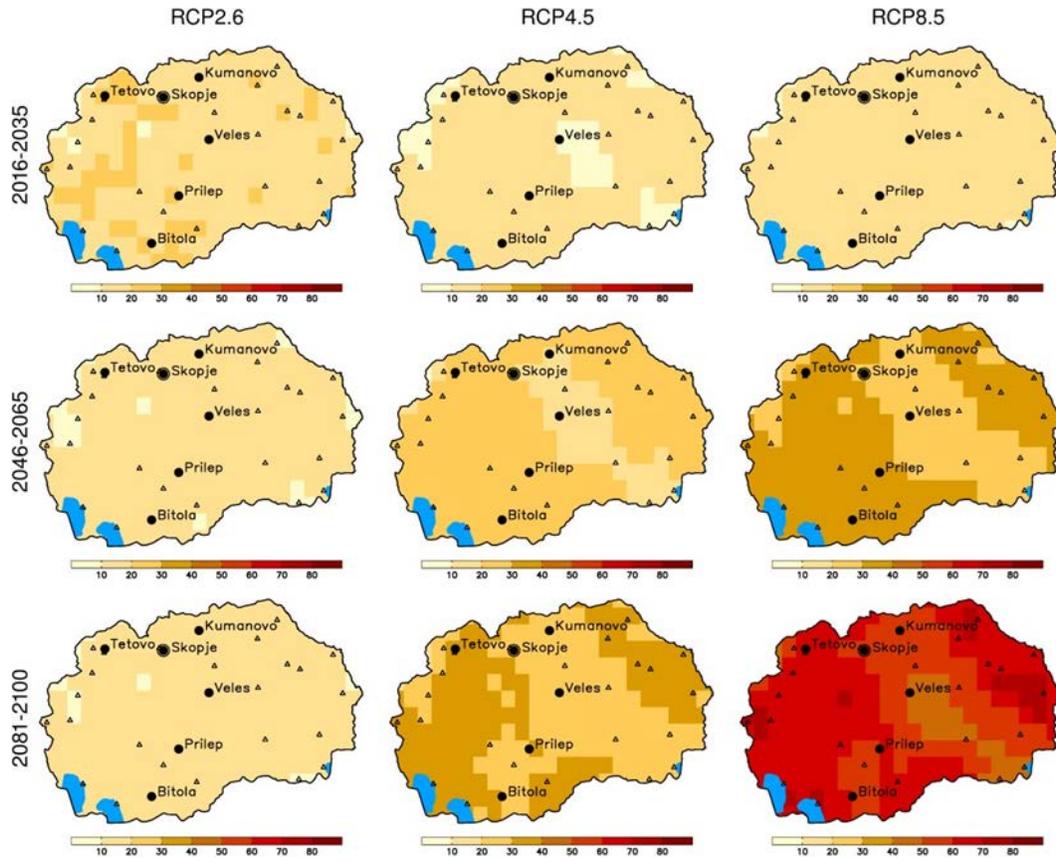


Figure 13. Expected changes in warm spell duration index - WSDI -Annual count of days with at least 6 consecutive days when TX > 90th percentile (extreme heat waves) for scenarios RCP2.6, RCP4.5 and RCP8.5, for three future periods (2016 -2035 year, 2046 - 2065 year and и 2081 - 2100 year) in respect to the period 1986-2005

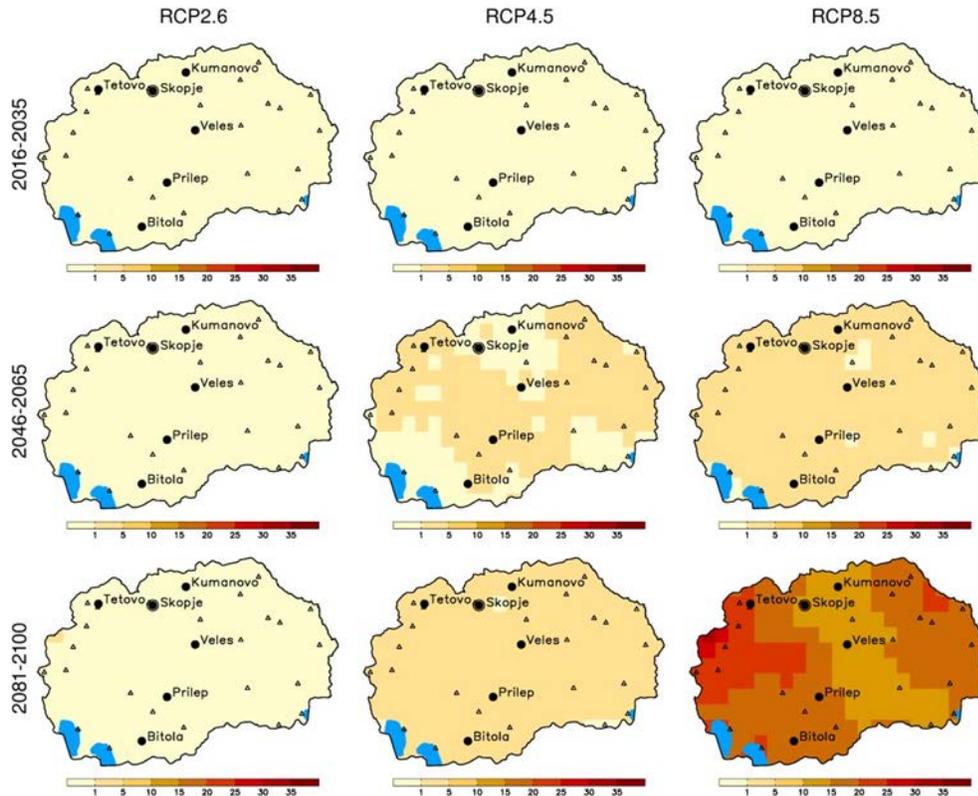
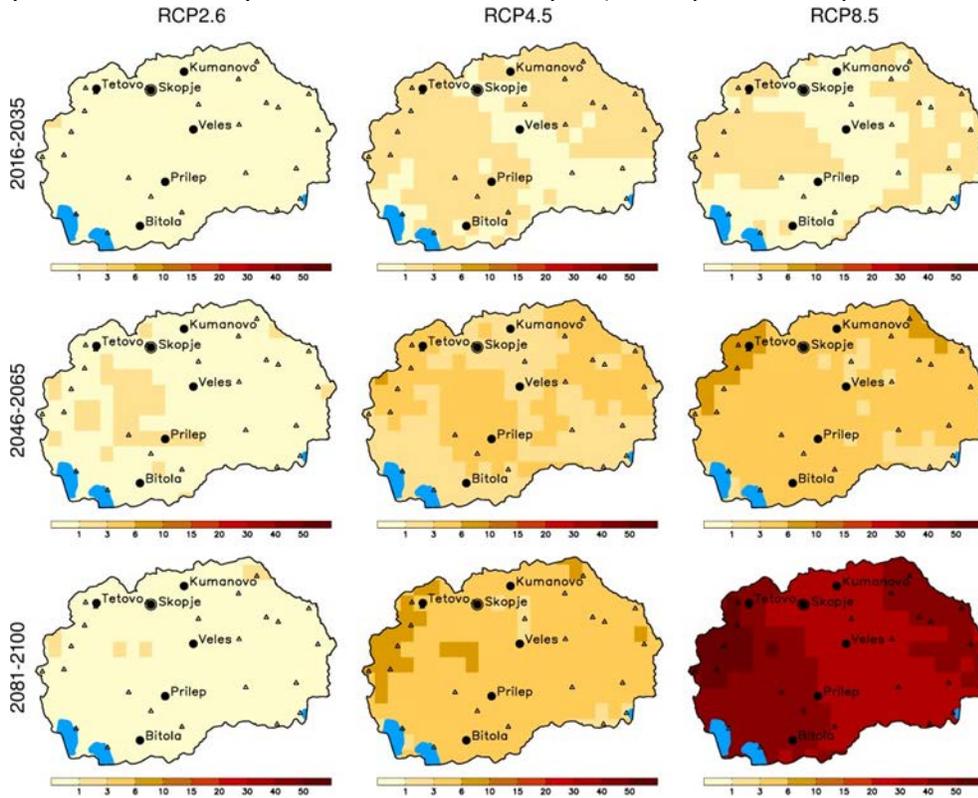


Figure 14. Expected changes in frequency of appearance of the extreme heat waves WSDI – (number of events in 20 years period with at least 6 consecutive days when TX > 90th percentile) for scenarios RCP2.6, RCP4.5 and RCP8.5, for three future periods (2016 -2035 year, 2046 - 2065 year and in 2081 - 2100 year) in respect to the period 1986-2005



### Precipitation extremes

Because of high spatial and temporal variability of extreme precipitation, there is no uniform signal in their changes in the future, following different scenarios. On the other hand, both analyzed indices, daily maximum precipitation and number of days with precipitation above 40 mm/day, shows in general positive change in the future, for all analyzed periods and scenarios. Upper limits of change is 60% increase in number of days with precipitation above 40 mm/day, and 20% increase in daily maximum precipitation accumulation. Physical background of this change is fact that warmer atmosphere that can holds more water vapor (7% more water vapor in 1 °C warmer air) indicating higher chances for more extreme precipitation, and consequently higher chances for induced flash foods.

Analysis of consecutive dray days index, reveals that in the future risk of drought will increase. In the near future increase of number of consecutive dry days is between 5 and 20 days, depending of part of the country and scenario. For the end of the century in case of *high*

scenario expected increase is above 30 days. This increase is directly related to the projected decrease in summer precipitation, especially in case of *mid* and *high* scenario.

Figure 15. Future annual change in daily extreme precipitation change (RX1D), for three future periods, 2016-2035, 2046-2065 and 2081-2100 with respect to the period 1986-2005 for the RCP2.6, RCP4.5 and RCP8.5 scenarios.

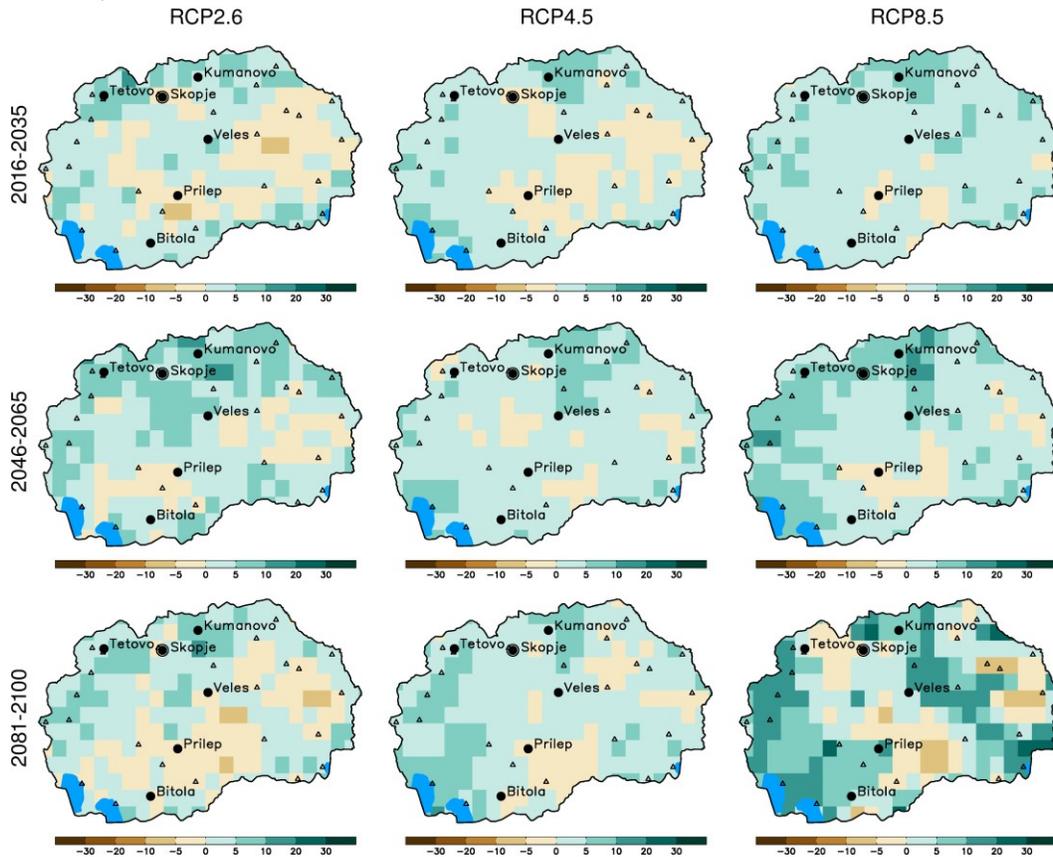
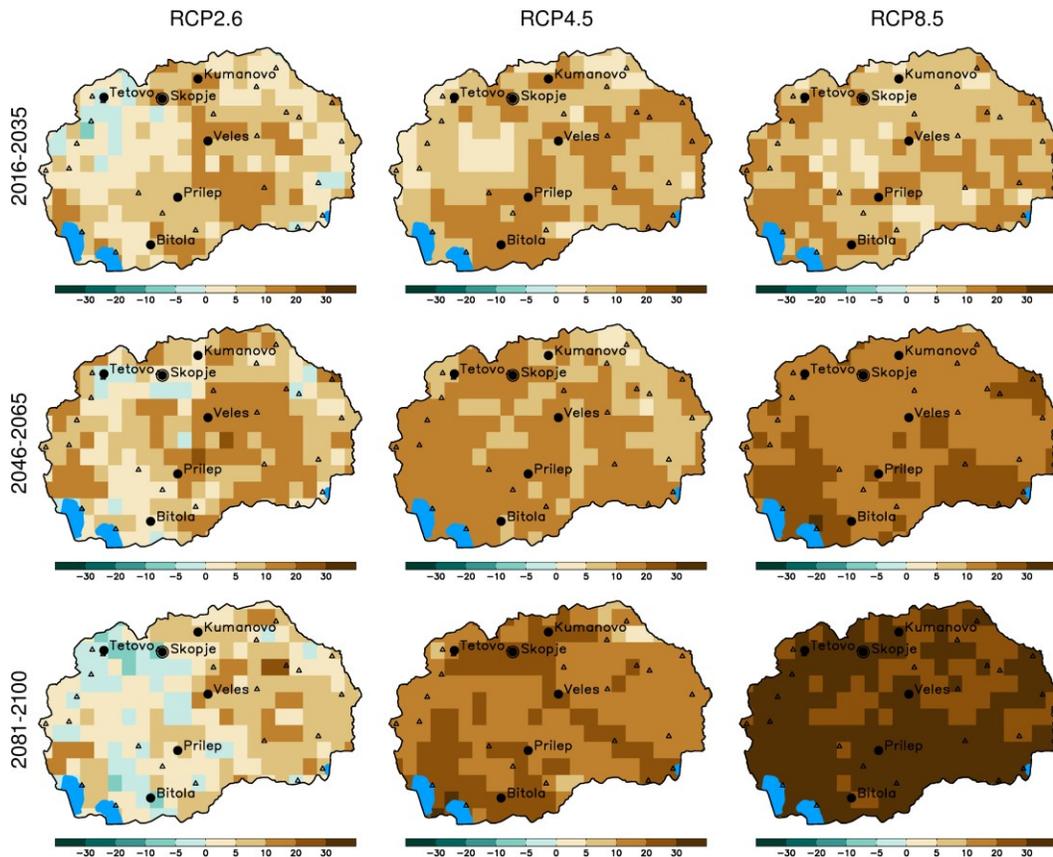


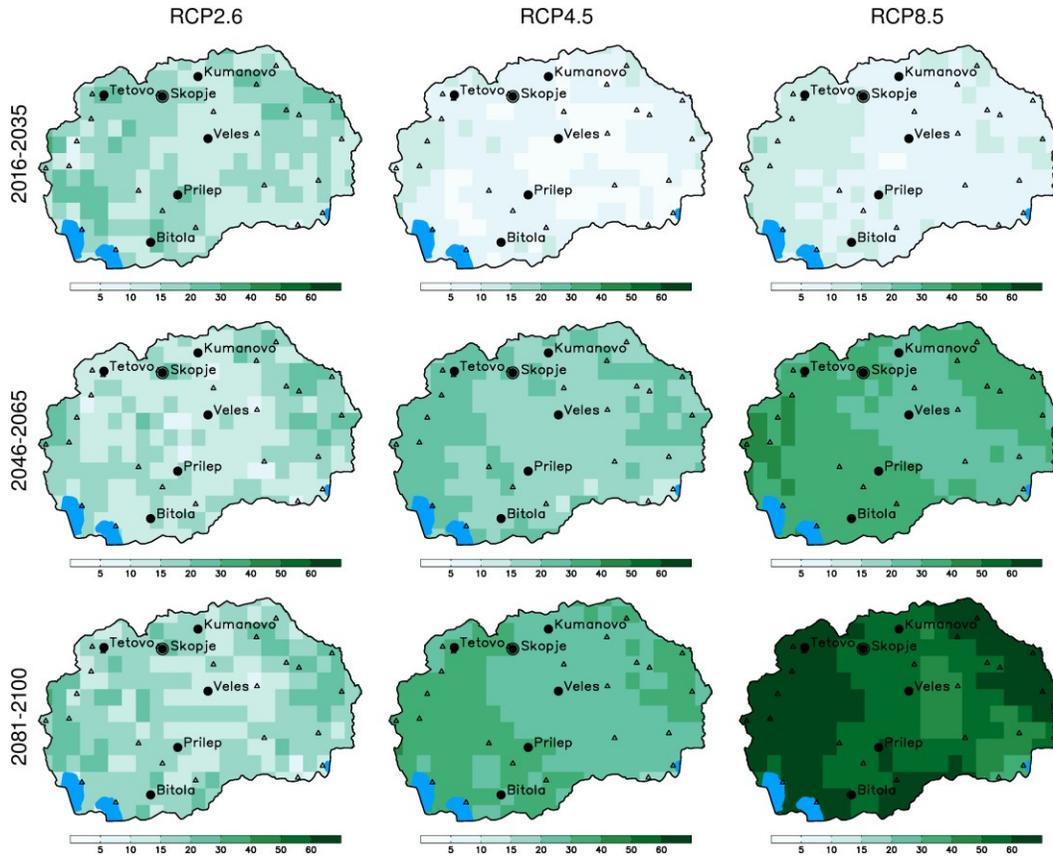
Figure 16. Future annual change in consecutive dry days, for three future periods, 2016-2035, 2046-2065 and 2081-2100 with respect to the period 1986-2005 for the RCP2.6, RCP4.5 and RCP8.5 scenarios.



### Growing season length

Due to temperature increase, extension of growing season length is expected. For the near future increase in growing season length is 5 to 20 days. For the end of the century, in case of *high* scenario expected increase is 50 more days, for the majority of the country, with means almost 2 more month of growing season.

Figure 17. Future annual change growing season length, for three future periods, 2016-2035, 2046-2065 and 2081-2100 with respect to the period 1986-2005 for the RCP2.6, RCP4.5 and RCP8.5 scenarios.



## Soil vulnerability to climate change

### *Introduction*

Climate change and soil degradation are among the major threats to agriculture and food security.

An increasing number of studies describe climate change impacts on crops. Crop models are widely used to support climate change impact assessments but the impacts of soil degradation have received much less attention, even though combating continuing degradation is of utmost importance (Bindraban et al., 2012). Soil with a lowered capability to store and release water and nutrients can provide only little relief to crops coping with impacts from climate change. Vulnerability of organic carbon pools to climate change has important repercussions for land sustainability and climate mitigation actions (Tubiello et al., 2007). Only healthy soils can help crops to cope better with increased climate variability.

Soil carbon is a mixture of organic material originating from above ground and below ground plant biomass, and living organisms compounding its biodiversity. Its turnover is a complex process among different pools consisting the SOC, which can last from days, hours or in some cases for decades. On the other hand, the soil organic matter (SOM) is crucial to terrestrial ecosystem processes and plays key roles in nutrient release, maintenance of soil structure, in greenhouse gas emissions, and is a major pool in the global carbon cycle. The worldwide SOC pool is estimated at 1400 Pg, which equals the sum of the atmospheric and biotic carbon pools (Hiederer R., Köchy M., 2011).

The assessment of the effects of climate change on soil carbon requires understanding how the changes in climate conditions, affects the underlying processes of the terrestrial carbon cycle. The rates of the overall processes related to the carbon turnover, in addition to the above mentioned factors (soil, management, land use), are severely affected by the climate change. The overall changes in soil carbon is determined with the balance between net gains of carbon through photosynthesis (Net Potential Productivity) and net losses through decomposition (soil respiration) and hydrological processes (leaching, erosion), processes directly affected by climate conditions.

SOC levels are maintained by a delicate balance between inputs and decomposition processes.(Gregory et all. 1995). SOC is subdivided into discrete pools, and the dynamics of each pool is governed by a large range of complex processes, which are tightly related to climate change. For these reasons, SOC turnover can be considered as a key indicator in evaluation of the vulnerability of soil to the pronounced impact of CC. There are certain modeling approaches which should be taken in consideration, enabling development of scenarios for carbon dynamics under different climate and management conditions.

### ***Monitoring and Modeling approaches***

An essential aspect of carbon turnover in terrestrial ecosystems is the development of methods and technologies for measurement and monitoring of carbon pools and fluxes. Forest and agriculture are key systems in carbon cycle, as they hold and rapidly exchange large amounts of carbon, which is particularly accelerated with the human impact.

With respect to monitoring, of primary importance is the requirement to define methodologies for measuring both soil carbon stocks and fluxes (gaseous, dissolved and particulate). There is a need to ensure continuation of long-term records, which hold evidence of temporal variability and information due to changes in management practices, vegetation composition and interactions with other environmental drivers. Concentrated efforts should be made to acquire measured information on the critical processes of the carbon cycle in soils. Such efforts could be part of soil monitoring schemes. Such schemes are already established in USA (Brown, G.D. 2013) and discussed on EU level (Schils R. 2008).

Understanding of each of the processes governing the carbon turnover from one pool to another, drivers staying behind these processes and its interactions, is the basis of each model related to SOC dynamic and future scenarios. The elevated CO<sub>2</sub> and changes in climate will alter the net primary production (NPP) and to that the respect, the amount and kind of dead plant material entering the top soil and the rate of decomposition and mineralization of the organic material – soil respiration.

While climate change is expected to have an impact on soil carbon in the long term, changes in the short term will more likely be driven by land management practices and land-use change, which can mask the evidence of climate change impact on soil carbon stocks. Changes in land use, soil management technologies in agriculture or changes in age-class structure of forests can be more important than climate change itself. (Smith et al., 2005, Zaehle et al., 2007).

Management is a key factor affecting SOC, which, under most situations, causes faster rates of change than would changes in CO<sub>2</sub> or climate. However, since change in climate may result in altered management, interactions between management and climate may be the most significant factor, which needs to be studied. Adoption of appropriate conservation and restoration practices can build up SOC contents, improving soil structure and aggregation, compared to intensively tilled soils.

Conservation tillage are in fact a complex set of measures towards preservation of agricultural soils from degradation and are focused towards preservation of SOC, soil moisture, intensity of soil erosion, and the overall health of soil, like: reduced or no-tillage systems, contour plowing, cover crops etc.

Continuous cropping can deplete soil fertility due to inadequate replacement of nutrients harvested with produce or lost through leaching, erosion, and atmospheric emissions. Most of the

processes responsible for soil degradation, including soil organic matter mineralization and erosion, are enhanced by higher temperature and more intense precipitation.

Nutrients balance in any stages of the plant growth, is a critical point in the plant/soil interactions. It's an notorious fact that, application of nitrogen enforces plant growth and soil carbon storage. Limited availability of nutrients can influence plant growth in a larger extent than the increase of temperatures or CO<sub>2</sub> concentrations. The effects of nutrients deposition, is expected to have bigger effects on carbon rich areas with limited quantities of nutrients. The increased availability of nitrogen is expected to enforce plant productivity and decrease decay rate of soil organic matter. Such effects on agricultural land is considerably smaller because these systems are under intensive cultivation and with high and regular amendment of nutrients. Some experiments showed decreasing of soil carbon, when excessive quantities of nitrogen were incorporated with cover crop material (Guangwei, D et al 2006) which support the statement that the carbon turnover on a low carbon agricultural system, has a different pathway.

Land use/land use change is another process, which significantly affects soil carbon stocks. Carbon is lost from soils when grasslands, managed forestlands or native ecosystems are converted to croplands, a process that is slowly reversed when cropland is converted back.

Crop management practices are site specific and vary spatially (field to field) and temporally (year to year) as individual growers adjust their management strategies.

In many cases, existing models overlook management practices. Having in mind this, management practices should be well documented, since they play serious role in modelling of SOC dynamics in agricultural systems.

Climatic conditions is another set of variables affecting the two most important stages of carbon cycle: decomposition (soil respiration) and NPP. Most relevant meteorological and climate parameters and indices usually taken in consideration in modeling of soil carbon cycle are:

CO<sub>2</sub> concentration in the atmosphere and CO<sub>2</sub> fluxes from and to the soil from the atmosphere, which affects net primary productivity and soil respiration intensity,

Air and soil temperature (daily, monthly or yearly averages), and related indices and extreme events. The effects of elevated temperatures on plants and its production is much complex and is related to the type of vegetative cover, phenological phases, nutrients supply, soil moisture, factors which are very important when modeling SOC turnover. Increasing temperatures is expected to have a higher impact on decomposition than its effects on plant production, since soil respiration is considered more vulnerable to changes in temperature than photosynthesis. On this way, elevated temperature contribute to the intensive topsoil carbon contents.

Hydrological conditions and soil water balance, is another key factor influencing the SOC decomposition rates, like: monthly or yearly sums of rainfalls, extreme rainfall events, soil

humidity, and evapotranspiration are the components, which define water limitation for the plants and are very often omitted in models. The direct influence of water shortage on decomposition rates and the net productivity is less well characterized than the temperature influence. With respect to its appearance, drought is considered as heavily depending to the hydrological conditions of certain areas. For analysis of its frequency of appearance, and severity a time series of constant monitoring is needed. Still, there are opposed findings for the influence of drought on the intensity of soil respiration. In some cases, the respiration is intensified, while in some cases depressed, depending of the hydrological conditions.

In general, there are many sources of uncertainty in model simulations of the CC impacts on soil carbon. This is just a short overview of the needed entry data sets for modeling the influence of CC on SOC and the overall carbon cycle.

#### Modeling approaches

The terms of climate change, the sizes of C pools and magnitudes of C fluxes among components of the ecosystem, including soils, and interactions among the driving variables, need to be both well understood for modeling purposes, when predictions of the impact of the global climate change on SOC is made. This complexity of the system makes the process of prediction of SOC dynamic, modeling and definition of future scenarios, a very difficult task. There are numerous sources of uncertainties, which should be taken into consideration.

Processes of changes in SOC in some cases occur slowly, while some processes are very fast, taking few days or hours to be accomplished. Biogeochemical models simulating C dynamics are often used to predict net C sequestration for different soil types and land management. The complexity of these models vary in broad ranges from a very simple empirical model up to very complex process based models. The former ones are emphasizing the biological, chemical and physical processes that influences the soil carbon turnover.

#### *Process-based modeling studies*

Process-based models are widely used to study changes in soil carbon stocks. There are a numerous models in place for prediction of the influence of the CC on soil organic matter turnover and evaluation of different scenarios on future SOM dynamics.

Models vary from relatively simple models like RothC (Coleman and Jenkinson, 1996) and to models covering the soil processes in more detail like CENTURY (Parton et al., 1993) and DNDC (Li et al., 1992).

Major issue limiting the usability of the process based models is their need for an appropriate detail input data making them to be localized (i.e., point based)

Usually, all of these models needs a cumbersome input data in order to gain valuable results and to calibrate the modeled outputs. Typical input variables that influence the decomposition processes in models as elaborated before are: long series of weather data and climate indices

with high temporal resolution, site specific and soil properties (soil texture as well as chemical characteristics), soil management practices, network of long-term experiments. Part of the needed data can be supplemented with global data sets, whilst some other more specific data related to soil; management practices and site specific are serious gap. For these reasons, up to this moment there are no attempts for modeling of the impact of CC on SOM turnover and development of scenarios for its future dynamics under different management practices and climate conditions.

Approaches for extending process C models from isolated points to landscape and regional scales have not been identified and evaluated. While current remote sensing techniques cannot directly monitor soil. Linkage of biogeochemical models to geographic information systems (GIS) has blurred the spatial-scale distinction between empirical and process models.

Recent advances in remote sensing of soils and crop residues can potentially provide some of the spatially variable biophysical parameters needed by these models to predict C dynamics across landscapes, such as NDVI, LAI, CEI indexes etc.

#### *Geostatistical analyses of spatially distributed soil samples*

Statistical analysis of spatially distributed soil locations can give an information for the changes of soil carbon in monitored soils in a two, or more time sequences. This monitoring program can be coupled with simultaneous measurements and data collection to outline all relevant changes between two monitoring campaigns (chronosequences) which directly reflects carbon turnover. This additional data sets can provide the needed information for evaluating the effects of other factors, such as land use, land use change or land management. On the other side, on field direct measurements and data collections cannot cover large landscapes with sufficient resolution, especially in an environment of repetitive measurements needed to adequately account for SOC dynamics.

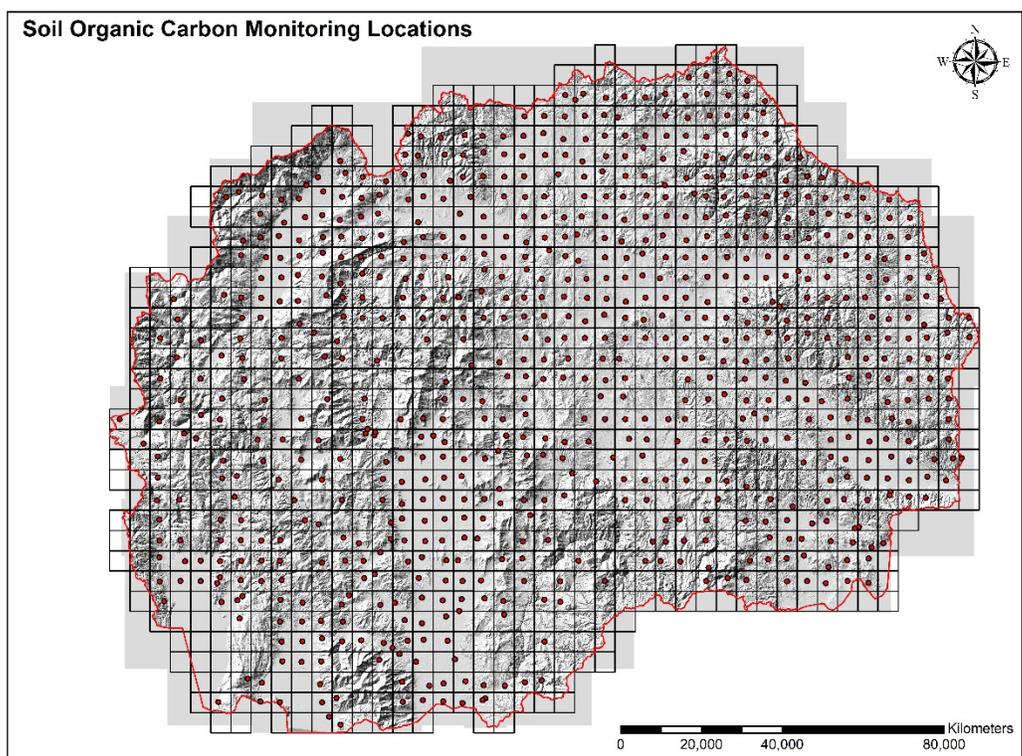
Empirical models which can correlate the environmental processes with parameters that are readily measured in the field and, are one of the most feasible approaches. Remote sensing systems are used for spatial and temporal detection of the needed coverages with environmental co-variables, needed to document the changes of the land conditions over time (Cohen and Goward 2004). If field measurements are properly supplemented with remotely sensed data and other mapped variables, into appropriate models, the derived data can more or less accurately quantify the carbon pools, exchange rates and mechanisms ruling the terrestrial carbon cycling. Most important points, in the field repetitive measurements are: a) sampling design, b) soil sampling procedures, c) repeatability of the sampling and laboratory measurements and d) data analysis.

Most sensitive part of the overall monitoring program is the sample design, which in fact needs to give an answer to the following questions: how many samples and where, what time step, what

sampling depth. There are several methods for selection of sampling sites, such as: random sampling, systematic and stratified sampling.

For the needs of the eventual future national land based monitoring program we are proposing the random sampling at a resolution of 25 sq. km, in total 900 sampling locations (Figure15). Sampling locations were identified based on the several criteria: prevailing area under certain land use type within the sampling sites, altitude, exposure and accessibility.

Figure 18. Soil Organic carbon Monitoring locations



Ideally, the sampling sites resolution should be with 1 sq.km resolution which will yield more than 25 thousand sapling locations. This is a cumbersome set of field data sites, which surprises the current national capacities. With regards, to the sapling procedures, laboratory testing and data interpretation, the already adopted EU methodology (LUCA Guide, JRC), should be followed.

Of course, this is just a proposal methodology which might be easily adjusted in a line with eventual actions toward enforcement of the capacities. The underlying methodology and approaches, which a in line with the LUCAS JRC program, would remain the same.

### *Previous work*

Development of methods and approaches known as digital soil mapping, in evaluation of the spatial and temporal distribution and dynamics of SOC is an important step in the process of identification of the most vulnerable areas to the depletion of SOC, identification of the key drivers and pressures and evaluation of the implemented measures. In the same time, DSM techniques are a key component within many of the models used for modeling of the CC on carbon turnover.

This chapter concentrates on the former attempts of estimating soil carbon changes as a difference between repeated measurements because this approach is more useful to estimate the contribution of climate change to soil carbon changes.

In the previous period two major attempts has been made towards evaluation of the spatial SOC contents and its dynamics in the country.

The first attempt to estimate the SOC content on a country level has been made during the elaboration of the national digital Soil Information System (MASIS). SOC content map has been prepared as a case study, by the means of a modern DSM techniques, based on the soil data set collected during the MASIS Project. Soil data used were produced during the continuous field survey and laboratory work as a part of the long-term project for preparation of the National Soil Map. The total number of examined sapling locations was 4300 and referred to a time span of a more than five decades. Additional environmental co-variables were used by the modelers in the process of preparation of this first product on a national level, like: digital terrain model and its derivatives, temperature and precipitation grid maps, as well as remotely sensed data and indices.

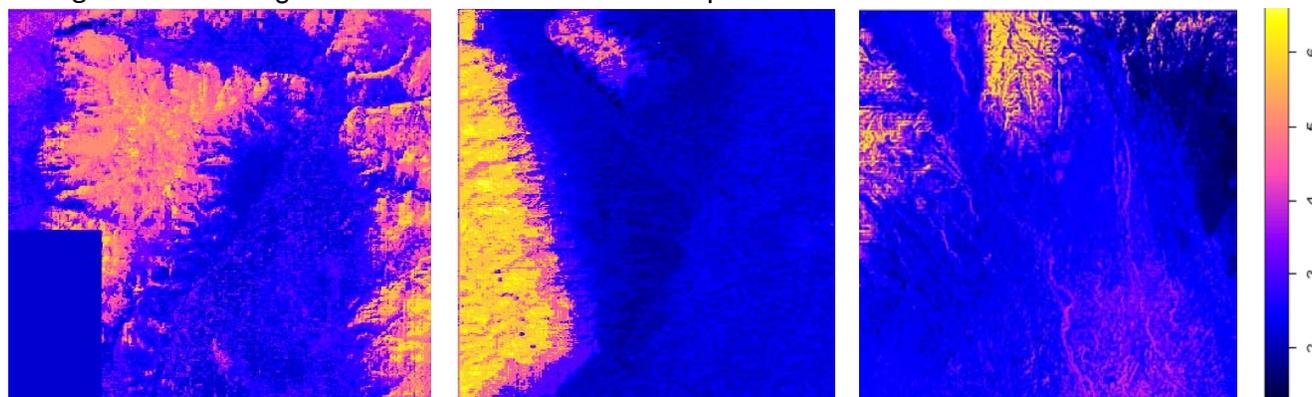
Another effort towards identification of the vulnerable areas to SOC depletion has been done within the Land Degradation Neutrality target-setting process. One of the 3 indicators used to estimate the land degradation trends was SOC dynamics. For the purposes of this study, modeling of the SOC content was based on Global Datasets<sup>1</sup> and other co-variables which are determined by means of remote sensing, and modeling of all realizations between these co-variables and the soil properties of the multi-index database for the soil has been modeled. In this way, the basic content of the SOC for 2000 has been set in a 250 m grid map, which served as a baseline for future estimations. To obtain an estimate of the change in SOC reserves in time (period 2000-2010), suitable for setting LDN targets, a modified IPCC methodology was used to predict the movements (changes) in SOC at the country level based on land use change / coverage. This different approach in estimation of SOC based on the land use change, taking in account the SOC losses/gains due to the conversion from one category of land use to another. Only a slight change in SOC were detected, following this methodology of only -3951 t, which is due to the conversion of 2,6 km<sup>2</sup> forest land to cropland and 3,9 km<sup>2</sup> of forest to shrubs (Mukaetov, et all. 2019).

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<sup>1</sup> 150,000 soil profiles collected over several decades by ISRIC,

Most recent work related to spatial modeling of SOM content, was performed on a pilot sites in three valleys located in southern parts of the country, identified within the LDN analysis as most prone to SOC depletion. Field soil survey has been organized and on the base of the collected soil property and soil management data, and additional co-variables used as predictors, spatial distribution maps were prepared (Figure 17).

Figure 19. Soil organic matter distribution on three pilot sites in North Macedonia



Ohrid pilot site

Prilep pilot site

Strumica pilot site

Source: UNEP Report

The highest content of the SOM was detected on mountainous locations (above 6%) while the lowest content of less than 2% are detected in the lowest parts of the valleys especially in Prilep test site.

These findings are in line with the findings of the (Schills R. et al, 2006) study stating that low levels are particularly evident in southern Europe where 74 % of the land is covered by soils that have less than 2 % of organic carbon in the topsoil (0–30 cm).

#### Soil Organic Carbon dynamics in the soils of North Macedonia

It is very challenging to identify the contribution of climate change to measured changes in soil carbon. Measurements of soil carbon changes are characterized by a substantial uncertainty and it is well known that land use and land management changes have large effects on soil carbon (Poeplay C., Don. A. 2013). Past changes in land use and management were probably the main cause and any climate change signal is masked by these other changes. For instance, according IPCC methodology, on areas with converted land use, the default period for reaching of SOC equilibrium is set on 20 year period.

In the circumstances of non-existence of sufficient national data to run some of the widely adopted geochemical models for estimation of CC impact on SOC turnover and quantification of the effects

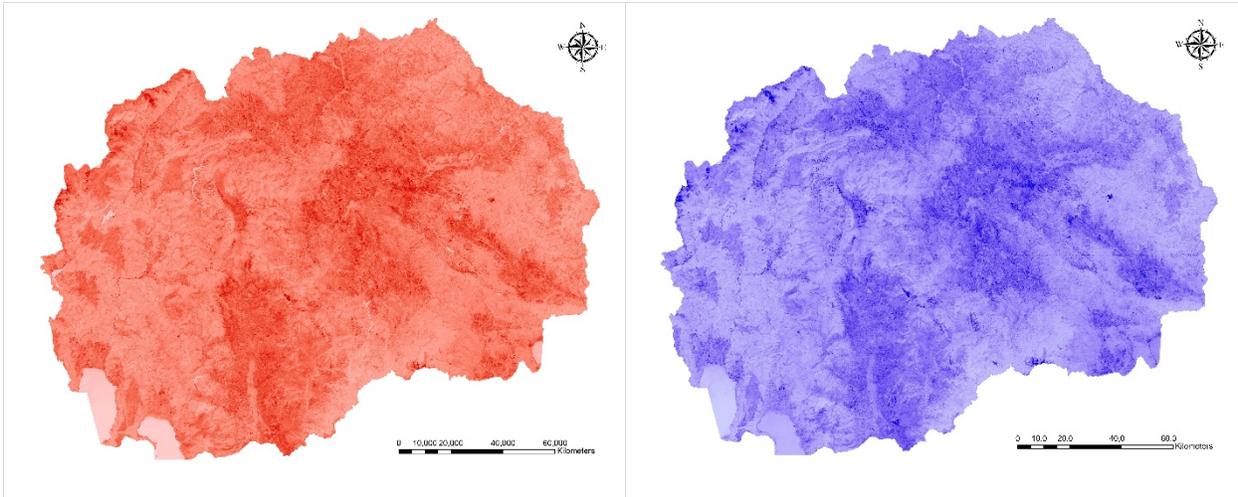
of soil management and climate scenarios on SOC, our main goal was to perform temporal and spatial analysis of the SOC dynamics with comparison of two soil monitoring periods. The approach and predictors used was similar as with the MASIS soil organic carbon map, which gave us a comfort for comparison of data.

Field data for soil quality and land use were collected for 942 locations (soil data set used was collected in the past 10 years and is a property of the Laboratory of Soil Science and Plant Nutrition of the Institute of Agriculture). All sampling locations were georeferenced, which enables overlapping of with other spatial coverages and assigning of additional spatial attributes, like altitude, land use etc. Values for the soil carbon were extracted from the historical datasets, for the each of the preselected 942 locations. On this way, we had a two datasets with soil carbon contents for the period before 2010 and another data set for the period from 2010, till present. The differences between these two datasets enabled us to have an overview for the temporal and spatial dynamics of the soil carbon on the exact locations over the country territory. In the next step, soil legacy data were accordingly harmonized, transformed to obtain better distribution and linkages with other co-variables.

However, this output although possessing spatial elements, could not give us a better understanding for the SOC dynamic over the compared periods. The outputs were site specific (for the exact locations) and did not contribute much to the most important question – which are the most vulnerable locations concerning the SOC depletion. In order to predict the SOC contents on the not visited sites locations, a digital soil mapping (DSM) techniques were implemented. A set of predictors were collected or elaborated and integrated with the SOC differences dataset into an empirical model, following the FAO Guide for SOC Mapping (FAO SOC Cookbook 2018).

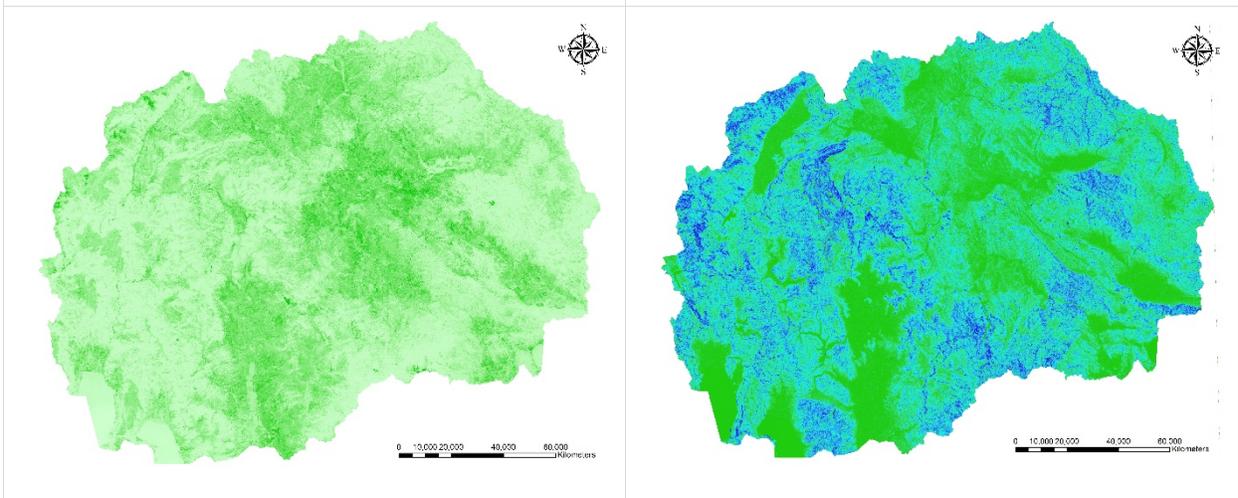
The predictors used referred to all variable which influences carbon dynamics in the terrestrial ecosystems. Some of them were used as a row datasets like: SENTINEL 2 satellite imagery (red, green, blue, NIR and SWIR bands). The images were taken during the vegetative period of July – August, 2020. The images were resized and masked to avoid the cloudless which was under 5%. The merged satellite images were merged and cropped to the boundaries of the country border (Figure 18).

Figure 20. Remotely sensed data (Sentinel 2 satellite images products)



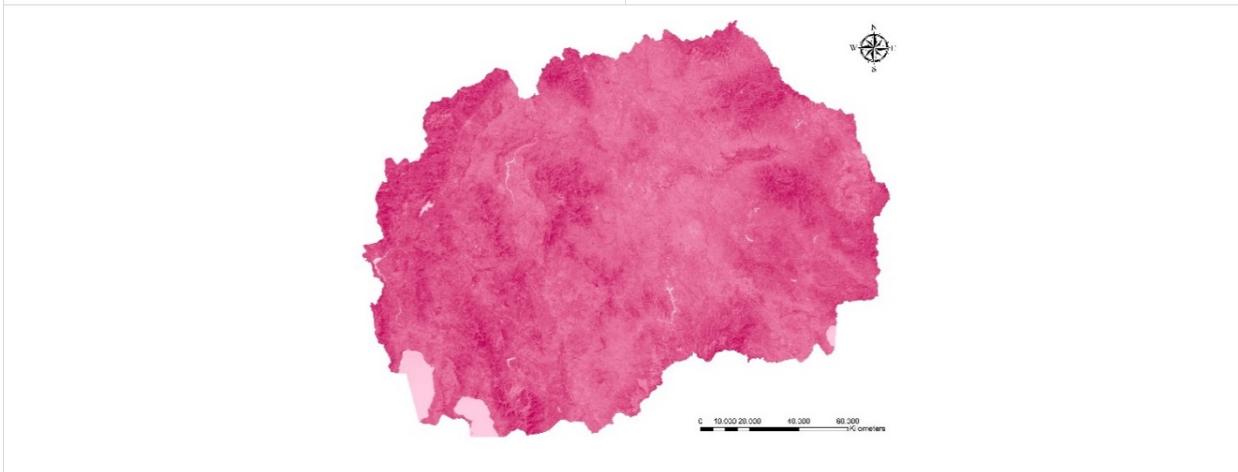
3. Red band

4. Blue band



5. Green band

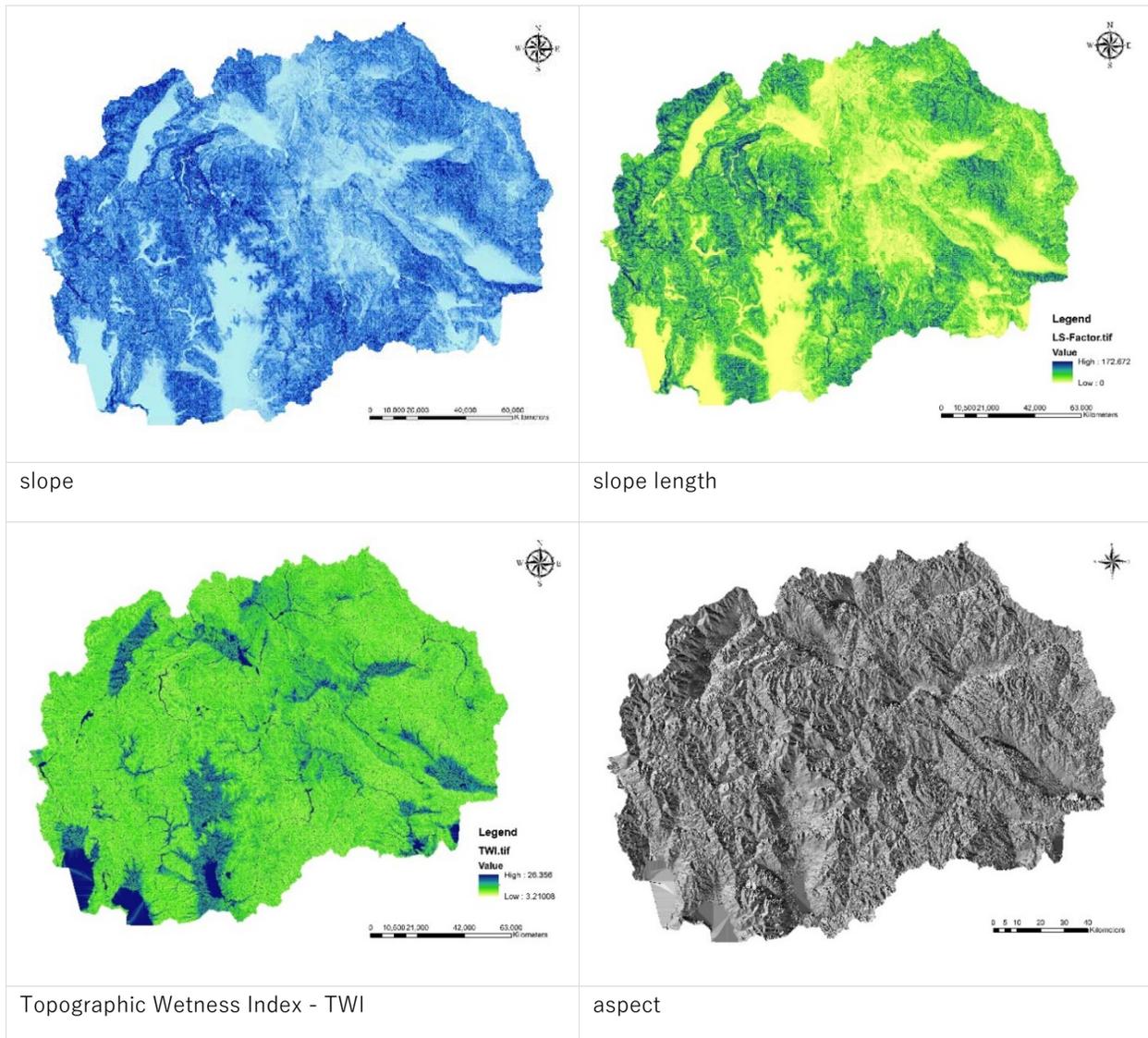
6. Near Infra Red - NIR



7. Short Wave Infra Red - SWIR

Other remotely sensed data used for this analysis, were the Aster global DTM with 30 m resolution and the MODIS NDVI grid coverage in a tiff format. Derivatives from the DTM produces in a SAGA software were used as an input data into the model, like: aspect, slope, slope length, topographic wetness index etc. (Figure 19).

Figure 21. Land topography characteristics



In terms of the climatic data, the monthly averages for the period 1990-2010 were used for deriving of a grid map for the country territory. For the same period, yearly sums of the precipitations were used for spatial modeling of the rainfalls.

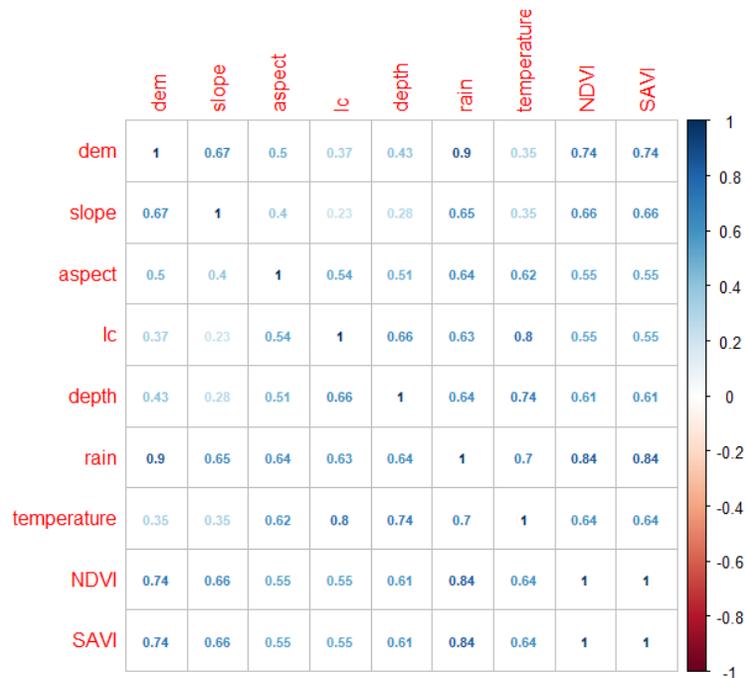
Other discrete predictors used were the soil map of the country (source. MASIS) which was converted into grid file with 63 classes and complexes and geological map with 142 geological formations. Land use map, was derived with photointerpretation of a Sentinel 2 for the period july-

august 2020. Twelve classes of land use were identified: broad leaved forest, coniferous forest, pastures, grassland, rice fields, shrubs, urban, water, wetlands, perennial crops, other.

All layers were synchronized into a same coordinate system with a 50 m pixel size resolution. Preoperational work has been performed with Quantum GIS software. Beside the predictors related to the climate conditions, land use and geomorphological and geological characteristics of the soil, several biophysical indexes were prepared as well, like Normalized Difference Vegetation Index (NDVI) for the vegetation period of 2020, Soil Adjusted Vegetation Index (SAVI) and Bare Soil Index (BI).

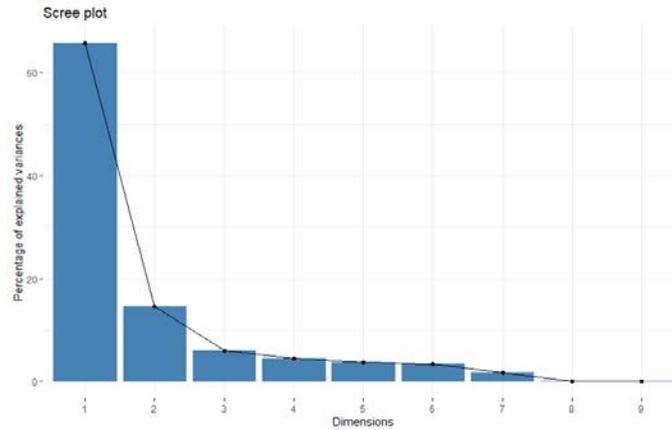
SOC differences data set as a GIS layer was uploaded together with the environmental factors into R software environment. All grid files were converted into data frames and autocorrelation matrix has been prepared in order to evaluate the degree of correlation among them (Figure 20). Significant correlation has been identified among them, which confirmed that the selected variables are logically connected like: rain and NDVI with correlation coefficient of 0.84, slope and rain and DEM 0.9, temperature and rain and lc (land cover) with rain and temperature.

Figure 22. Correlation matrix of the predictor variables



In the next stage in order to reduce this cumbersome set of variables and to observe the possible trend and relations between the variables, a PCA has been performed. As shown in

Figure 23. Graph Analysis of the predictors variation

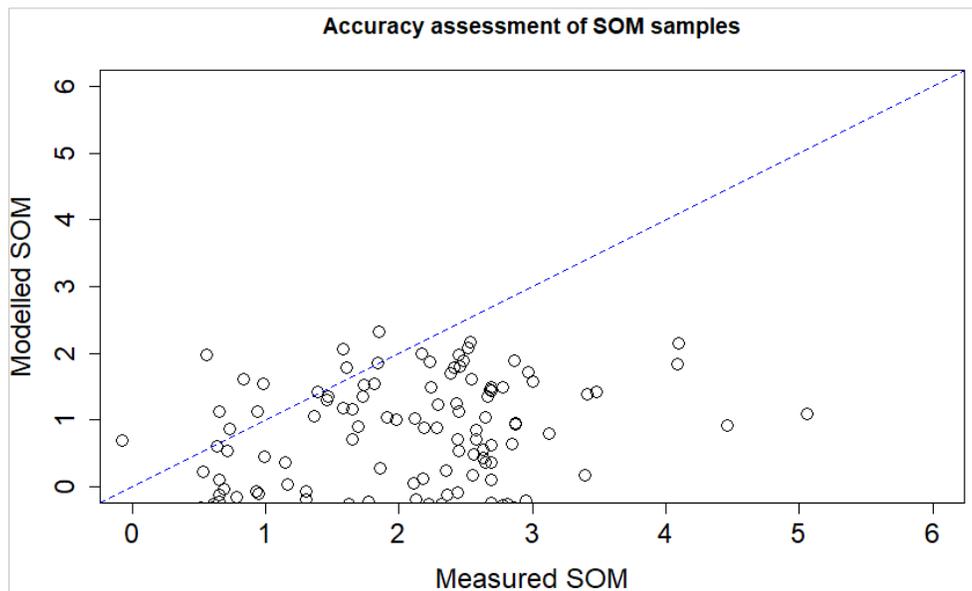


The first four principal components explain more than 95% of the variability among the predictors, and were taken further as an input data into the model.

Soil data were transformed in order to obtain better distribution, and after that were integrated with the selected variables into a mutual spatial database. One quarter of the locations were set aside for a validation purposes, while the other three quarters were used into the model.

Several multilinear models were tested in order to estimate its coefficients of determination or how good they explain the variability between the dependent and the independent variables. Among the tested ones (e.g. CUBIST, Random Forest, CART, BayesianGLM), the Quantile Random Forest showed the best results.

Figure 24. Accuracy assessment of the modeled SOC

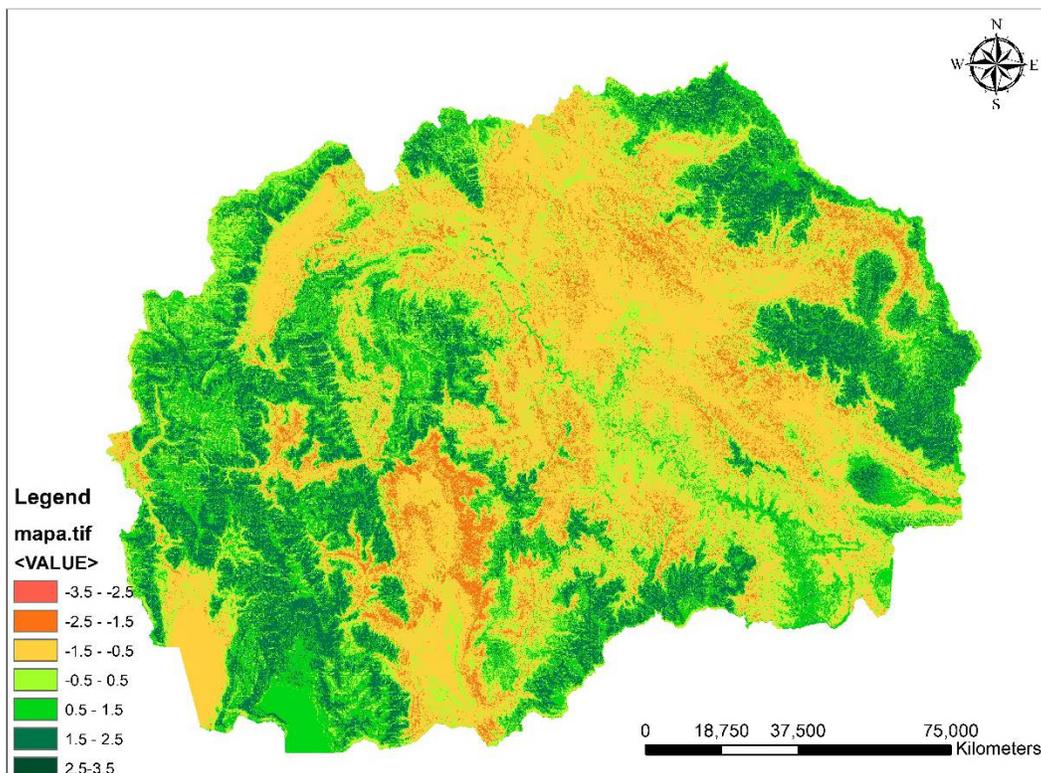


The correlation plot shows that correlation between the predicted and tested data are not on a satisfactory level and yields 0.32  $R^2$ . As presented in the map there are general underestimation

of the SOC decline with the model and a lot of outliers which influences the correlation coefficient. Having in mind that the predictors used, showed a good correlation among them self, this situation is most probably result to the uneven spatial spread of the used locations which can influence the validity. For this reason, for the future monitoring program of particular interest is to organize the field survey activities in a line with the above elaborated methodology approaches. This will enable more reliable data sets and better results in prediction and estimation of soil carbon.

The final SOC decline map is presented on Figure 23. Out of the presented results it can be concluded that for the period of the las 10 year the most vulnerable areas to SOC depletion are the region under agricultural production especially in the central part of the country. South east region and the Pelagonija and the Polog valleys. The depletion of the SOC is in the ranges of 1-2 %. In the mountainous regions in the western part of the country and in the northern-east part like Osogovo and Plackovica mountain and the regions of Berovo and Delcevo, as well on Kozuf mountain an increasing of the SOC is notable under forest vegetation and pastures. This situation leads us to a conclusion that an immediate climate actions should be implemented in order to protect these areas from further loss of soil carbon.

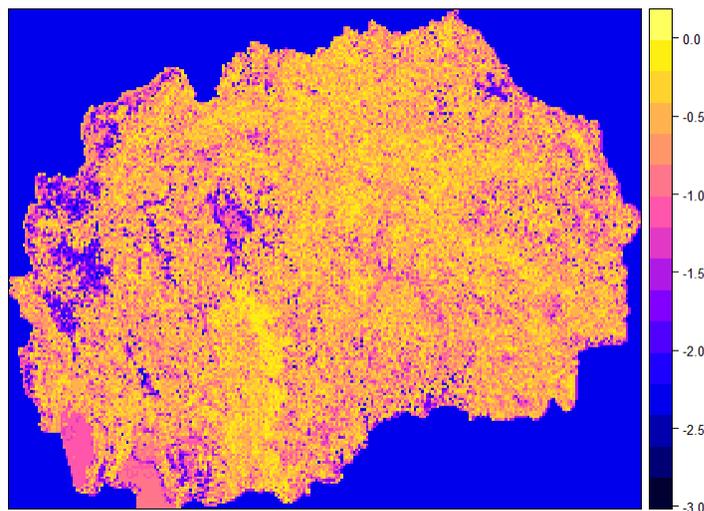
Figure 25. Soil organic carbon depletion map



In the final step of the modeling of the soil carbon, an uncertainty map have been elaborated in order to reveal the degree of error in the modeled values (Figure 24). Highest uncertainty was

observed on some localities in the mountainous areas in the western part of the country and the Baba mountain and the region of Dautica and Karadzica mountains. This is mostly result to the lack of SOC monitoring data for the mountainous regions. This gap, is another element to the previously elaborated need for continuous and exhaustive ground measurements of the SOC continent which should compass all environmental and management aspects related to the carbon dynamics. If such databases and field measurements are going to be completed which will give a round to run a more complex process models and develop od scenarios in order to evaluate the future trends of carbon turnover.

Figure 26. Soil organic carbon uncertainty map



## Adaptation of Agricultural Soils

Soils are critical to food security and considered as very important natural resource for crop production. It is estimated that globally about 95% of food is directly or indirectly produced on our soils. Healthy soils are the foundation of the food system. The soils are the basis for agriculture and the medium in which nearly all food-producing plants grow. Healthy soils produce healthy crops that in turn nourish people and animals. The notorious fact is that soil quality is directly linked to food quality and quantity. Soils supply the essential nutrients, water, oxygen and root support that food-producing plants need to grow and flourish. They also serve as a buffer to protect delicate plant roots from drastic fluctuations in temperature.

The fact is that soils are too slowly formed and too quickly lost. The climatic variables such as rainfall and temperature play an important role in the soil formation process. However, same factors influence number of processes of soil degradation, destruction and even soil loss. Climate change influence the temperatures, rainfall accumulation, rainfall pattern and rainfall intensity etc. There is need to better understand the impact of climate change on soil processes and properties, and how soil management techniques contribute to climate change (CC) adaptations/resilience, reduction in GHG emissions and

increase in agricultural productivity. Soil resilience refers to the magnitude of disturbance (caused by climate change in this case) that can be absorbed or accommodated before the system changes its structure. The soil properties and functions that are closely related to soil resilience and mostly affected by CC are soil structure and texture, organic matter content, nutrient dynamics, soil organisms, soil pH and cation exchange capacity (FAO, 2013).

Soils should be adequately monitored, protected and maintained in order to ensure that the above-mentioned crucial soil properties and functions remain in place. A range of soil management practices, including soil fertility improvements and soil erosion control, have been developed and applied by farmers and researchers in different parts of the world with a goal to achieve sustainable food security. However, a single soil management practice may solve some problems, but it is required to have integrated soil management and monitoring as tool for assessing the situation, understanding processes and their trends and development of sound-based policies and adaptation practices.

### ***Soil conservation practices – Cover crops as an effective measure for soil carbon preservation***

Soil is the main terrestrial organic carbon pool, storing three and four times more carbon than the atmosphere and the aboveground vegetation, respectively (Doetterl et al. 2016). Soil carbon sequestration by terrestrial vegetation, as one of the most important options for greenhouse gas mitigation, has long been identified by the intergovernmental Panel on climate change. The rate of soil sequestration in soils under agricultural use varied from 0.1 to 1.0 tons C hectare<sup>-1</sup> every year (Paustian et al. 2016).

Soil conservation is a set of measures striving to preserve the overall soil fertility. Three main principles are—less tillage, more soil cover and improved crop rotations—the first two can directly affect the carbon dynamics of cropping soil (Hunt et al. 2020). Increasing soil protection by crop residues or cover crops; or adding of organic matter to the soil through manure application, green manure, or crop residues; coupled with other elements of the farming system (fertilizers, pesticides, tillage equipment) can improve soil quality.

In systems that relied on tillage, residues were sometimes removed and used for some purposes, but more often, they are simply burnt to allow tillage in preparation for the next crop. Burning the biomass residue is the easiest and most time-efficient mode of ensuring that the field is ready for the next cropping season in time. Needless to say that this practice is not environmentally sustainable.

Crop residue burnings is a very common practice in the agricultural production of N. Macedonia. Although burning of post-harvest organic material and stubbles are banned by law, this is still a common practice especially in the phase of field preparation for the next cropping season. Crop residues should be treated as a fuel, compost, building materials or animal feed, not as waste. However, the crop residues can be significant source of organic matter, which normally should be incorporated in the agricultural soil.

Moreover, burning practice leads to severe degradation of air quality, which is of particular importance nearby urban centers. There are many reasons for this situation, among which tradition, unawareness for the disadvantages and damages, as well as inexistence of a functional system for control and support, are the most important ones. However, many of them although well aware of the consequences of open burning lack tools and know-how to adopt alternative practices.

There are no official data for the areas affected and quantities of the burned organic material in the agricultural sector, hence we cannot give an precise figure for the total annual loss of organic matter.

In the modern days of agricultural science, cover crop and crop rotation with green manuring offer a technology to achieve sustainable production efficiently.

**Cover crops** The term cover crop means several different measures of soil maintenance under vegetation: winter cover crops, green manure (among crops), sowing of fodder plants after the main crop, intercrop in perennial plantations etc. In winter cover cropping systems, when cover crops are part of the field crop rotation, usually in spring they are incorporated in soil as a green manure, enriching the soil with a high quantities of raw organic matter. When cover crops are used in perennial plantations, (vineyards, or orchards), usually grasses or mix of perennial grasses they have a combined roll: to reduce the cultivation, to conserve the soil moisture during the summer period and to enrich soil carbon with green manuring or mulching of the organic material and of course, to protect the soil during the winter. For all the above-mentioned effects, the role of cover crops cannot be considered strictly as a mitigation measure, aimed towards carbon sequestration on agricultural land, but also as an adaptive measure, given that cover crops play a protective role of soils during the summer (conservation of soil moisture) and autumn/spring periods (soil water erosion).

Cover crops can be annual, biennial or perennial herbaceous plants, often combination of several plant species of plants (Vukadinović and Vukadinović, 2016). Usually winter cover crops are used, like various legumes (clover, beans, etc.), rye (even a mixture of rye, barley and wheat), or some other grains that tolerates winter breeding conditions. Cover crops grown in summer are mainly intended for sideration and are used to fill the crop rotation for enrichment of the soil with nutrients, especially poorly fertile soils, or soil preparation for perennial crops. Various legumes are used, as well as other plant species such as millet, fodder sorghum, Sudan grass, rauola, buckwheat, etc., which will help to improve the physico-chemical properties of the soil and weed control.

There is a strong relationship between cover crops included into a field rotation of field crops and incorporated as a green manure and soil organic matter (SOC) content on agricultural soils. This relation is confirmed by many authors under different climatic and soil conditions, different management practices.

Still, it's should be noted that the effects of cover crop measure could significantly vary from case to case, depending to the: experimental period, which is very important in order to be able to detect treatment effects against the background noise due to spatial SOC variability and measurement errors, type of the cover crops and management practices could significantly influence results.

In vineyards the yearly accumulation of SOC could vary from 0.17 g/kg-1/y in the case of non-legume cover, up to 0.43 g/kg-1/y when legume crops are used and high nitrogen amendments are applied (Mazzoncini et al., 2011). Dong et al. (2005) is reporting an increasing of SOC for 3.4 kg/m<sup>3</sup> soil for the top layer (0-25cm) between variants with hairy vetch and ray used as cover crop in rotation with corn, and the variant with no cover crops, for a 10 years period. This means that the average increasing of the SOC per year could be estimated to 1.11 t/ha/y (or approx. 0.37 gr/kg-1/y), when only rye was used as a cover crop the mean annual increase of SOC was 0.81 t/ha/y (or approx. 0.27 gr/kg-1/y).

However, cover crops included in the crop rotation of field crops and its consecutive incorporation as green manure, is an operation aiming towards increase soil organic carbon. There are lot of evidences supporting this relationship. According Soon et al. (2007), in the top 15 cm layer after 12 years of field experiments of no-till versus vs. conventional tillage and 4 crop sequences, the highest increase of the SOC content is with red clover as cover crop in the rotation (20.3 gr/kg-1/y), then either the pea (17.8 gr/kg-1/y) or fallow rotation (18 gr/kg-1/y).

Usually, cover cropping is a measure commonly used in vineyards and orchard production, because farmers can establish and maintain perennial crops as a cover crops for several years, using them as an organic mulch or pressing the plants as a living mulch.

Vineyard and orchards management practices have been continuously intensified in the last decades, in terms of the planting systems and techniques applied, introduction of new high quality varieties. Crop production intensification, although increasing yields and quality, lowers soil fertility and biodiversity due to the excessive exploitation of natural resources, massive introduction of external inputs and substantial alteration of agroecosystem equilibria.

Cover crops in vineyards present multiple advantages like to increase soil organic matter content and nutrients in the soil, due to the mineralization of the aerial and underground biomass, improve soil physical properties as porosity, structure, and aggregates stability, increase water holding capacity, reduce soil erosion, and increase the biological activity in the soil (Frye and Blevins, 1989).

The effects of cover crops in viticulture can be very variable and contrasting, depending on the soil properties, type of cover crop, climate conditions and management practices. According Novara et al. (2019) the increasing of SOC content for a period of 5 years in vineyards of the Mediterranean, under *Vicia faba* as a cover crop compared to conventional cultivation on a sloppy terrain is 0.78 g/kg (0.16 g/kg-1/y) and 0.59 g/kg-1/y (0.12 g/kg-1/y) on a flat area. This is rather lower values, compared with the resulted

from other authors, but the specifics in management practices and climate conditions should be taken into account. For instance, in a similar Mediterranean climate conditions Manzzoni et al. (2011) when legume cover crops are amended with different amounts of nitrogen, the annual increase of SOC vary in a range of 0.43 g/kg for legumes with high nitrogen fertilizers application, 0.41 with low nitrogen application and 0.17 g/kg when non-legume crops are used as a cover crop, without nitrogen fertilization. Data for the effects of cover crops sown as an intercrop or used as manure, are reported in the work of Tarricone et al. (2020). According the authors the average increase of SOC for the two years period for all three treatments compared to conventional tillage is 33%. Highest content of SOC was found when white clover (*Trifolium subterraneum*) was sowed as cover crop – 25.51 g/kg, or annual increasing of 8.50 g/kg compared with conventional cultivation. Similar higher increasing of the SOC can be find in the research of Gattullo et al. (2020) who is reporting an increasing of 3.9 g/kg for a period of 3 years (1.3 g/kg/y) between vineyards under cover crops (6.76 g/kg) and conventional tillage (2.86 g/kg). These are a rather high increasing of SOC quantity, but it should be noted that the reported data are for a short period of experimentation of only two years.

Long term experiments are needed to obtain reliable data for the influence of cover crops, otherwise variability of SOC stock changes might be significant and are most probably due to the differences in the initial quantities of SOC on experimental fields, insufficient experimental time to detect the influence of the treatments, and background noise due to the spatial variability of soil properties and experimental errors (Poeplay et al., 2015).

Cover crops either used within the crop rotation or incorporated into the agricultural soil as a green manure, or used as an intercrop into perennial plantations, have a positive effect on the carbon sequestration through increasing of the organic carbon into the soil.

In order to improve the sustainability of wine grape production and maintain the level of soil carbon, farmers were advised to use the organic material produced with pruning of the vineyards as organic mulch together with some other organic by-products from the wineries, rather than dumping it off-site. The potential benefits from using of mulches includes: nutrient release, increased soil organic matter, improved soil structure, better physical and biological properties of the soil, etc. Pruning residues are the most accessible form of organic material for amendment of soils.

Some recent investigations, supports the theory for the benefits of mulching pruning residues in vineyards. An increase of more than 1.24 to 1.44% of SOM in the top soil layer (10 cm) compared to the control variant is reported by Yilmaz et al (2017). After 10 years of treatments, Garcia–Orenes et al. (2016) noted the higher concentrations of total organic carbon in the treatments with organic fertilization (grapevine pruning with sheep manure and grapevine pruning with legume cover crop), compared with treatment with inorganic fertilization.

It should be noted that, in many cases, proven benefits of certain actions and practices might not be adopted in practice due to its complexity of its adoption and implementation, cost-effectiveness, lack of finance etc. According our experience, mulching of the pruning residues was initially approved by the producers with enthusiasm, giving though that this practice spare then from a labor-intensive practice for manipulation of the pruning residuals and in the same time, the mulching of the pruning residues is of benefit for their soil. The high price of the mulching machine, which was not cost – effective for their small parcels under vineyards was the biggest obstacle for wide adoption of this measure in practice.

Previous investigation in the country showed that soil organic carbon content is reduced in agriculture land, especially at land under field crops with no crop rotation (monocrop) like: tobacco production, cereals etc., where the quantities of SOC are usually in a range of 0.5-3.2% or in average 1.5%. On perennial plantations the average content of SOC is somewhat higher (2.66%), ranging from 1.0 - 4.7%. According the soil experts, main reasons for depletion are: intensive soil tillage, uncontrolled use of mineral fertilizers and low application of organic fertilizers.

According Statistical yearbook of the R of N. Macedonia (2020), in 2019 a total area of 23.996 ha was under vineyards. The most vineyards are located in Vardar region with about 45% of total vineyards in the country. Most of the vineyards in this area are influenced with modified Mediterranean climate, characterized by moderately cold and rainy winters, and hot and dry summers. In an environment of nonexistence of national data, the similarity of climate and the other environmental factors in this agricultural region enables us to use results from other Mediterranean countries, as (Mazzonicini et al. 2011 and Novara et al. 2019) in our projections for the benefits of cover crop as an adaptation measure.

If we assume that these 45% of area under vineyards (approx. 11.000 ha) in this region, which is the center of the Macedonian wine production, will be under cover crops which could contribute with annual increase of 0.43 g/kg/y od SOC, then the total contribution of this measure to the yearly increase of soil carbon per hectare would be 1.5 t/ha/y, or 16.500 t/y of SOC on all area under vineyards in the Vardar region. With supposed linear increase of the quantities of soil carbon, we can expect an increase of 1% of the SOC in a period of 20 years. This is rather long period for SOC increase of one 1%, but it should be noted that this is result just to the effects of one measure, in an unfavorable climatic condition and under intensive production system.

What is important is that if these assumptions are right, we could be able to stop the depletion of the SOC on agricultural soil and even more to increase it to a certain extent with adoption of this measure. Still, the need for national experimental data is evident, if we want to have more precise picture for the effects of some adaptation measures in practice.

## Vulnerability in crop production

### *Effects of weather events on crops*

Huge portion of the crop production is located in open space therefore very exposed to the impact of the weather and extreme weather events. The expected climate change will worsen present situation and will further increase exposure of the crops. The sensitivity will also increase due to high temperatures that will make heat stress of the crops more frequent. Moreover, the most of the growing season maximal temperatures will be far above optimal for photosynthetic activities and crops will reduce their organic matter synthesis. The high temperatures expressed as prolonged and more severe heat waves will even increase present yield losses caused by heat waves and high temperatures. Moreover, the high temperatures contribute to the sun burns and discoloration of the fruits. The high temperatures combined with higher insolation are causing sun burns, on the crops, that is very evident on the terrains with West exposition or on the west side of the fields. The sun is low on the horizon, leaves cannot protect the fruits from that angle and sun burns will appear. This problem is present for a longer period in the country and grape growers in the country started to cover fruits from the West side with leaves. This is usually done by lower reduction of the vegetative growth and putting branches that are not cut over the fruits. However, the increased vegetative growth to apply this measure have negative impact to the biomass partitioning.

The high temperature should be always analyzed in combination with water availability. Crops use huge amount of water on transpiration not only for photosynthesis and transport of nutrients and assimilates, but also for cooling. The crops reacted differently to the high temperatures with changing the angle of the leaves, banding the leaves, making spiral shape of the leaves etc. just in order to reduce portion of the leaves exposed to direct sunlight. The real cooling can be done only by evaporative cooling as result of transpiration. However, the efficiency of this cooling is not very high, frequently there is not enough water and sometimes the transport of water from the roots to the leaves can not be fast enough to transport sufficient amount of water for transpiration. In such case crops will experience so called physiological drought, or crops experienced drought even though there is sufficient amount of the water into the soil. This is quite common situation in the country, and if supporting tissue is not strong enough effects are visible in form of wilting (sugar beet is the most evident case, with leaves felt on the soil in hottest period of the day), However, some crops express different signs, but this is quite common situation that affect the crops and reduce the crop yield particularly if high temperatures are accompanied with hot and dry wind. However, the much more common problem associated to the interaction of temperature and water is agricultural drought. The agricultural drought is happening almost every growing season in the majority of agricultural areas in the country. That's why North Macedonian agriculture is classified as water limited agriculture. Climate change will alleviate the drought problem, drought will be more prominent, more severe and will further reduce crop yield. Reduction of the precipitation during the summer period will further increase this problem. The latest evidence of the negative effects of prolonged heat waves was this growing season when number of growers were not able to prevent their tomato crops from abortion of the flowers caused by long lasting heat wave, increased air dryness and increased aridity. This caused very strange market response and price of tomato in the top of the season suddenly raised and quality of the tomatoes offered by the market was extremely low.

However, the crops in the country are exposed not only on high temperatures, lower precipitation and strong droughts. The opposite extremes as low temperatures and excessive rainfalls are also affecting the crop production. The important question is the last frost that happened in spring. The frequent frost damages on the early flowering fruits are recorded during the historical records. If last spring frost will be later in the season the damages are higher, more crops are affected and economical impact is alleviated. In last 5 years the last spring frost appeared much later in the season then regularly (close to the end of April) and caused severe damages to fruit growing sector. The climate change, will cause hither weather, but will cause higher variation in the appearance of the last spring frost and crops will be more exposed to this risk.

The excessive rainfalls create water logging on low permeable soils. Some crops as green pepper is very sensitive to water logging and lack of air into the soils and quickly reacts to the such condition. The crop can be destroyed even with several consecutive days of water logging. However, this is not very common because about 80 thousand hectares that are under risk of water logging are covered with constructed drainage systems. Several floods in the last period happened when soil should be cultivated and/or sowing window for summer crops is active and caused damages on agriculture, particularly in Bitola area.

The last several years some extreme intensive rainfalls happened and, in some cases, created tragical losses of human lives. Noting can be compared to this tragical situation, but later the agricultural soils in the surrounding were severely polluted by the deposited material transported by the flooding water to the level that agricultural production was not possible without land reclamation measures.

Moreover, the intensive rainfalls are promoting erosion proceses and number of other problems associated with weather and extrema weather evens are present in the country. These situation are evident even in present climate and it is expected to grow. Low adaptive capacities will make crop sector more vulnerable than previously. In such case only building of the adaptive capacities is available solution to reduce crop vulnerability.

Crop production is directly and indirectly affected by climate change in six main ways. Part of them are quite widely studied, but some need further investigation (Table 6).

Table 6. Direct and indirect effects of climate chnge on crop production

Climate change direct and indirect effects on crop production	Crop responses to direct climate change effects	
Climate change impact	Direct effect	Crop response
Direct effects Increasing CO <sub>2</sub> levels Changes in temperature, rainfall, radiation and humidity Extreme events, e.g. heat waves, hail, drought and looding	Increased CO <sub>2</sub>  Increased temperature	Increases in yield if other factors remain constant  Accelerates development and maturity resulting in yield reductions

<p>Indirect effects</p> <p>Shifts in crop suitability – creating a northward expansion of warm-season crops</p> <p>Changes in plant nutrition and the increasing incidence of weeds, diseases and pests pressures</p> <p>Degradation of resources, e.g. soil erosion; nutrient losses and environmental pollution</p>	<p>Decreased temperature</p> <p>Decreased rainfall</p> <p>Increasing rainfall</p>	<p>Increases susceptibility to late frosts</p> <p>Yield reductions although can be offset by early development</p> <p>Increases lodging resulting in yield loss</p>
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Source: Rial-Lovera et al., 2016

Climate projection in R. N. Macedonia and its impact on wheat, maize and grapevine production

The ensemble average, as previously explained, 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. The projections clearly display the spatial variability of yield impacts across the country and the difference between the crops. For rain-fed wheat, the major growing areas in the continental and Mediterranean agro-ecological zones are projected to experience a moderate increase in yields of up to 10% for both 2025 and 2050. For rain-fed maize, moderate (0-10%) and severe yield declines (10-25%) are projected for the majority of Macedonia by 2025 and almost all of Macedonia is projected to experience severe maize yield declines of up to 25% by 2050, with some highly vulnerable areas projecting catastrophic yield declines of greater than 25%.

Vineyards in in the country have unfavorable structure in terms of the age of the plantations (MAFWE, 2011). In the same time the size of the plots is very small which is due to the long-term fragmentation of the agricultural land as a result of the inheriting tradition, inexistence of land market and long period of insufficient investments in this sector. More than 60% of the vineyards are older than 15 years. This situation of small parcels and old plantations makes the viticulture sector prone to the negative impact of climate change which is especially due to the low capacity of farmers to apply effective CC adaptation measures and low efficiency of the adaptive measures on small sized plots.

Climate changes are expected to cause yields losses in most agriculture crops. The second national plan of the UNFCCC (2008) estimates annual losses of around 30 million euro’s by 2025 due to reduced yields of winter wheat, grapes and alfalfa, if there is no irrigation. Analyses in

various studies have shown that a significant decline in crop yields can be expected if climate changes adaptation measures are not implemented. These losses are projected to increase over time. Without adaptation the losses could become larger than current net income, which would jeopardize the economic sustainability of agriculture in some parts. There will be probably losses even for irrigated crops, although those losses are projected to be smaller compared to losses for non-irrigated crops.

### ***Study approach***

Wheat is most important staple food and with sowing area of 73072 ha is the most common cereal crop, with an increasing trend of only 0.2%, but with realized production 17% higher compared with 2017 (241 106 t), which is exclusively due to the higher average yield per unit area (3,396 kg ha<sup>-1</sup> in 2018 versus 2,746 kg ha<sup>-1</sup> in 2017). The total needs for wheat and wheat flour for the milling industry have been around 300,000 tons/years. Including 2018, the milling companies purchased about 78,000 tons of mercantile wheat, which represents 32% of domestic production.

Maize is mainly use as animal feed and is cultivate on 36 417 ha or on 22.1% of the areas with cereals with a tendency to increase (31 429 ha in 2017). Analogous to the areas, the realized total production in 2018 is the largest - 187 676 t or has an increasing trend of 46% compared to 2017 (120 156 t). The increased production is also a result of the increased average yield per unit area, which in 2018 is 5 164 kg ha<sup>-1</sup>.i.e. 26% higher than in 2017 (3,840 kg ha<sup>-1</sup>).

Viticulture is an important agricultural branch with participation of 17-20% of agricultural GDP. After tobacco wine is the second most important product in terms of export value of agricultural products. The importance of this sector is bigger because from about 25,000 farms which are involved in grape production, 70% are individual. The vineyards have a trend of constant growth, from 21,000 ha as registered in 2011, to 24,000 ha in 2016 (or by 9%). The share of vineyards in the arable land for the same period increased from 4.11% (in 2011) to 4.65% (in 2016). In the grape assortment, the table varieties are present with 30%, while the wine one account 70%, of which 60% are red and 40% are white varieties.

In the present study the trends of the certain climate indicators have been estimated by three RCP scenarious: 2.6, 4.5 and 8.5, using three values of the temperature as a base:  $n = 0^{\circ}\text{C}$ ,  $n = 5^{\circ}\text{C}$  and  $n = 10^{\circ}\text{C}$  respectively comparing the two 30-year periods – 2030 (near-future) and 2060 (distant future) with the 2000, with predictions how these changes will affect to the potential wheat, maize and grapevine production. For the analysis of the results, five grids were selected for each crop, a selection which was made based on the total production of the specific crop realized in the last five years (period 2015-2019) (Statistic Yearbook of the RN Macedonia, 2020). Grids 308 (Bitola), 411 (Mogila), 917 (Sveti Nikole), 712 (Dolneni) and 1314 (Kumanovo) were

selected for wheat (photo 1). Grids 308 (Bitola), 504 (Struga), 722 (Bosilovo), 1106 (Bogovinje) and 1118 (Cheshinovo / Oblechevo) stood out for maize (Photo 2), while grids 520 (Valandovo / Gevgelija), 617 (Demirkapija), 716 (Kavadarci)/Negorino / Rosoman), 914 (Veles) and 920 (Radovish) were selected for grapevine (Photo 3). Each of grids covered an area of 10 x 10 km.

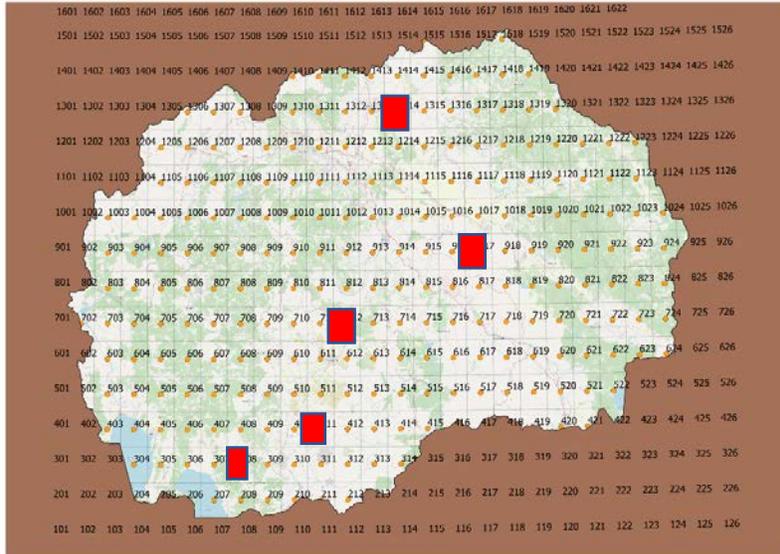


Figure 27.. Selected grids for wheat



Figure 28.. Selected grids for maize

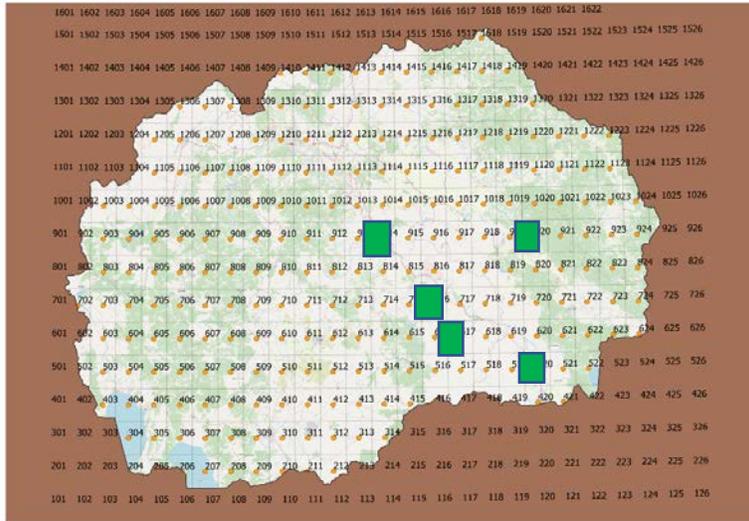


Figure 29. Selected grids for grapevine

### Case study - Wheat

#### Mean daily temperature

Table 7 and Figure from 27 to 29 show the changes in daily temperature values in case of wheat. The values are present as averages of the selected grids for the period 2000-2030-2060, for the three scenarios.

Table 7. Wheat: Mean daily temperature

	t 0 °C			t 5 °C			t 10 °C		
	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
2000	12,6	13,2	13,1	15,5	16	15,9	18,5	17,9	17,8
2030	13,8	13,6	13,6	15,3	15,6	16	19,2	18,2	18,6
2060	13,9	14,1	14,6	15,3	15,6	16,5	19,1	18,8	19,2

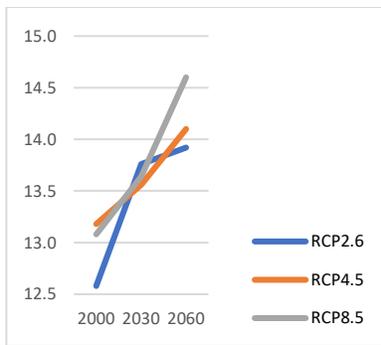


Figure 30.. Wheat, t 0 °C. Mean daily temperature, period 2000-2060, RCP2.6-RCP8.5

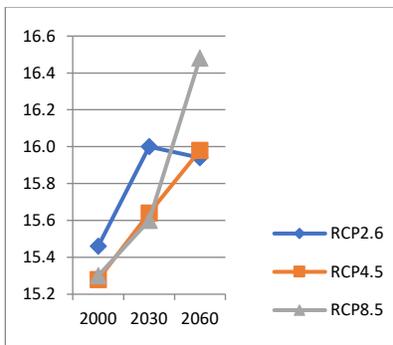


Figure 31.. Wheat, t 5 °C. Mean daily temperature, period 2000-2060, RCP2.6-RCP8.5

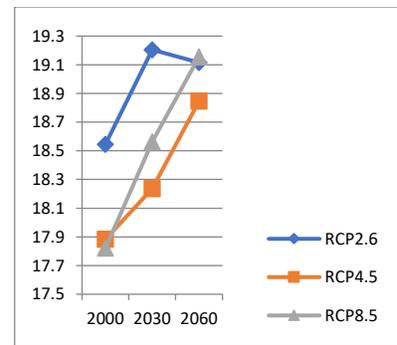


Figure 32.. Wheat, t 10 °C. Mean daily temperature, period 2000-2060, RCP2.6-RCP8.5

As compared 2000 with 2030 and 2060 the mean annual temperature at t 0 °C will rise by 1,2 and 1,3 °C in RCP2.6, by 0,4 and 0,9 °C in RCP4.5 and by 0,5 and 1,5 °C in RCP8.5 (Chart 1). The differences between RCP's at t 5 °C are almost negligible and only in RCP8.5 in 2060 (compared to 2000) the temperature will increase by 0,6 °C (Chart 2). When t base is 10 °C the mean daily temperature will increase by 0,7 and 0,6 °C in RCP 2.6, by 0,5 and 0,9 °C at RCP4.5 and by 0,8 and 1,4 °C in RCP8.5 respectively (Chart 3). The question is how such an increase in average temperature will affect to the vulnerability of wheat production. The increased temperature has negative impact of photosynthesis and respiration and reduces the yield of wheat. The optimum temperature for photosynthesis is 20-25 °C; at the higher temperature (35-36 °C), the photosynthesis process completely stops. Grain formation and filling, beginning after the flowering and largely determining the yield, strongly depend on intensity of photosynthesis. Rise in night-time temperature will cause intensified respiration, which will negatively affect wheat growth, development and productivity. High temperature and moisture deficit in autumn cause drought that adversely affects seed germination and reduces plant density per unit area. It impedes plant germination and reduces the percentage of overwintered plants. High temperature in spring and early summer in conjunction with moisture deficit has a negative effect on wheat heading, reducing the amount of productive heads per unit area. When drought appears during the booting process, it impedes the growth of wheat to its normal size, while during the flowering stage it reduces the number of grains per plant. High temperature and moisture deficit after the flowering stage cause early ripening, shorten the period during which grains are supplied with nutrients and negatively affect yields. For the selected territory with wheat the increase of mean temperature expected in 2030 and 2060 against 2000 is likely to hamper photosynthesis. Assesing et al. (2014) found that for each °C increase in global mean temperature, there is a reduction in global wheat grain production of about 6%, with a 50% probability of between -4.2% and -8.2% loss, based on the multi-model ensemble. Considering present global production of 701 Mt (<http://www.fao.org>) and impacts of temperature only, and assuming no change in production areas or management, 6% means a possible reduction of 42 Mt per °C of temperature increase. Xiao et al (2018) also conclude that future climate change could have a significant impact on wheat phenology particularly in changes in flowering and

maturity dates under the RCP4.5 and RCP8.5 scenarios, where the effects of RCP8.5 on phenology were significantly higher than those of RCP4.5.

*The last spring frost*

A spring frost occurs when the minimum air temperature drops below 0°C, even the average daily air temperature is still positive (Graczyk and Szwed, 2020).

The projections for the appearance of the last spring frost in the selected grids for wheat and the differences in the number of days between the analyzed years and scenarios are presented in Chart 4 and 5.

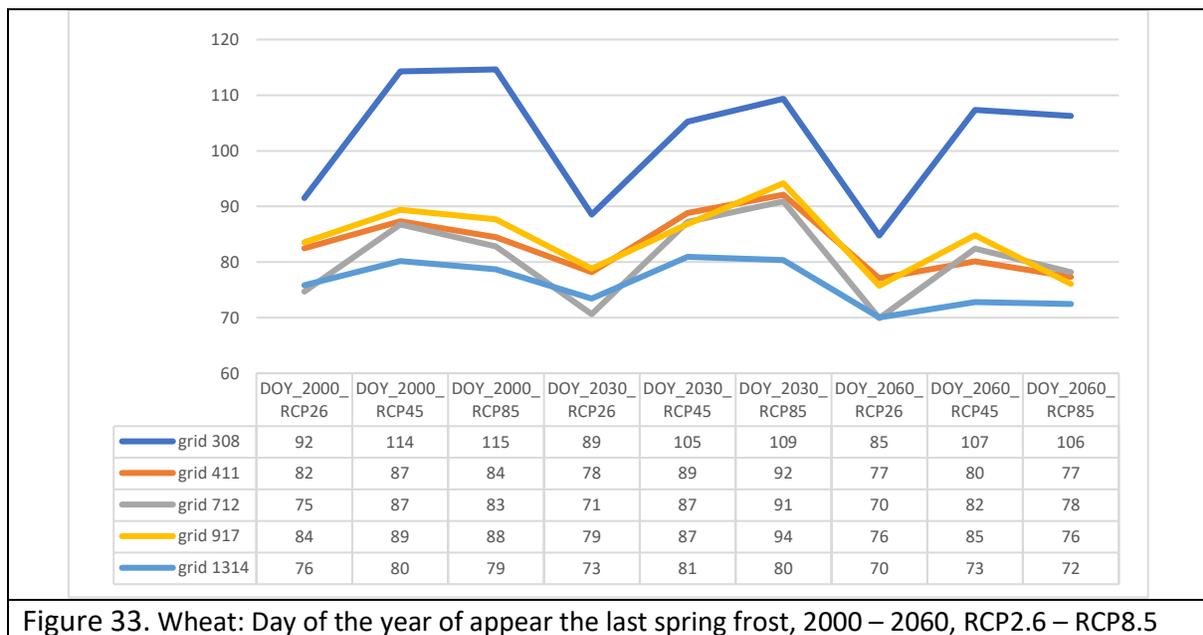


Figure 33. Wheat: Day of the year of appear the last spring frost, 2000 – 2060, RCP2.6 – RCP8.5

Analyzed by grids the last spring frost at grid 308 in 2000 compared RCP2.6 with RCP4.5 and RCP8.5 appeared later for 22 and 23 days, for 16 and 20 days in 2030 and for 22 and 21 in 2060 respectively. For grid 411 these differences in terms of their latter occurrence are 5 and 2 days in 2000, 11 and 14 days in 2030 and 3 days in case of RCP8.5 comparing with RCP2.6 in 2060. Identical trend of increasing the number of days when comparing the RCP scenarios was found at the other grids: from 8 (RCP8.5/2000 and RCP8.5/2060) to 20 (RCP8.5/2030) at scenario 712; from 4 (RCP8.5/2000) to 15 days (RCP8.5/2030) at grid 917 i.e. from 2 (RCP8.5/2060) to 9 days (RCP8.5/2030) in case of grid 1314 respectively (Chart 4).

Analyzed by grids compared 2000 with 2030 and 2060 in the certain RCP's scenarios, the last spring frost in all analyzed grids appeared earlier: from 2,4 days at grid 1314 (RCP2.6/2030-2000)

to 6,9 days at grid 308 (RCP4.5/2060-2000). Only in case of RCP8.5 in 2030 at grids 712, 917 and 1314, the last spring frost will occur later, for 1,7 (grid 1314) to 8,1 days (grid 712) respectively (Chart 5).

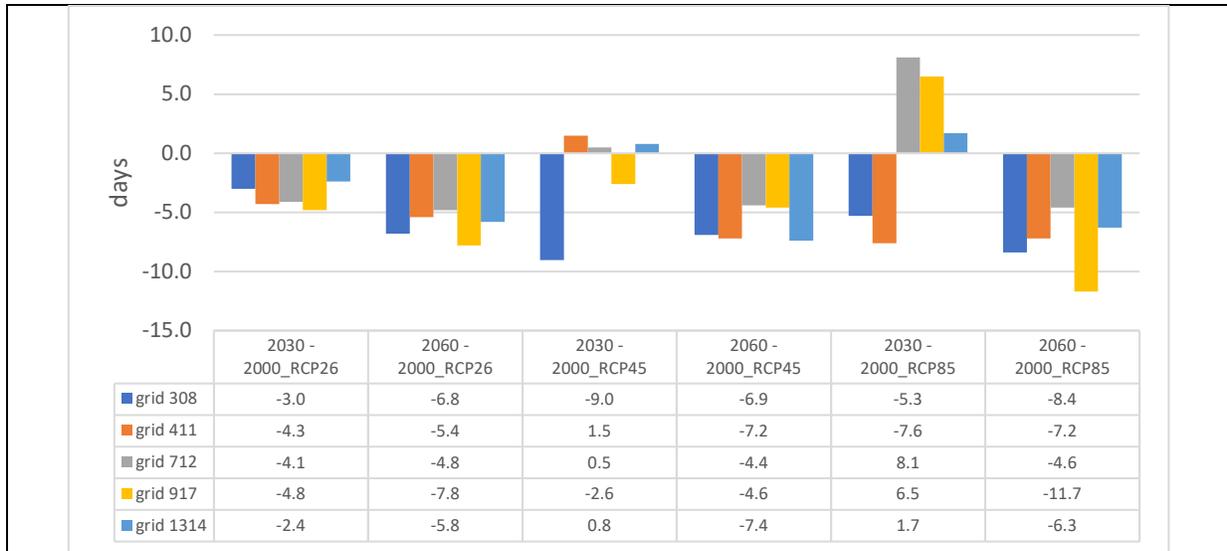


Figure 34. Wheat: Differences in number of days of appear the last spring frost between different years and scenarios

In this projections that was not done, but what is especially important is at what stage of wheat development does the spring frost occur and the damages they can cause. The injury symptoms of wheat resulting from spring frost is presented in Table 8.

Table 8. Injury Symptoms of Wheat Resulting from Freezing Temperatures

Growth stages	Approximate injurious temperature (two hours)	Primary symptoms	Yield effect
Tillering	-11 °C	Leaf chlorosis; burning of leaf tips; silage odor; blue cast to field	Slight to Moderate
Jointing	-4 °C	Death of growing point; leaf yellowing or burning; lesions, splitting or bending of lower stem; odor	Moderate to Severe
Boot	-2 °C	Floret sterility; head trapped in boot; damage to lower stem; leaf discoloration; odor	Moderate to Severe

Heading	-1 °C	Floret sterility; white awns or white heads; damage to lower stems; leaf discoloration	Severe
Flowering	1 -2 °C	Floret sterility; white awns or white heads; damage to lower stems; leaf discoloration	Severe
Milk	2 °C	White awns or white heads; damage to lower stems; leaf discoloration; shrunkened, roughened or discolored kernels	Moderate to Severe
Dough	2 0C	Shriveled or discolored kernels	Slight to Moderate

Source: <https://sanangelo.tamu.edu/extension/agronomy/agronomy-publications/freeze-injury-on-wheat/>

Hence, changes in the sowing period from the optimal sowing deadlines (period between 15 October and 15 November when in our conditions wheat is sowing) would be more than risky. High temperatures at the beginning of autumn can have adverse effects on the germination and can cause early development, increasing in the same time the vulnerability to insects and viral infection. Late sowing of winter wheat is also detrimental to yields. Late planting does not allow enough time for crop growth before dormancy sets in. This can result in insufficient root growth, making the plants more susceptible to drought and winter injury. In addition late planting can prevent the crop from achieving full vernalization prior to dormancy. Solutions must be sought in sowing of varieties resistant to low temperatures as well as genotypes with shorter vegetation that would reach grain maturity in the third decade of June.

*Growing degree days (Sum of effective temperatures)*

Growing Degree Day (GDD) is a measurement of the heat accumulation above a specific base temperature. It relates plant growth, development and maturity (Parthasarathi, Velu, & Jeyakumar, 2013) in terms of specific GDD requirement of each phenological stage. On the whole, the growing season length and actual dry matter production critically depend on seasonal temperature conditions. It is calculated by the formula:

$$GDD = \frac{T_{max} + T_{min}}{2} - T_{base}$$

For wheat T base is 5 °C.

Table 9. Wheat: Sum of effective temperature depends from grids, year and scenario, t 0 °C

	grid 308	grid 411	grid 712	grid 917	grid 1314	
	t sum ndy	Average				

										RCP2.6	
RCP2.6/2000	3612	318	4526	330	4397	13.5	4608	333	4659	334	4360
RCP2.6/2030	3868	328	4825	339	4677	13.9	4786	332	4690	331	4569
RCP2.6/2060	3884	325	4849	335	4700	14.1	4763	332	4670	332	4573
											RCP4.5
RCP4.5/2000	3146	302	4504	330	4292	336	4860	337	4957	341	4352
RCP4.5/2030	3340	311	4773	335	4515	332	5020	339	4890	338	4508
RCP4.5/2060	3530	315	5003	338	4736	339	5135	344	5004	344	4682
											RCP8.5
RCP8.5/2000	3118	301	4481	330	4271	333	4904	335	5012	340	4357
RCP8.5/2030	3417	317	4894	343	4627	335	5247	341	5118	341	4661
RCP8.5/2060	3771	324	5314	347	5022	343	5523	347	5376	347	5001

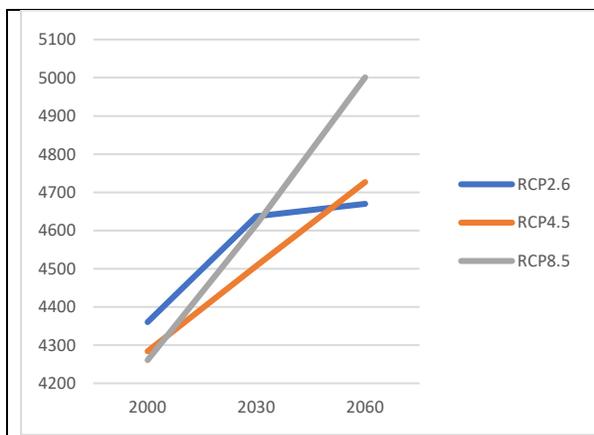


Figure 35. Wheat: average effective temperature  $t$   $^{\circ}\text{C}$ , years vs RCP scenario

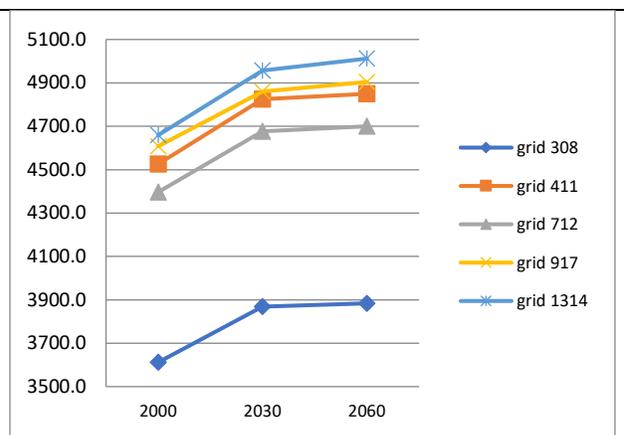


Figure 36. Wheat: Sum of effective temperatures,  $t$   $^{\circ}\text{C}$ , scenario RCP2.6 (2000-2060)

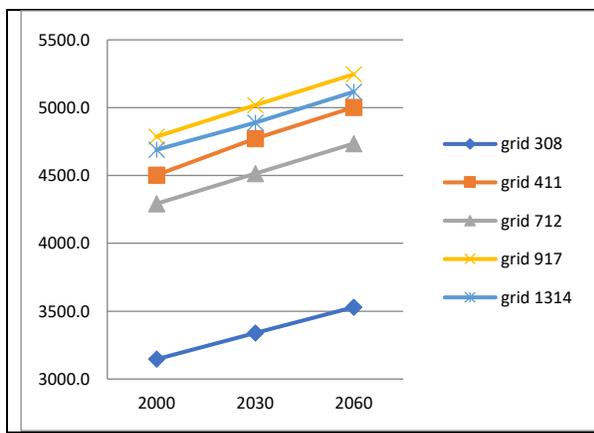


Figure 37. Wheat: Sum of effective temperatures,  $t$   $^{\circ}\text{C}$ , scenario RCP4.5 (2000-2060)

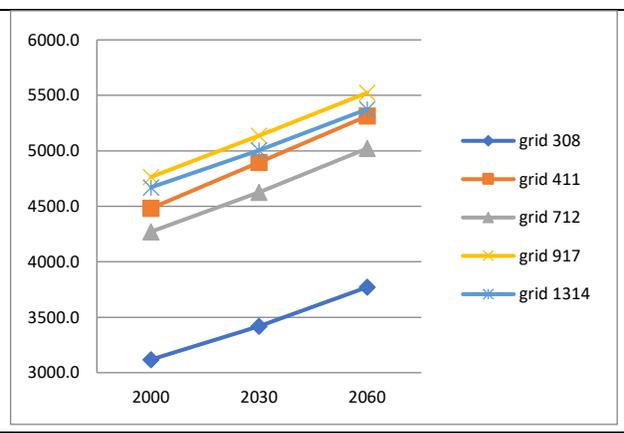


Figure 38.. Wheat: Sum of effective temperatures,  $t$   $^{\circ}\text{C}$ , scenario RCP8.5 (2000-2060)

In case when  $t$  is  $^{\circ}\text{C}$  with the exception of the RCP2.6 scenario where in all grids from 2000 to 2030 the temperature tends to increase intensively while by 2060 that increase is more

moderate, in scenarios 4.5 and 8.5 the increase is always with a more pronounced upward line (Chart 7-9). The same conclusion was determined during the analysis of the average values, where in 2030 and 2060 compare with 2000 the effective temperatures are increased by 209 and 213 °C (RCP2.6), by 156 and 330 °C (RCP4.5) and by 304 and 644 °C (RCP8.5) respectively (Chart 6). Considering the grids, the lowest values of effective temperatures in all scenarios were determined at grid 308 - from 3118 °C (RCP8.5 / 2000) to 3884 °C (RCP2.6 / 2060). The other grids have much higher sum of temperatures reaching a value up to 5523 °C at grid 917 (RCP8.5 / 2060). What is more than obvious is the large differences in the increased effective temperatures between the grid 308 and the other four, differences that are up to 1800 °C (Table 3).

Identity in terms of increasing of effective temperatures is found at a minimum of t 5 °C, both separately between the grids (Chart 11 – 13) and according to the established average values (Chart 12). The lowest values again were determined at grid 308 - from 2930 °C (RCP8.5 / 2000) to 3688 °C (RCP2.6 / 2030). The other values ranged from 4116 °C at grid 712 (RCP8.5 / 2000) to 5413 °C (RCP8.5 / 2060) at grid 917 (Table 4).

Table 10. Wheat: Sum of effective temperature depends from grids, year and scenario, t 5 °C

	grid 308		grid 411		grid 712		grid 917		grid 1314		average
	t sum	ndy	t sum	ndy							
											RCP2.6
RCP2.6/2000	3437	253	4384	278	4246	270	4463	278	4507	278	4208
RCP2.6/2030	3688	263	4681	287	4527	280	4717	284	4809	287	4484
RCP2.6/2060	3727	268	4733	291	4571	284	4779	289	4881	291	4538
											RCP4.5
RCP4.5/2000	2952	228	4370	279	4142	270	4655	286	4550	282	4134
RCP4.5/2030	3150	238	4648	290	4372	279	4889	292	4751	288	4362
RCP4.5/2060	3344	247	4887	297	4611	289	5133	300	4996	297	4594
											RCP8.5
RCP8.5/2000	2930	227	4340	277	4116	268	4628	284	4527	280	4108
RCP8.5/2030	3207	241	4772	299	4488	288	5013	301	4875	297	4471
RCP8.5/2060	3578	256	5207	307	4901	298	5413	308	5258	305	4871

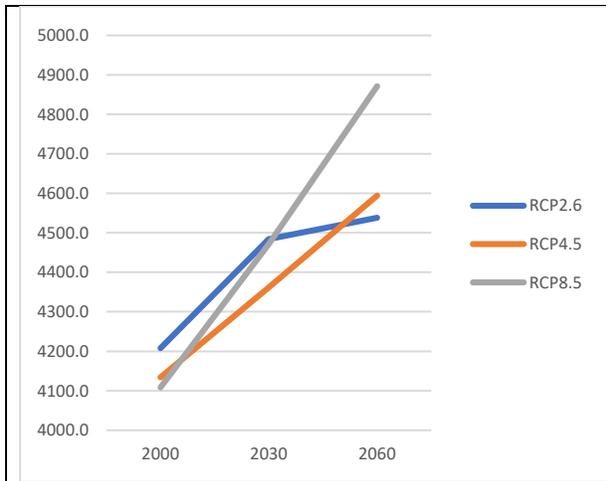


Figure 39.. Wheat: average effective temperature t 5 °C, years vs scenarios

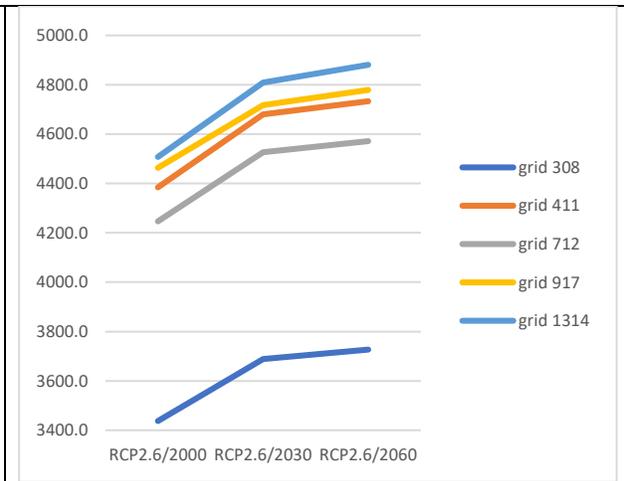


Figure 40. Wheat: Sum of effective temperatures, t 5 °C, scenario RCP2.6 (2000-2060)

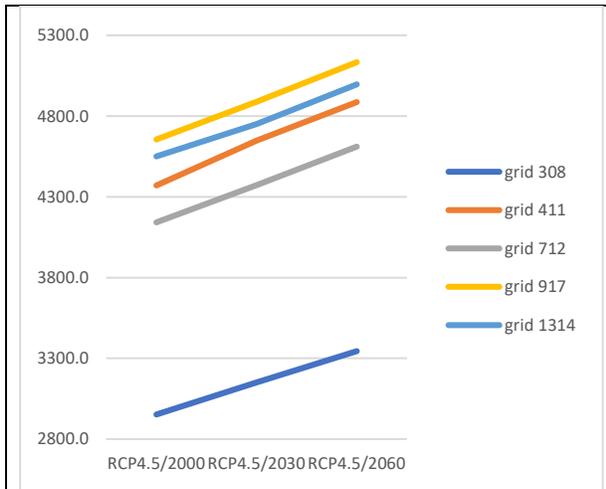


Figure 41.. Wheat: Sum of effective temperatures, t 5 °C, scenario RCP4.5 (2000-2060)

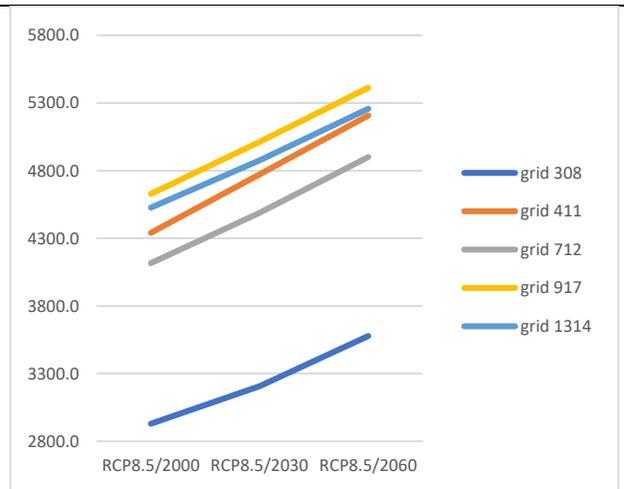


Figure 42. Wheat: Sum of effective temperatures, t 5 °C, scenario RCP8.5 (2000-2060)

At t 10 °C the trend of increasing of effective temperatures is almost identical (as t 0 and 5 °C), with the exception of grid 308 in scenario RCP2.6 where from 2904 °C in 2000, the effective temperatures in 2030 increase for 752 °C and then in 2060 decrease for 496 °C (compared 2060 with 2030) (Chart 15). The determined average values in all scenarios in 2000 are almost identical by sum of temperatures (3736, 3642 and 3628 °C respectively). In 2030 in the RCP2.6 the effective temperatures increase by 365 °C reached 4101 °C, and then in 2060 decrease by 60 °C, to 4041 °C. In the RCP4.5 differences in increased temperature in 2030 and 2060 vs 2000 were ranked from 226 and 453 °C, while in RCP8.5, 308 and 739 °C respectable (Table 5; Chart 17).

Table 11. Wheat: Sum of effective temperature depends from grids, year and scenario, t 10 °C

	grid 308		grid 411		grid 712		grid 917		grid 1314		average
	t sum	ndy	t sum	ndy							
											RCP2.6
RCP2.6/2000	2904	181	3906	214	3797	210	4012	217	4061	217	3736
RCP2.6/2030	3656	208	4189	221	4059	217	4263	223	4340	224	4101
RCP2.6/2060	3160	191	4232	224	4085	219	4304	226	4424	229	4041
											RCP4.5
RCP4.5/2000	2437	159	3866	212	3657	205	4175	221	4074	218	3642
RCP4.5/2030	2623	167	4141	223	3879	213	4419	230	4277	225	3868
RCP4.5/2060	2816	175	4395	232	4083	219	4665	238	4517	233	4095
											RCP8.5
RCP8.5/2000	2405	157	3865	213	3651	205	4156	221	4061	217	3628
RCP8.5/2030	2649	165	4223	226	3947	215	4504	234	4359	228	3936
RCP8.5/2060	3036	181	4700	241	4362	227	4957	247	4780	241	4367

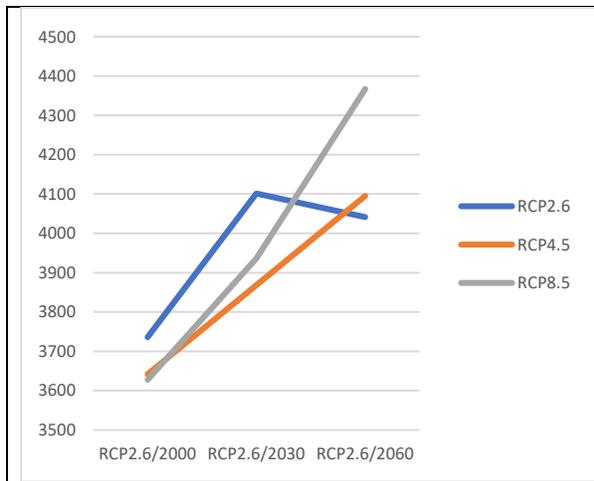


Figure 43. Wheat: average effective temperature, t 10 °C, years vs RCP scenario

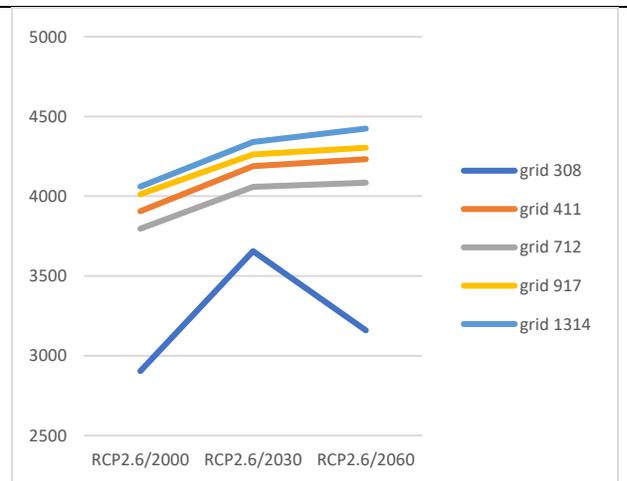
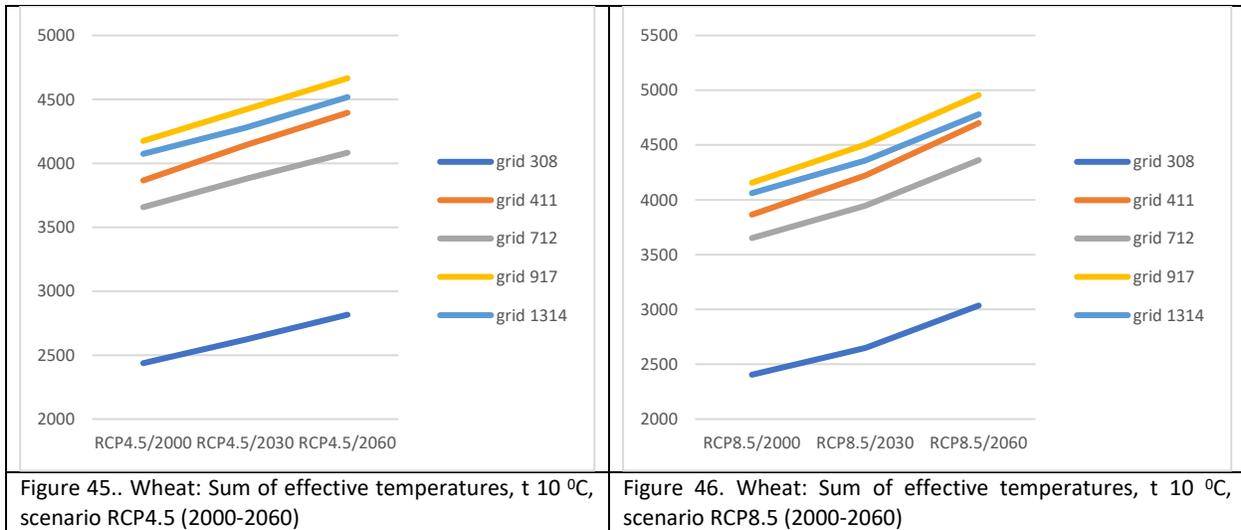


Figure 44. Wheat: Sum of effective temperatures, t 10 °C, scenario RCP2.6 (2000-2060)



Depends from the year, variety and time of sowing the GDD for winter wheat varieties are around 2000 °C (<https://ipad.fas.usda.gov/>). Regardless of the test temperature in our investigations (0, 5 and 10 °C) such high values of effective temperatures will certainly be one of the essential factors that will affect the vulnerability in wheat production in the near-future and distant future (2030 and 2060). Without appropriate measures which will mitigate the negative impacts and without the application of appropriate adaptation measures, wheat production in the next 50 years would be drastically reduced.

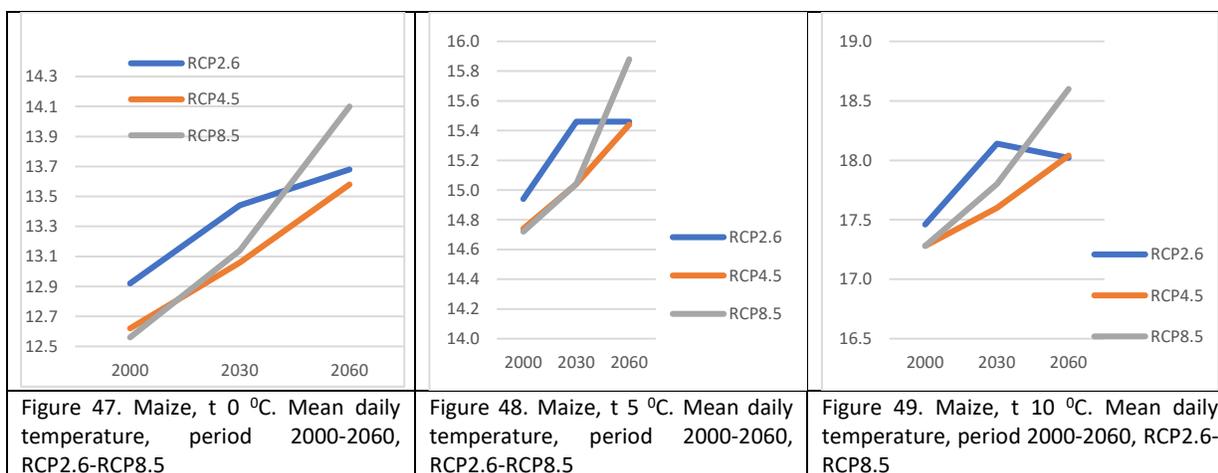
### Case study – Maize

#### Mean daily temperature

Table 7 as well Chart from 18 to 20 show the changes in daily temperature values. The values are shown as averages of the selected grids for maize for the period 2000-2060, for the three scenarios.

Table 12. Maize: Mean daily temperature/RCP scenario

	t 0 °C			t 5 °C			t 10 °C		
	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
2000	12.9	12.6	12.6	14.9	14.7	14.7	17.5	17.3	17.3
2030	13.4	13.1	13.1	15.5	15.0	15.0	18.1	17.6	17.8
2060	13.7	13.6	14.1	15.5	15.4	15.9	18.0	18.0	18.6



According to the calculated values compared 2030 and 2060 with 2000 the temperature will rise for 0,5 and 0,8 °C at RCP2.6; for 0,5 and 1,0 °C at RCP4.5 and for 0,5 and 1,5 °C at RCP8.5 when t = 0 °C. The same trend of increasing is concluded at t = 5 and 10 °C, from 0,6 °C in RCP2.6, to 1,2 °C in RCP8.5 and from 0,5 in RCP2.6 to 1,3 °C in RCP8.5 respectively (Table 7). What is more characteristic are large differences in average daily temperatures between the examined grids and years, with marked differences between grid 308 and 722 where temperature increases for 3,6 and 3,5 °C at RCP2.6, for 3,9 and 4,3 °C at RCP4.5. i.e. for 4,0 and 4,7 °C at RCP8.5 respectively. The differences between grid 308 and the others selected are between 1-3 °C (Table 8).

Table 13. Mean daily temperature by grid (t = 10 °C)<sup>2</sup>

	t avg 308	t avg 504	t avg 722	t avg 1106	t avg 1118
TAO_2000_RCP2.6	16.1	17.3	19.0	16.5	18.4
TAO_2030_RCP2.6	16.6	18.0	19.7	17.2	19.2
TAO_2060_RCP2.6	16.5	17.9	19.6	17.1	19.0
	t avg 308	t avg 504	t avg 722	t avg 1106	t avg 1118
TAO_2000_RCP4.5	15.3	16.9	18.9	16.8	18.5
TAO_2030_RCP4.5	15.7	17.2	19.2	17.1	18.8
TAO_2060_RCP4.5	16.1	17.7	19.6	17.6	19.2
	t avg 308	t avg 504	t avg 722	t avg 1106	t avg 1118
TAO_2000_RCP8.5	15.3	16.9	18.9	16.8	18.5
TAO_2030_RCP8.5	16.0	17.4	19.3	17.4	18.9
TAO_2060_RCP8.5	16.8	18.2	20.0	18.3	19.7

<sup>2</sup> Example is for t = 10 °C, as a threshold temperature for maize development

Various studies have been carried out to assess the impact of climate change on maize production in which revealed that rising temperatures shortened crop growth stage and reduced maize yields, hence revenue from maize decreased (Wandaka, 2013). Maize production is expected to decrease by 23% by 2100 based on simulations from climate scenarios (Wandaka, 2013)

*The last spring frost*

The appearance of the last spring frost in the selected grids for maize and the differences in the number of days between the analyzed years and scenarios are presented in Chart 21 and 22. In the five grids the curve of increasing or decreasing which represent the number of days in the year until the appearance of the last spring frost (depending on the year and the RCP scenario) is identical, with the most expressive in the case of the RCP2.6 where the appearance of the last spring frost is the latest, while in RCP4.5 and RCP8.5 the number of days is reduced, i.e. the possible occurrence of the last spring frost is earlier. According to the grids, the most sensitive will be 722 where the spring frost will appear the earliest – 70 day of the year (RCP2.6/2030) with differences with RCP4.5 and RCP 8.5 for 9 and 5 days, as well as in 2060 – 68 day of the year with differences between RCP’s of only of 1 day (RCP4.5 vs RCP2.6). The latest occurrence is determined at grid 308 where in 2030 when comparing RCP4.5 and 8.5 with 2.6, the last spring frost occurs later for 16 and 20 days, i.e. for 22 and 21 days in 2060 respectively (Chart 21).

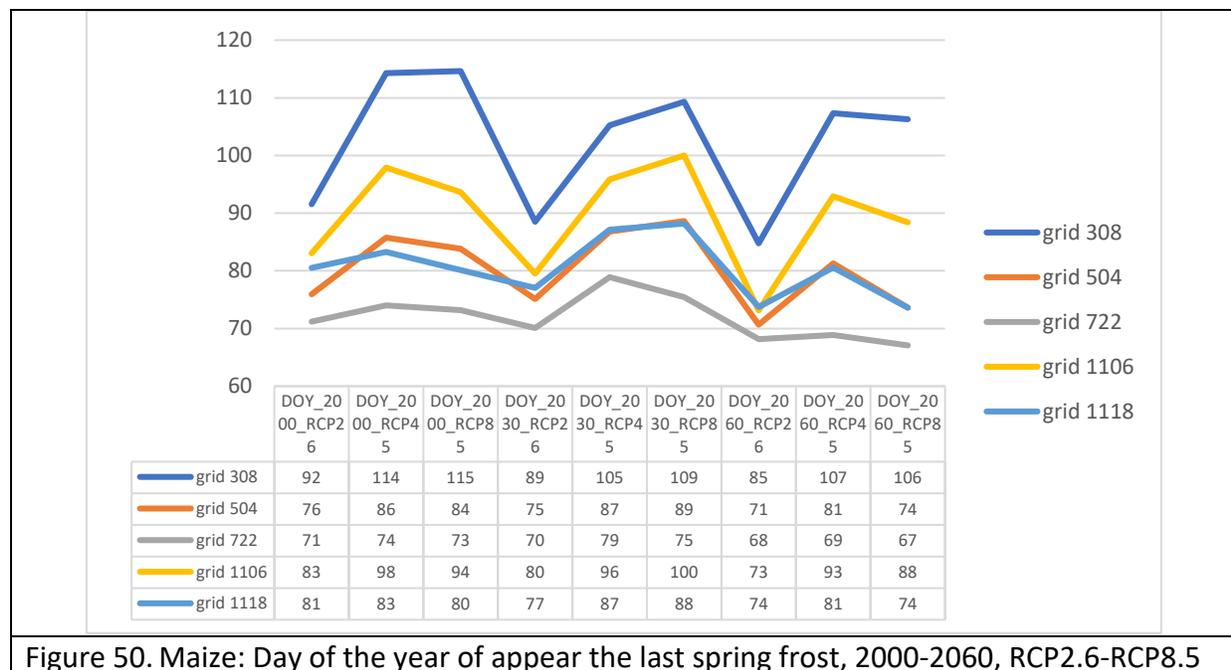


Figure 50. Maize: Day of the year of appear the last spring frost, 2000-2060, RCP2.6-RCP8.5

Analyzing the differences in days until the appearance of the last spring frost between the examined years and scenarios, a positive number of days were determined in grids 504, 722,

1106 and 1118, when comparing 2000 with 2030 specifically in the scenario RCP4.5 - from +1 day (grid 504) to +4.9 (grid 722) and in the scenario RCP8.5 - from + 2.2 days (grid 722) to 8.1 days (grid 1118). In all other scenarios the number of days had negative values, i.e. the spring frost would appear earlier, in some cases for more than 10 days (grid 504, RCP8.5, 2060-2000) (Chart 22).

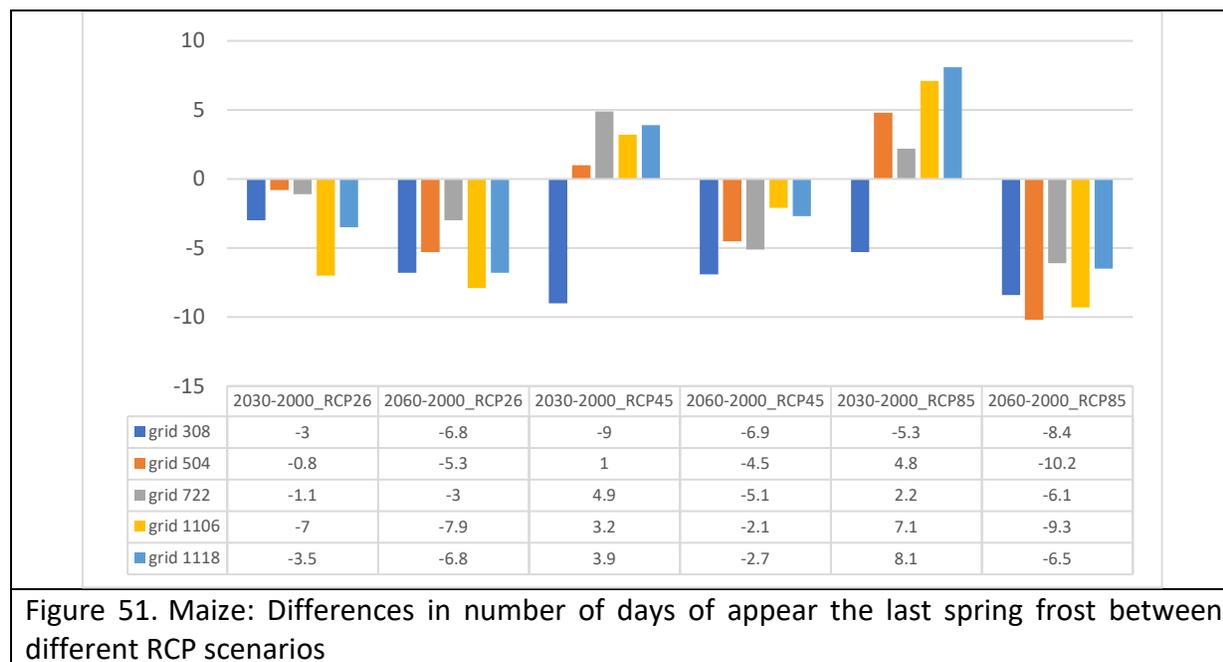


Figure 51. Maize: Differences in number of days of appear the last spring frost between different RCP scenarios

Having in mind that maize as a spring crop (in our conditions) is sown from April 20 (110th day of the year) and genotypes with shorter vegetation even later, according to the existing values only in the case of grid 308 there is a danger of spring frost damages which in the dependence on the year and the scenario occurs between 106 and 115 days of the year. On the other hand, early sowing as a measure of adaptation in some future scenarios as a result of the increased temperature might prove to be risky considering the fact that the calculated values for the appearance of spring frost are between 67 and 100 days/year.

#### Sum of effective temperature

In case of maize the values of effective temperature depends from grids, scenario and years are as follows:

Table 14. Maize: Sum of effective temperature depends from grids, year and scenario, t 0 °C

	grid 308		grid 504		grid 722		grid 1106		grid 1118		average
	t sum	ndy	t sum	ndy	t sum	ndy	t sum	ndy	t sum	ndy	
RCP2.6/2000	3612	319	4375	341	4989	344	3745	307	4751	337	4294

RCP2.6/2030	3868	328	4691	349	5293	352	4083	320	5022	342	4591
RCP2.6/2060	3884	325	4695	344	5339	350	4095	316	4985	342	4600
											RCP4.5
RCP4.5/2000	3146	302	4087	335	4917	341	3769	310	4674	334	4119
RCP4.5/2030	3340	311	4299	340	5138	344	3962	317	4895	338	4327
RCP4.5/2060	3530	315	4535	343	5345	347	4222	323	5119	342	4550
											RCP8.5
RCP8.5/2000	3118	301	4063	335	4889	341	3750	310	4648	333	4093
RCP8.5/2030	3417	317	4419	345	5245	350	4100	325	5000	344	4436
RCP8.5/2060	3771	324	4821	349	5603	352	4526	331	5387	347	4822

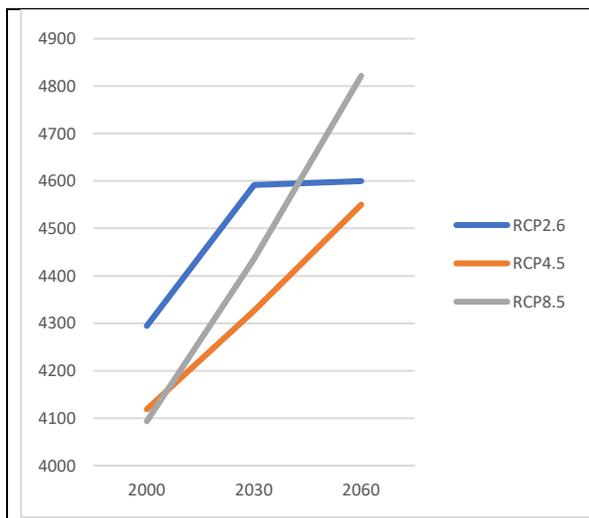


Figure 52. Maize: average effective temperature, t 0 °C (years vs scenarios)

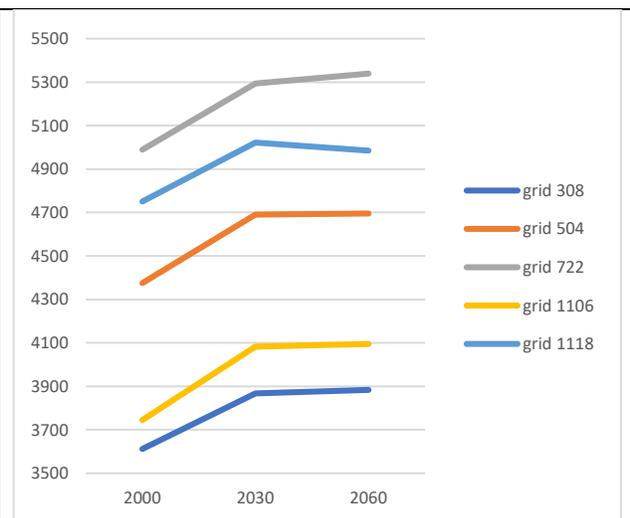


Figure 53. Maize: Sum of effective temperatures, t 0 °C, scenario RCP2.6 (2000-2060)

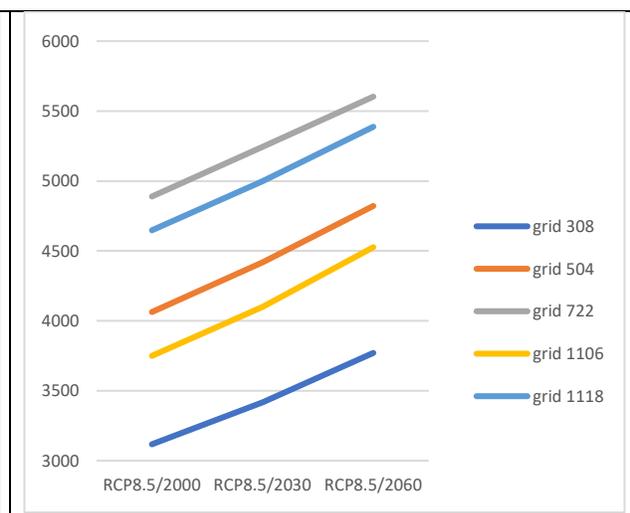
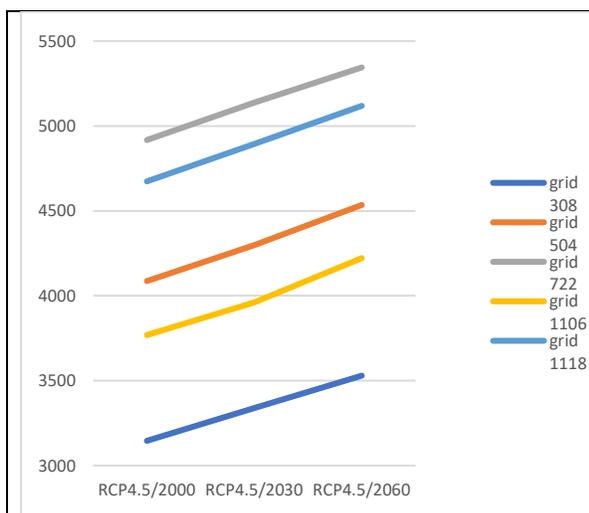


Figure 54. Maize: Sum of effective temperatures, t 0 °C, scenario RCP4.5 (2000-2060)	Figure 55. Maize: Sum of effective temperatures, t 0 °C, scenario RCP8.5 (2000-2060)
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As in the case of wheat, the sum of effective temperatures in RCP2.6 for maize, from 2000 to 2030 raise for 297 °C (from 4294 °C to 4591 °C) while by 2060 that increasing trend becomes more moderate and reaches 4600 °C (Chart 23). The same identity is concluded considering the grids at RCP2.6 where in all five grids from 2030 to 2060 the effective temperatures have a trend of evenness, slight increase or decrease. (Chart 24). In all scenarios grid 308 vs the years of investigation has the lowest values, while grid 722 has the highest effective temperatures reaching 5000 °C and above in 2030 and 2060 respectively (Table 9; Chart 25 and 26). Evident differences in the effective temperatures at t 5 °C (compared to t 0 °C) were not established, with confirmed identity in the years of trials versus scenarios.

Table 15. Maize: Sum of effective temperature depends from grids, year and scenario, t 5 °C

	grid 308		grid 504		grid 722		grid 1106		grid 1118		average
	t sum	ndy	t sum	ndy	t sum	ndy	t sum	ndy	t sum	ndy	
											RCP2.6
RCP2.6/2000	3437	253	4221	287	4852	296	3607	255	4487	282	4121
RCP2.6/2030	3688	263	4543	299	5160	306	3947	269	4794	292	4426
RCP2.6/2060	3727	268	4571	301	5223	308	3974	272	4861	296	4471
											RCP4.5
RCP4.5/2000	2952	228	3923	276	4795	297	3608	250	4542	287	3964
RCP4.5/2030	3150	238	4148	286	5021	303	3807	259	4768	294	4179
RCP4.5/2060	3344	247	4401	295	5235	308	4089	273	5004	300	4415
											RCP8.5
RCP8.5/2000	2930	227	3892	274	4758	294	3589	249	4512	285	3936
RCP8.5/2030	3207	241	4273	294	5134	311	3942	268	4878	302	4287
RCP8.5/2060	3578	256	4702	306	5501	316	4401	285	5280	309	4692

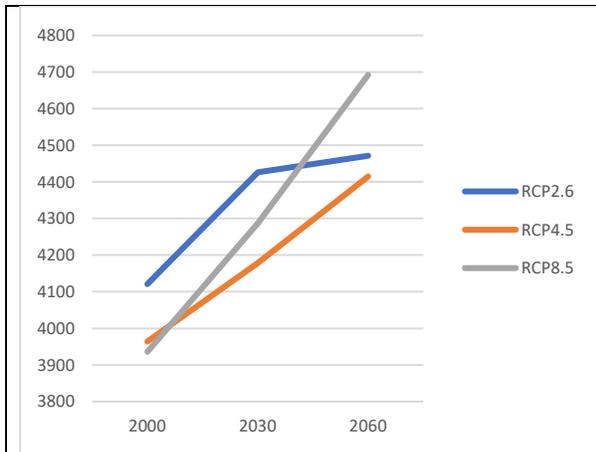


Figure 56. Maize: average effective temperature, t 5 °C (years vs scenarios)

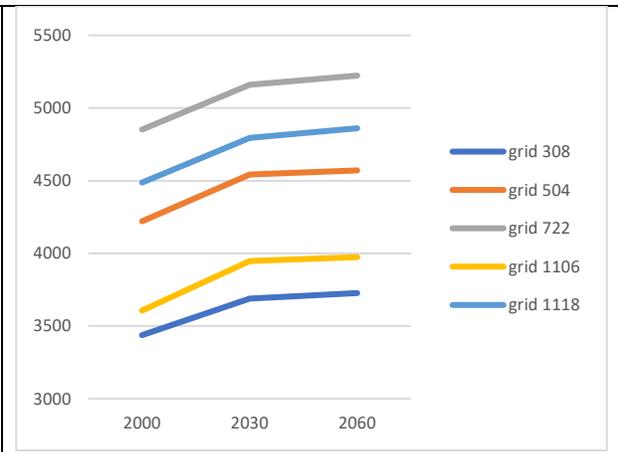


Figure 57. Maize: Sum of effective temperatures, t 5 °C, scenario RCP2.6 (2000-2060)

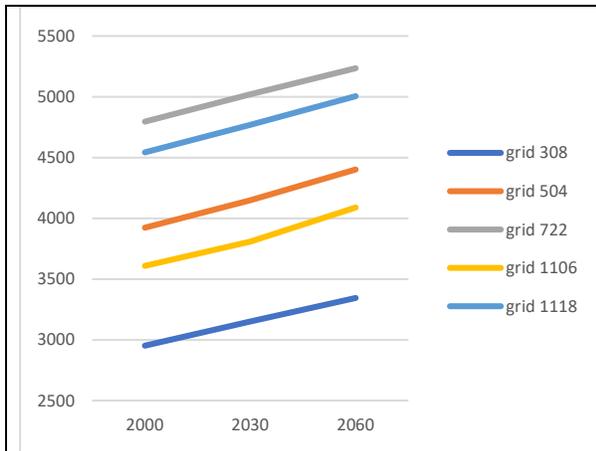


Figure 58. Maize: Sum of effective temperatures, t 5 °C, scenario RCP4.5(2000-2060)

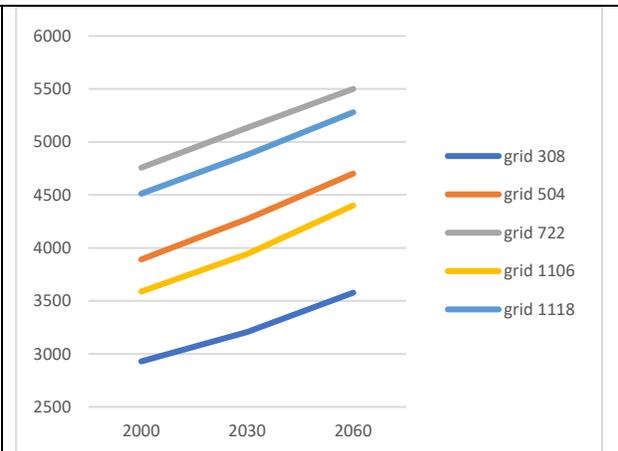


Figure 59. Maize: Sum of effective temperatures, t 5 °C, scenario RCP8.5(2000-2060)

Consequently, in RCP2.6 when comparing 2000 with 2030 the value of effective temperatures increases by +305 °C, and in comparison of 2060 with 2030 that increase is +45 °C. In the case of RCP4.5, comparing 2030 with 2000 the increase is +215 °C, sum which is approximate when comparing 2060 with 2030 (+236 °C), while in scenario RCP8.5 the differences in temperatures in 2030 and 2060 are +351 i.e. +405 °C respectively (Chart 27). In the selected grids with maize in the case of the RCP2.6, by 2030 the sum of effective temperatures shows an increase. From 2030 to 2060 that increasing is more moderate comparing with RCP4.5 and 8.5 where the effective temperature rise with a pronounced upward line. From the grids as the most characteristic stand out 308 and 722 with values of the effective temperatures which at grid 308 are from 2903 (RCP8.5/2000) to 3688 °C (RCP2.6/2000) while at 722 from 4758 (RCP8.5/2000) to 5501 °C (RCP8.5/2060) respectively (Table 16).

Table 16. Maize: Sum of effective temperature depends from grids, year and scenario, t 10 °C

	grid 308	grid 504	grid 722	grid 1106	grid 1118
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	t sum	ndy	Average								
											RCP2.6
RCP2.6/2000	2904	181	3643	210	4357	229	3108	189	4009	218	3604
RCP2.6/2030	3154	190	3936	218	4640	236	3426	199	4288	224	3889
RCP2.6/2060	3160	191	3979	222	4720	241	3444	201	4363	229	3933
											RCP4.5
RCP4.5/2000	3154	190	3936	218	4640	236	3426	199	4288	224	3889
RCP4.5/2030	2623	167	3560	207	4503	234	3328	195	4267	227	3656
RCP4.5/2060	2816	175	3809	216	4733	242	3568	203	4516	235	3889
											RCP8.5
RCP8.5/2000	2405	157	3330	198	4236	224	3117	186	4012	217	3420
RCP8.5/2030	2649	165	3632	209	4573	237	3407	196	4334	229	3719
RCP8.5/2060	3036	181	4083	224	4997	250	3851	211	4791	244	4152

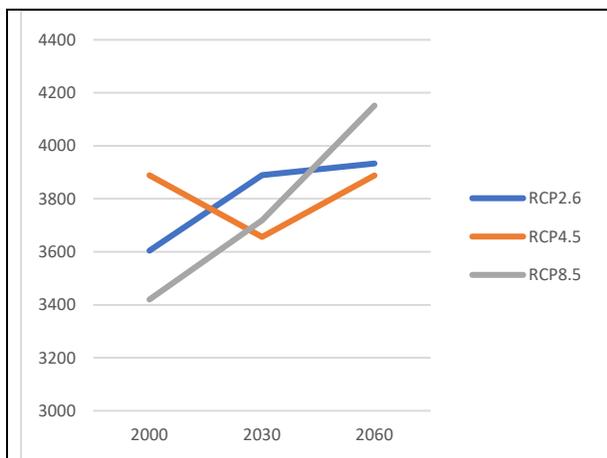


Figure 60. Maize: average effective temperature, t 10 °C (years vs scenarios)

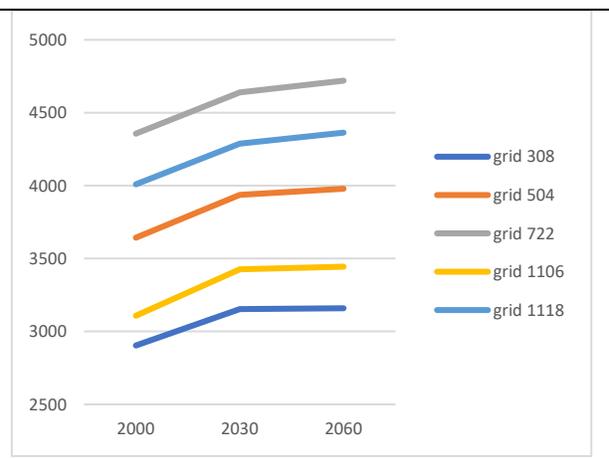


Figure 61. Maize: Sum of effective temperatures, t 10 °C, scenario RCP2.6 (2000-2060)

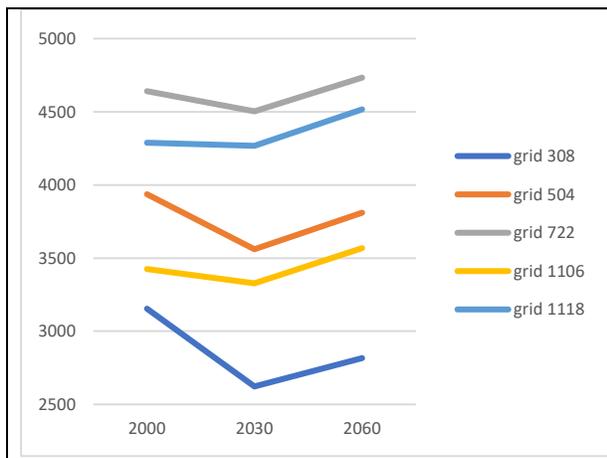


Figure 62. Maize: Sum of effective temperatures, t 10 °C, scenario RCP4.5 (2000-2060)

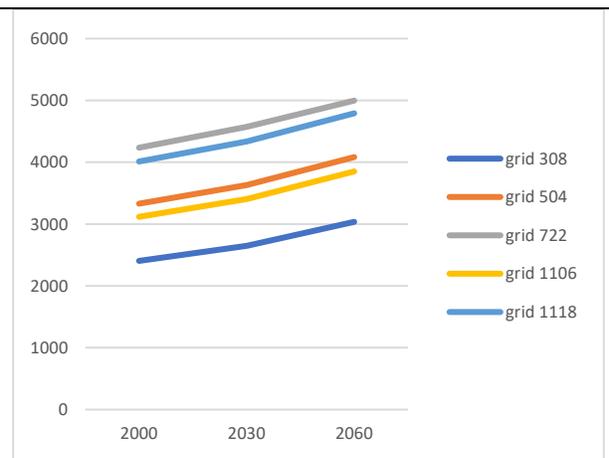


Figure 63. Maize: Sum of effective temperatures, t 10 °C, scenario RCP8.5 (2000-2060)

What is more characteristic when considering the sums of effective temperatures both according to the determined values per grid and according to the average values at 10 °C is RCP4.5 where from 2000 to 2030 the temperature fall for 233 °C and from 2030 to 2060 rise again for 233 OC reaching 3889 OC (as it was in 2000) (Chart 31). RCP2.6 and 8.5 have the same dynamics of more intense or moderate increasing considering at temperatures 0 and 5 °C. Grids 308 and 722 again are most characteristic as grids with the lowest or highest values of effective temperatures depending on the years and RCP scenarios (Table 11).

There is no doubt that such high effective temperatures will have an impact on maize production, especially in the selected grids. Higher effective temperature sums will be response for earlier maturity, shorter time for grain filling and advance in maturity which will have a direct negative effect in yield quality and quantity. Therefore adopting the suitable adaptation option will be more than necessity in terms for effectively help maize production to resist the specific climatic stress that has been captured in the vulnerability assessment.

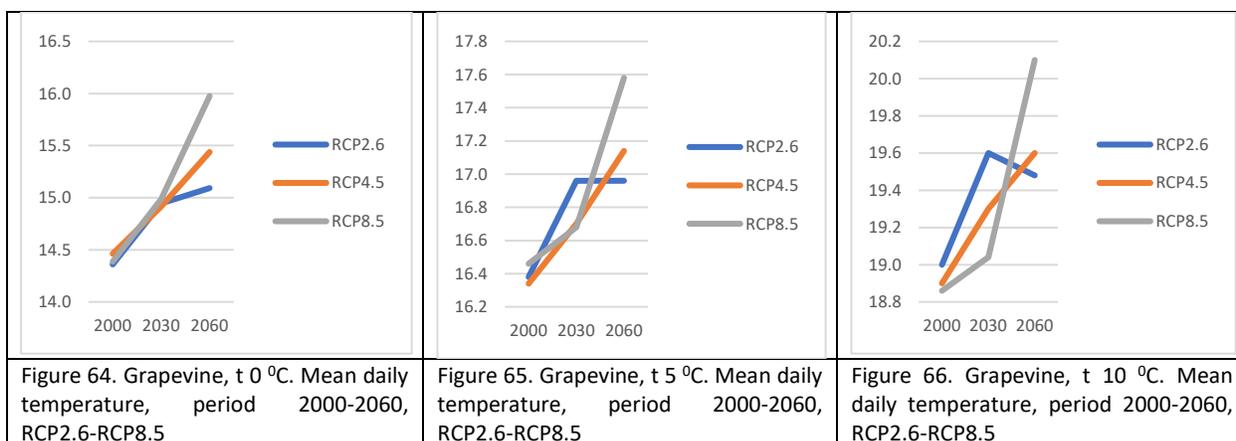
**Case study – grapevine**

Studies have shown that grapevine development and the initiation of bud burst will not begin until a temperature of between 7 °C and 11 °C is reached (Jackson and Spurling, 1988; Fitzharris and Endlicher, 1996). However, this threshold temperature also depends on the latitude, grape variety and the year (Galet, 2000). As the temperature increases above this threshold, growth occurs within all parts of the grapevine until the optimal rate growth occurs. Any temperature higher than this causes growth to decline and eventually stop all together (Jackson, 2001).

The mean daily temperature as an average values from selected grids for grapevine production are presented in Table 12 and Charts 35 – 37.

Table 17. Grapevine: Mean daily temperature/RCP scenario

	t 0 °C			t 5 °C			t 10 °C		
	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
2000	14.4	14.5	14.4	16.4	16.3	16.5	19.0	18.9	18.9
2030	14.9	14.9	15.0	17.0	16.7	16.7	19.6	19.3	19.0
2060	15.1	15.4	16.0	17.0	17.1	17.6	19.5	19.6	20.1



As compared 2000 with 2030 and 2060 the mean annual temperature at t 0 °C will rise by 0,5 and 0,7 °C in RCP2.6, by 0,4 and 0,9 °C in RCP4.5 and by 0,6 and 1,1 °C in RCP8.5 (Chart 35), at t 5 °C by 0,6 °C in RCP2.6, by 0,4 i.e. 0,8 °C in RCP4.5 as well as by 0,2 and 1,1 °C in RCP8.5 (Chart 36). When t is 10 °C the mean daily temperature will increase by 0,6 and 0,5 °C in RCP 2.6, by 0,4 and 0,7 °C at RCP4.5 and by 0,1 and 1,2 °C in RCP8.5 respectively (Chart 37). The differences between mean daily temperature among examine grids are more evident (Table 13).

Table 18. Mean daily temperature by grids (t = 10 °C)<sup>3</sup>

	t avg 520	t avg 617	t avg 716	t avg 914	t avg 920
TAO_2000_RCP2.6	19.9	18.7	20.0	19.4	17.0
TAO_2030_RCP2.6	20.4	19.3	20.6	20.0	17.7
TAO_2060_RCP2.6	20.3	19.2	20.6	19.8	17.5
	t avg 520	t avg 617	t avg 716	t avg 914	t avg 920
TAO_2000_RCP4.5	19.9	18.4	19.6	19.3	17.3
TAO_2030_RCP4.5	20.3	18.8	20.0	19.7	17.7
TAO_2060_RCP4.5	20.5	19.1	20.3	20.0	18.1
	t avg 520	t avg 617	t avg 716	t avg 914	t avg 920
TAO_2000_RCP8.5	19.8	18.4	19.6	19.3	17.2
TAO_2030_RCP8.5	18.8	18.9	20.0	19.7	17.8
TAO_2060_RCP8.5	20.9	19.6	20.9	20.5	18.6

From the data the mean daily temperature at RCP 2.6 will rise for 3,6 °C (grid 920 vs grid 716; 2030 and 2060 vs 2000), for 3,0 i.e. 3,2 °C at RCP 4.5 (grid 920 vs grid 520) and for 2,8 to 3,7 °C respectively (grid 920 vs grids 520 and 716) (Table 13). According Santos et al. (2020) increased temperature (between 1,3 and 1,7 °C) will influence on grapevine yield, as well as berry and wine

<sup>3</sup> Example is for t = 10 °C, as a threshold temperature for grapevine development

quality. In this regard, they were found that higher temperatures during the growing season promoted a decrease in the grape berry total acidity content, upward trends in sugar content or probable alcohol, and a decoupling between technological and phenolic maturity. Earlier phenological timings and growing season shortening may lead to ripening during excessively warm conditions, with increased alcohol content, decreased acidity, and modifications in wine sensory profiles.

*The last spring frost*

The appearance of the last spring frost in the chosen grids for grapevine and the differences in the number of days between the analyzed years and scenarios are presented in Chart 38 and 39.

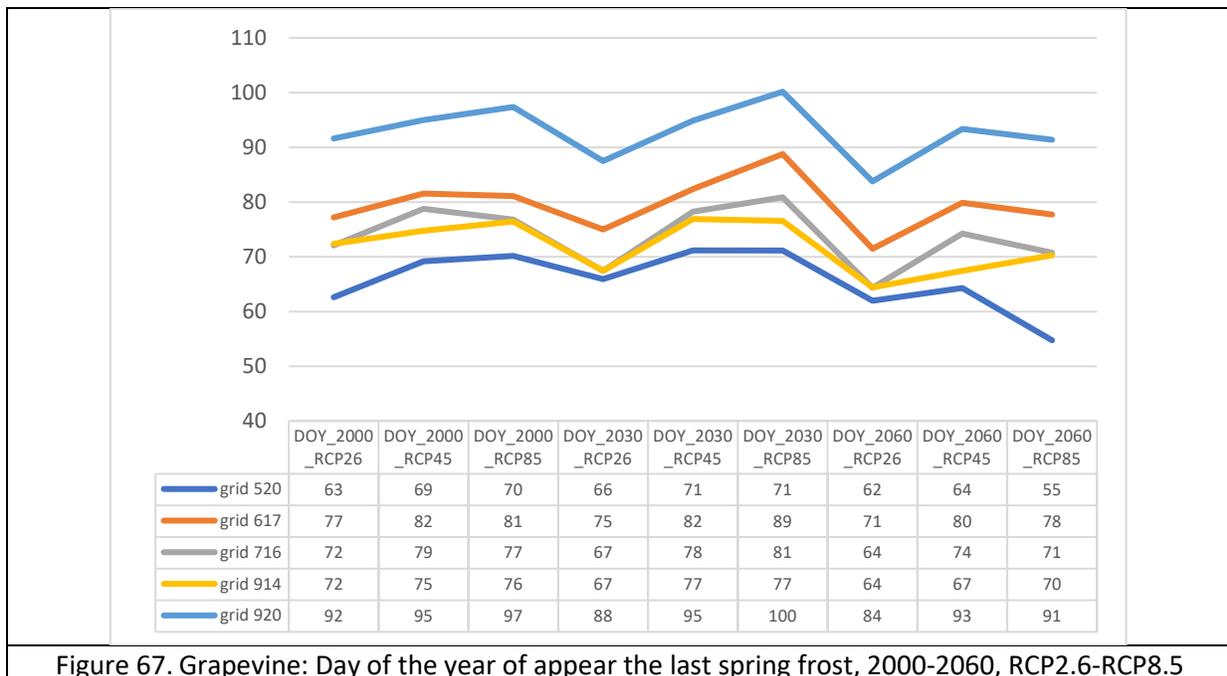


Figure 67. Grapevine: Day of the year of appear the last spring frost, 2000-2060, RCP2.6-RCP8.5

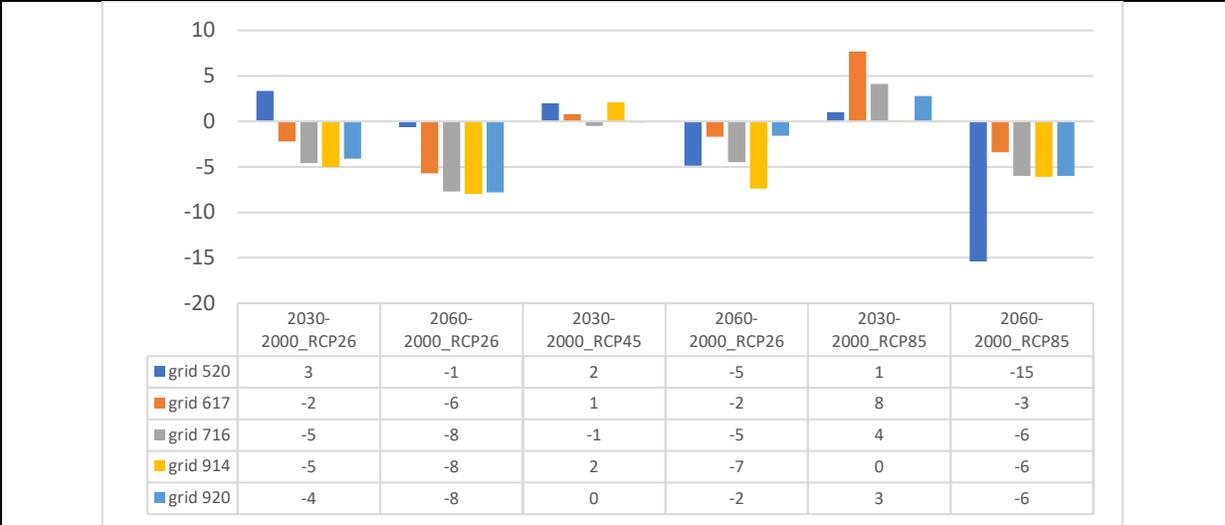


Figure 68. Grapevine: Differences in number of days of appear the last spring frost between different years and scenarios

Compared to wheat and maize, the occurrence of the last spring frost on the selected grids with the grapevine production was established much earlier: 55 days/year in the scenario RCP8.5 in 2060 (grid 520 as the earliest occurrence) to 100 days/year in the scenario RCP8.5 in 2030 (grid 920) (Chart 38). With the exception of 2030 with 2000 in RCP8.5 i.e. 2030 with 2000 RCP4.5, in the other scenarios the differences between 2030 and 2060 compared to 2000 show negative values which in grid 520 in scenario RCP8.5 is even 15 days earlier (Chart 39). However, whether the early occurrence of low temperatures in the spring would cause some damage to the grapevine production is ungrateful to comment because it largely depends from the duration of low temperatures, from the variety, field exposure, soil type and other abiotic factors.

When it comes to the resistance of the grapevine to the frost the length of the frost-free period is also important. The frost-free period is defined as the average number of days between the last frost of winter and/or spring and the first frost of autumn. It is known as the growing season. The minimum number of frost free days required for productive viticulture is 180. Low temperatures have the ability to cause damage and injury in plants, and a plants tolerance to low temperatures depends on its stage of development. In spring, as buds swell, their susceptibility to cold damage increases. Therefore, a bud that can survive  $-15^{\circ}\text{C}$  in the middle of winter, will have its resistance lowered to  $1-2^{\circ}\text{C}$  at bud burst. From the time of bud burst, temperatures below  $-1^{\circ}\text{C}$  damage buds, leaves and fruit. In the spring, frost kills emerging buds and their shoots, as well as any developing fruit. New growth will result after the damage has occurred, but the secondary shoots are much less productive than the primary shoots and maturity will be delayed due to grapes ripening later in the season. Early winter frosts will kill leaves and the remaining fruit will have to carry out their growth without the carbohydrates supplied from those leaves. Serious frost events will severely damage the fruit (Jackson, 2001)

*Sum of effective temperatures*

Amerine and Winkler (1944) carried out one of the most well-known studies of the correlation between the sums of effective temperature and vine phenology. From the principal grape growing regions, they evaluated the influence of the climatic environment on the differing grape varieties. They achieved this by separating the grape districts into five climatic regions based on the GDD, using a base threshold temperature of 10 °C for the period 1st of April to 31st of October. The regions are defined as below:

Region I = Cool – below 1390 °C

Region II = 1390 - 1667 °C

Region III = 1667 - 1945 °C

Region IV = 1945 - 2220 °C

Region V = Very hot – above 2220 °C

The data from our investigation are as follows:

Table 19. Grapevine: Sum of effective temperature depends from grids, year and scenario, t 0 °C

	grid 520		grid 617		grid 716		grid 914		grid 920		Average
	t sum	ndy									
											RCP2.6
RCP2.6/2000	5324	347	4715	332	5240	339	4943	337	3959	325	4836
RCP2.6/2030	5622	353	4987	337	5529	345	5252	345	4289	338	5136
RCP2.6/2060	5645	352	5016	336	5559	342	5284	344	4330	338	5167
											RCP4.5
RCP4.5/2000	5376	344	4570	328	5149	336	4967	335	4072	324	4827
RCP4.5/2030	5615	348	4794	335	5402	342	5206	340	4284	330	5060
RCP4.5/2060	5828	351	5004	337	5639	344	5445	343	4491	333	5281
											RCP8.5
RCP8.5/2000	5354	346	4544	328	5129	336	4952	335	4043	323	4804
RCP8.5/2030	5740	354	4908	342	5542	348	5342	347	4376	337	5182
RCP8.5/2060	6108	356	5269	344	5947	350	5746	349	4739	340	5562

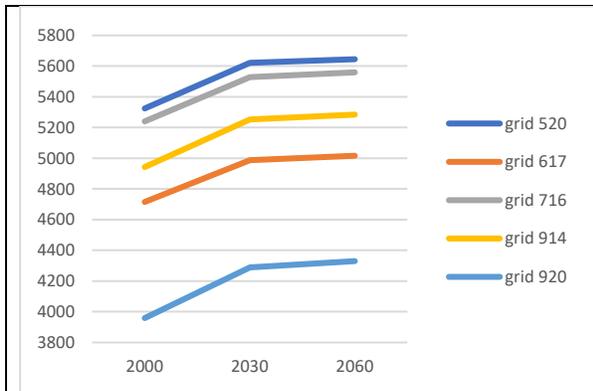


Figure 69. Grapevine: Sum of effective temperatures, t 0 °C, scenario RCP2.6 (2000-2060)

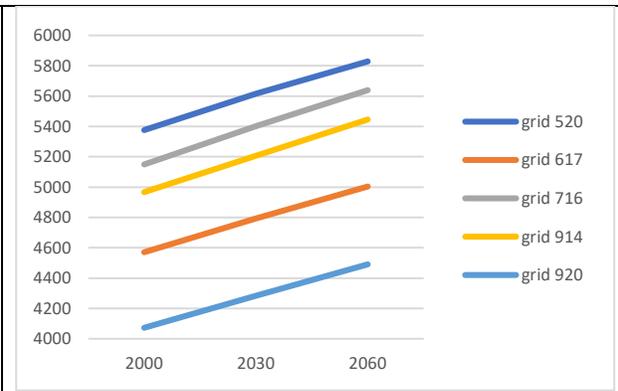


Figure 70. Grapevine: Sum of effective temperatures, t 0 °C, scenario RCP4.5 (2000-2060)

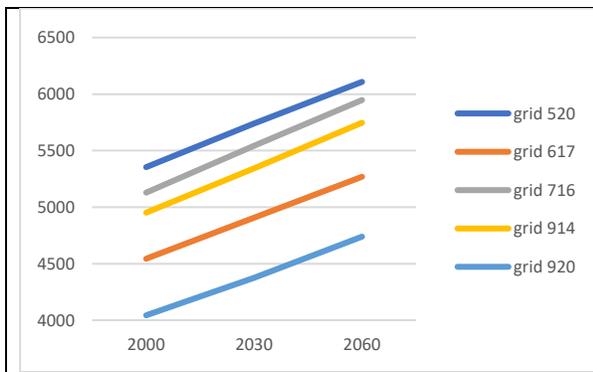


Figure 71. Grapevine: Sum of effective temperatures, t 0 °C, scenario RCP8.5 (2000-2060)

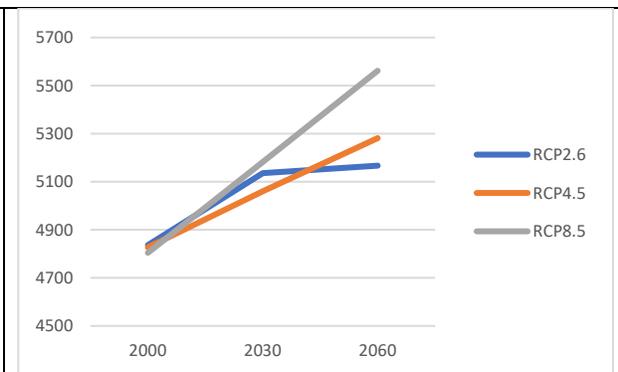


Figure 72. Grapevine: average effective temperature, t 0 °C (years vs scenarios)

When t is 0 °C with the exception of the RCP2.6 where in all grids from 2000 to 2030 the temperature tends to increase intensively from 289 °C (grid 716) to 330 °C (grid 920), by 2060 that increase is more moderate, from 23 °C (grid 520) to 41 °C (grid 920) (Chart 40). The same conclusion was determined during the analysis of the average values where from 2000 to 2030 i.e. 2060 in RCP2.6 temperature rise 300 and 331 °C (Chart 43). In RCP4.5 and 8.5 the rise in temperature is always continuous with differences between 2030 with 2000 and 2060 with 2030 of around 200 °C (Chart 41 and 42). Considering the grids, the lowest effective temperatures in all scenarios were determined at grid 920 - from 3959 °C (RCP2.6/2000) to 4739 °C (RCP8.5/2060). The other grids have much higher sum of temperatures reaching a value up to 6108 °C at grid 520 (RCP8.5 / 2060) (Table 14).

Identity in terms of increasing of effective temperatures is conclude at t 5 °C as well as at 10 °C, both separately between the grids (Chart 44 – 46; Chart 48-50) and according to the established average values (Chart 47; Chart 51). At t 5 °C grid 920 has lowest effective temperature ranking from 3795 °C (RCP2.6 / 2000) to 4600 °C (RCP8.5 / 2060). The other values ranged from 4402 °C at grid 617 (RCP8.5 / 2000) to 6022 °C (RCP8.5 / 2060) at grid 520 (Table 15). At t 10 °C the lowest

values again were established at grid 920, while the highest at grid 520 reaching maximum of 5565 °C in 2060/RCP8.5 (Table 16).

Table 20. Grapevine: Sum of effective temperature depends from grids, year and scenario, t 5 °C

	grid 520		grid 617		grid 716		grid 914		grid 920		Average
	t sum	ndy									
											RCP2.6
RCP2.6/2000	5200	304	4575	282	5113	293	4806	287	3795	263	4698
RCP2.6/2030	5503	312	4856	291	5397	298	5112	294	4112	276	4996
RCP2.6/2060	5530	312	4897	293	5448	302	5161	298	4175	282	5042
											RCP4.5
RCP4.5/2000	5270	306	4433	279	5035	295	4840	289	3910	266	4697
RCP4.5/2030	5517	314	4663	288	5294	303	5081	297	4123	273	4936
RCP4.5/2060	5733	318	4885	294	5537	308	5337	305	4348	281	5168
											RCP8.5
RCP8.5/2000	5242	305	4402	277	5008	293	4821	288	3883	264	4671
RCP8.5/2030	5640	320	4783	296	5438	311	5229	306	4220	281	5062
RCP8.5/2060	6022	326	5155	303	5852	317	5644	314	4600	290	5455

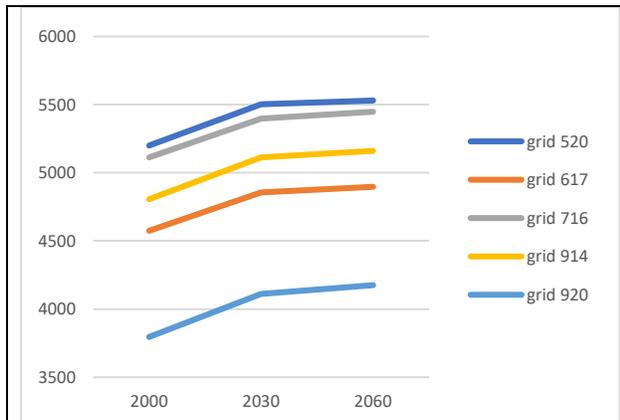


Figure 73. Grapevine: Sum of effective temperatures, t 5 °C, scenario RCP2.6 (2000-2060)

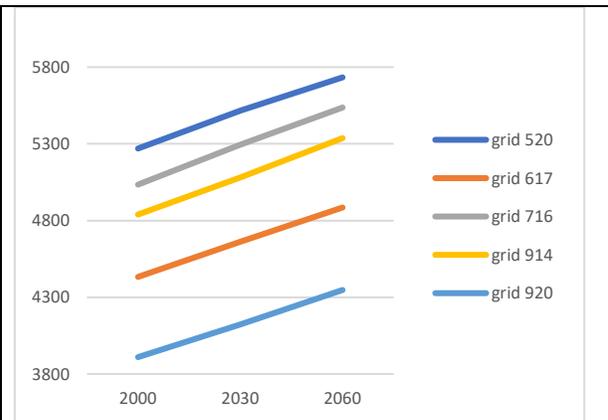


Figure 74. Grapevine: Sum of effective temperatures, t 5 °C, scenario RCP4.5 (2000-2060)

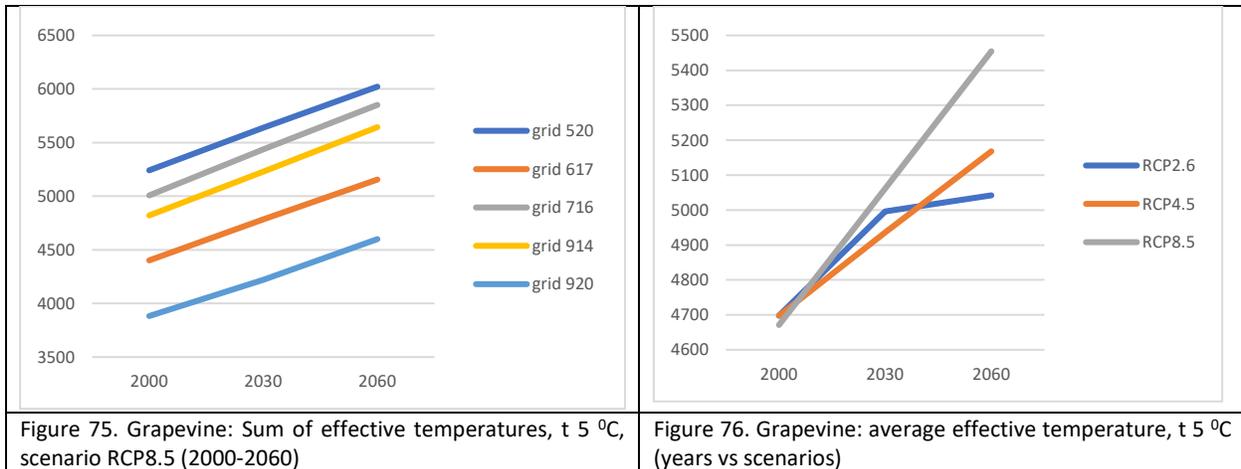


Table 21. Grapevine: Sum of effective temperature depends from grids, year and scenario, t 10 °C

	grid 520		grid 617		grid 716		grid 914		grid 920		average
	t sum	ndy									
											RCP2.6
RCP2.6/2000	4706	237	4114	220	4670	234	4340	224	3275	193	4221
RCP2.6/2030	5001	245	4378	227	4964	241	4649	233	3566	202	4512
RCP2.6/2060	5053	249	4425	230	5014	244	4708	237	3621	207	4564
											RCP4.5
RCP4.5/2000	4775	240	3945	214	4574	233	4386	228	3403	197	4216
RCP4.5/2030	5021	248	4173	222	4833	242	4613	235	3617	205	4452
RCP4.5/2060	5271	257	4397	230	5108	252	4881	244	3820	211	4695
											RCP8.5
RCP8.5/2000	4747	239	3924	213	4547	232	4362	226	3385	197	4193
RCP8.5/2030	5131	254	4252	225	4539	236	4729	240	3658	205	4462
RCP8.5/2060	5565	266	4664	238	5410	259	5185	253	4055	218	4976

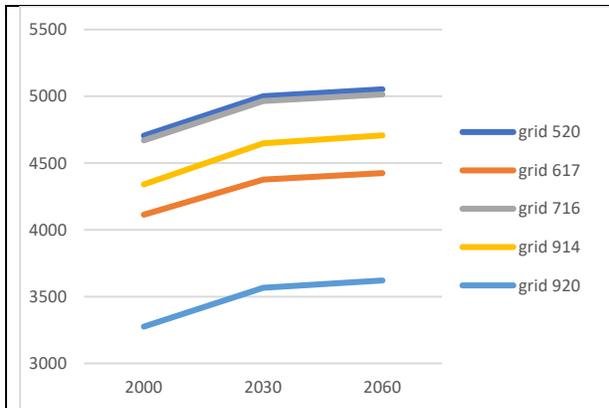


Figure 77. Grapevine: Sum of effective temperatures, t 10 °C, scenario RCP2.6 (2000-2060)

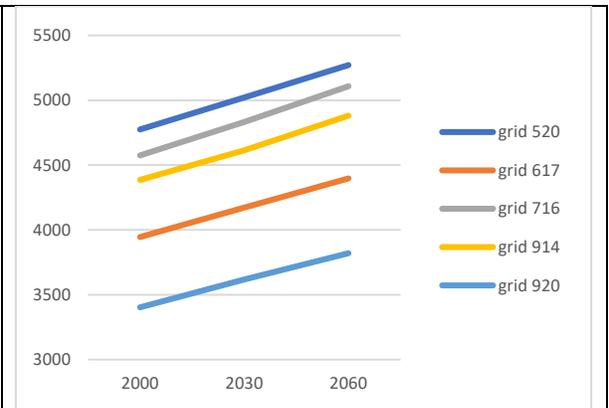


Figure 78. Grapevine: Sum of effective temperatures, t 10 °C, scenario RCP4.5 (2000-2060)

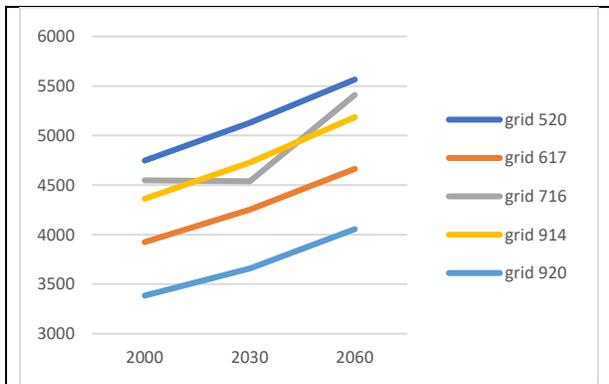


Figure 79. Grapevine: Sum of effective temperatures, t 10 °C, scenario RCP8.5 (2000-2060)

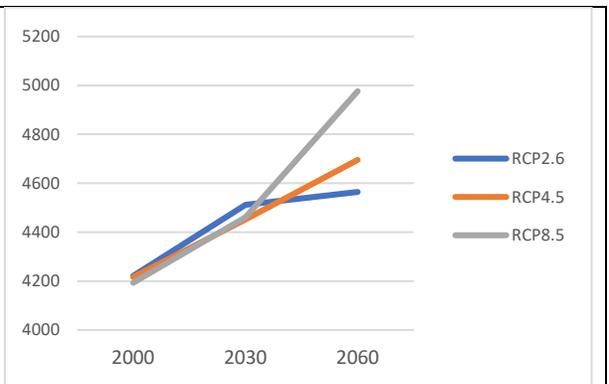


Figure 80. Grapevine: average effective temperature, t 10 °C (years vs scenarios)

## Conclusions

After the result analyses, the main conclusions are as follows:

Temperature is expected to rise during growing season and especially in summer months for 1.0 in 2030 and for 1.6 °C in 2060, what is one of conditions for drought present.

More days with extreme high temperature will have negative influence on wheat, maize and grapevine physiology.

Higher effective temperature sums are response for earlier maturity, shorter time for grain filling and advance in maturity of wheat and maize. That will have a direct negative effect in yield quality and quantity. With higher effective temperature in grapevine production more emphasized

differences in plant development phases for the next 50-year period can be expected that will result with lowering the quality for wine making sector.

### ***Modelling approach***

The effects of climate change on crop yield can be converted into the yield response using the crop model. For the purpose of the first and second national communication the empirical models were used. The third national communication contributed significantly to the increase of the modelling capacities in the country and the biophysical model CropSyst was used. However, the chronic lack of investment in the research, particularly research in Agricultural sector made young researchers that developed capacities to the level to use most advanced crop models just to give up research and move to other sectors. Therefore, some other modelling approaches are required, preferably less complex crop models that can be much easier transferred, and need fewer intensive data sets. Moreover, the models of choice should be enough robust, process of calibration and validation should be clear and datasets for this purpose should be available. The previous research in crop yield response to the climate change emphasized the water limitation as major driver for yield reduction in the present and even more in future climate. Therefore, the choice of the model is using the FAO AquaCrop model, that is heavily supported by number of researchers and institutions and globally recognized as robust model that can operate with reduced data inputs. It was particularly important because the data required for modeling, validation and calibration in the country is lacking, or if existing, access to the data is heavily restricted.

AquaCrop is a crop growth model developed by the Land and Water Division of FAO to address food security and to assess the effect of environment and management on crop production. AquaCrop simulates yield response to water of herbaceous crops, and is particularly suited to address conditions where water is a key limiting factor in crop production. When designing the model, an optimum balance between simplicity, accuracy and robustness was pursued. To be widely applicable AquaCrop uses only a relatively small number of explicit parameters and mostly-intuitive input-variables requiring simple methods for their determination. On the other hand, the calculation procedures is grounded on basic and often complex biophysical processes to guarantee an accurate simulation of the response of the crop in the plant-soil system.

The climate datasets used in the modeling process were sourced from the previous activity conducted by Djurdjevic, Report on climate change projections and changes in climate extremes for Macedonia, 2019. For three different GHG emissions scenarios, RCP2.6 (low), RCP4.5 (mid) and RCP8.5 (high) future climate projections of essential climate variables, temperature and precipitation for territory of Macedonia. The datasets cover period from 2006 to 2100, and reference period 1986-2005. The results were obtained from EURO-CORDEX database, from

which results of three regional climate models were analyzed for low and seven models for mid and high scenarios.

The AquaCrop model consider the number of parameters that can be set in order to conduct the modeling for various environment. The modelling was done using the daily values for the 3 basic meteorological parameters (maximal daily temperature, minimal daily temperature and daily rainfall accumulation). This dataset is not sufficient for calculation of the Penman Monteith evapotranspiration, therefore the model for calculating the daily values of the evapotranspiration by Hagreaves-Semany metodology and Hagreaves-Semani methodology modified by Alen was developed, and these values were used as input in the model.

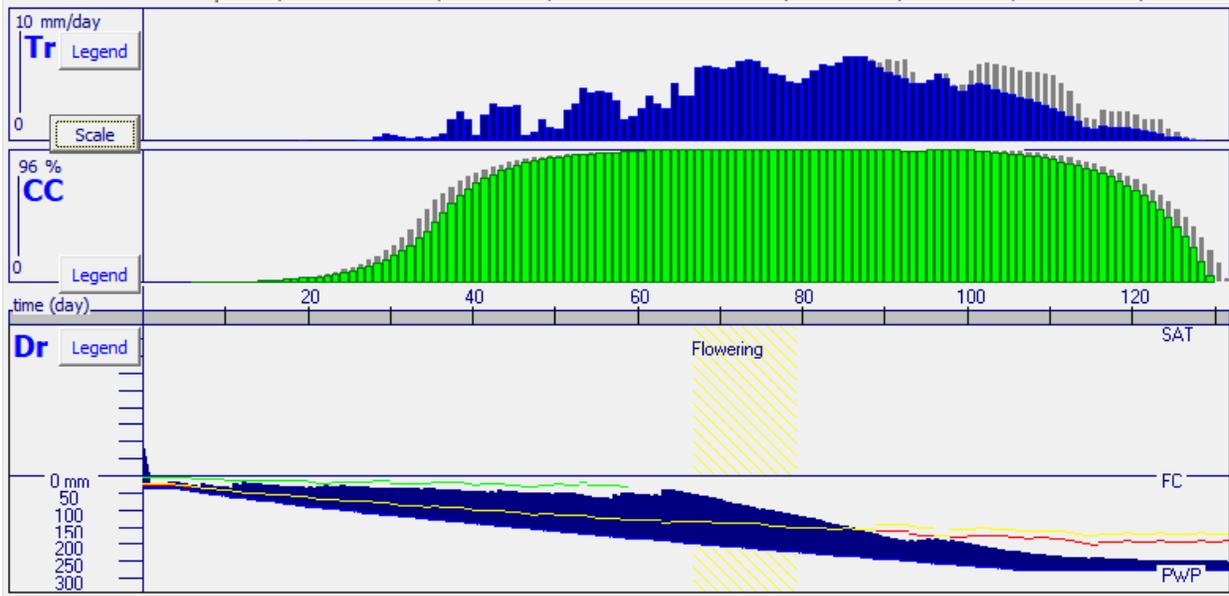
The crop modeled was maize, as crop that is very tolerant to the increased temperature (crop with C4 photosynthesis pathway) and have very positive response to irrigation. The maize crop is usually irrigated in the country and the data required for parametrization, calibration and validation of the model are available from the national scientific community. The AquaCrop model do not work with perennial crops, therefor the orchards and vineyards cannot be modelled. Moreover the data for wheat response to irrigation is very limited, wheat is rarely irrigated and almost no research in the country addressing irrigated wheat. Thwwerefore, the crop model results will address only maize.

The modeling approach was to keep all other factors in optimal level and to evaluate the crop yield response to the water without inducing the reduction from other factors. Therefore, the soil type used for modeling was deep and uniform sandy loam soil, without restriction in the fertility and rooting depth. The initial condition for the summer crops is that the top soil layer is already dried, but the layers below of the top layer are wet and water for germination, and initial crop development is available. The models were run for 3 different CO<sub>2</sub> realization pathways (RCP 2.6, RCP4.5 and RCP8.5) and 3 periods of 30 years. The period from 1986 to 2015, centered for the year 2000 was used as base case (referent value) and two datasets centered for the year 2030 and 2060 was compared to the reference period.

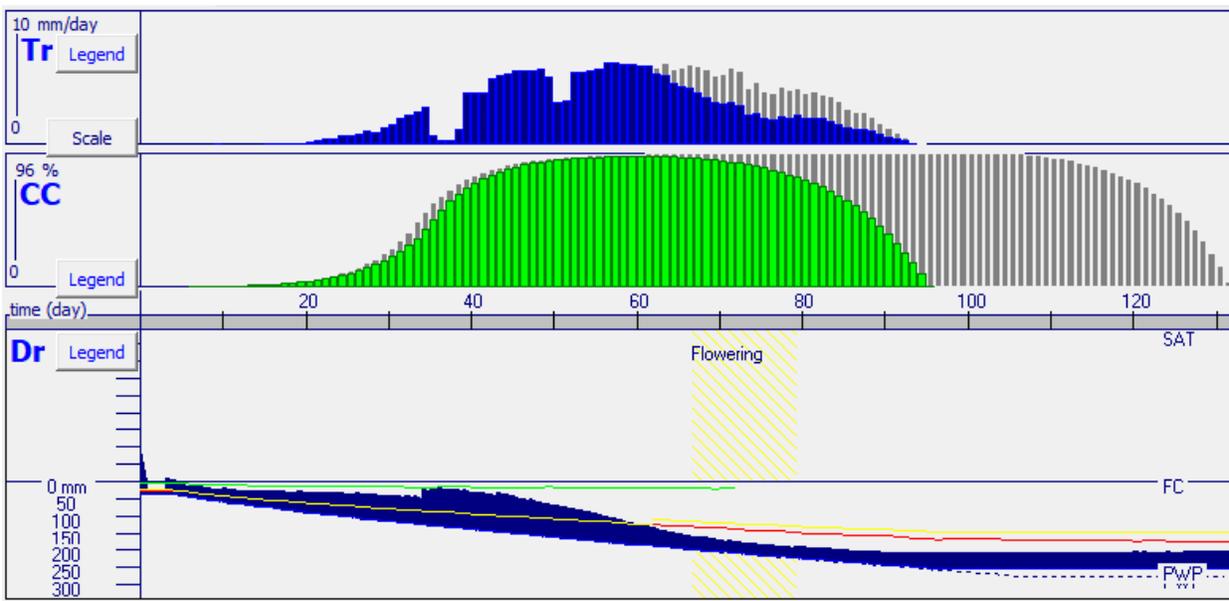
The modeling results presented in following figure show the two cases: i) good year, when water deficit starts after the flowering stage, canopy cower developed normally, ripening stage is less sensitive to the water shortage, and evident reduction in transpiration after the day of season 100 did not affected the yield and ii) water deficit took place before flowering, crop is severely damaged by the water shortage and senescence took place before day 100. The yield is severely reduced and harvest is not possible.

Figure 81. AquaCrop model output for the water deficit in different stages of the crop growth i) late stages and ii) early stages, and maize response to water deficit in different growth stage

i.



ii.



Tr – transpiration, CC – Canopy cover, Dr- Root zone water depletion

The figure above shows that the crop response on water is not associated only with amount of water but also to the period of crop growth when deficit starts. However, the results for the vulnerability show that maize crop is rather tolerant to the drought that will appear after the flowering stage. Particularly it is tolerant if water stress appears after the milky ripening stage.

The following table give the crop response compared to the base case in year 2060. The quantification of the vulnerability is presented as yield loss in kg and in %.

Table 22. Simulated yield response to climate change as result of different Representative Concentration Pathways (RCP) for maize in year 2060 compared to the base case (year 2000)

scenario	Yield in kg/ha	Yield in %	Yield difference from base case in kg/ha	Yield difference from base case in %
2000 Base case	8905	100	0	0
2060 RCP2.6	9988	112.1	1083	112.2
2060 RCP4.5	7462	83.8	-1443	83.8
2060 RCP8.5	5461	61.3	-3444	61.3

The yield reduction in the mid-term depends of the realization pathway, and highly depend on the human behavior, The RCP2.6 realization pathway will result even with increased yield as result of the CO<sub>2</sub> fertilization and prevented further increase of the temperature. However, it is almost clear that this realization pathway will not happened. In the case of the RCP4.5 maize yield reduction will be about 16% and in worst case if RCP8.5 will take a place, the yield reduction will be close to 40%.

Likely the expected yield reduction will be between 20 and 40%, depend on the CO<sub>2</sub> concentration, and level of the temperature increase

## Adaptation of the crop sector

### Modelling activities

Number of reports and consultations conducted in the past 20 years prioritized the irrigation as one of the best adaptation options for crop production in the country. However, the irrigation passed trough number of reforms that resulted with significant changes in irrigation and drainage sector. Due to the water limitation during the summer period, and water shortage for crop growth and sustainable productivity, the number of important investments in the development of irrigation were undertaken as the most efficient available practice for reducing water shortage for normal agricultural production. According to the time, the dynamics, the sources of financing and the other conditions for construction, there are three historical periods in the development of the irrigation, as follows: first period until 1958, second period from 1958 to 1975 and third from 1975 to the 1998. In the first period, 27 HMS were built, covering 19,026 ha, in the second period, 3 large systems covering an area of 68,448 ha were built. Moreover, 46 smaller systems were constructed that provide irrigation on 39,514 ha. In the third period, 28 new irrigation systems were built, providing irrigation to 36,704 ha. After 1999 more attention was paid on the rehabilitation of the already constructed, but damaged infrastructure and several important rehabilitation activities took place, However, there was number of activities in construction of new reservoirs, but even planned, the irrigation network is not constructed yet.

According to the technical documentation, on the basis of which the systems were built, it was planned to provide irrigation on 163,693 ha of fertile land, but the constructed basic facilities (dams, reservoirs,

pumping stations, main canals, etc.) can provide irrigation in a medium dry year. on 144894 ha of agricultural land. The irrigation potential is estimated at approximately 250 000 ha of arable land

According to SSO data, irrigation systems cover about a quarter of arable agricultural land (123 thousand ha) of which about 80 thousand hectares are irrigated. The effective irrigated area according to MAFWE is smaller and is 24,303 hectares in 2019, but MAFWE reports only areas irrigated through the Public Enterprises. Therefore the assumption is that up to 100 thousand hectares of the previously constructed irrigable area are not used in present, due to number of reason. The assumption is based on the constructed irrigable area, that is managed by the Water economy enterprises in the country and actually irrigated area reported by MAFWE. In same time actually irrigated area is about 80 thousand hectares and minimal irrigable area that is not irrigated is about 50 000 hectares. However, some of the irrigated area in present is not in the frame of the previously constructed irrigation schemes and was developed by the farmers to compensate problems they have in irrigation of their crops (areas not covered by the irrigation schemes, or areas in the frame of irrigation schemes where irrigation water was not delivered).

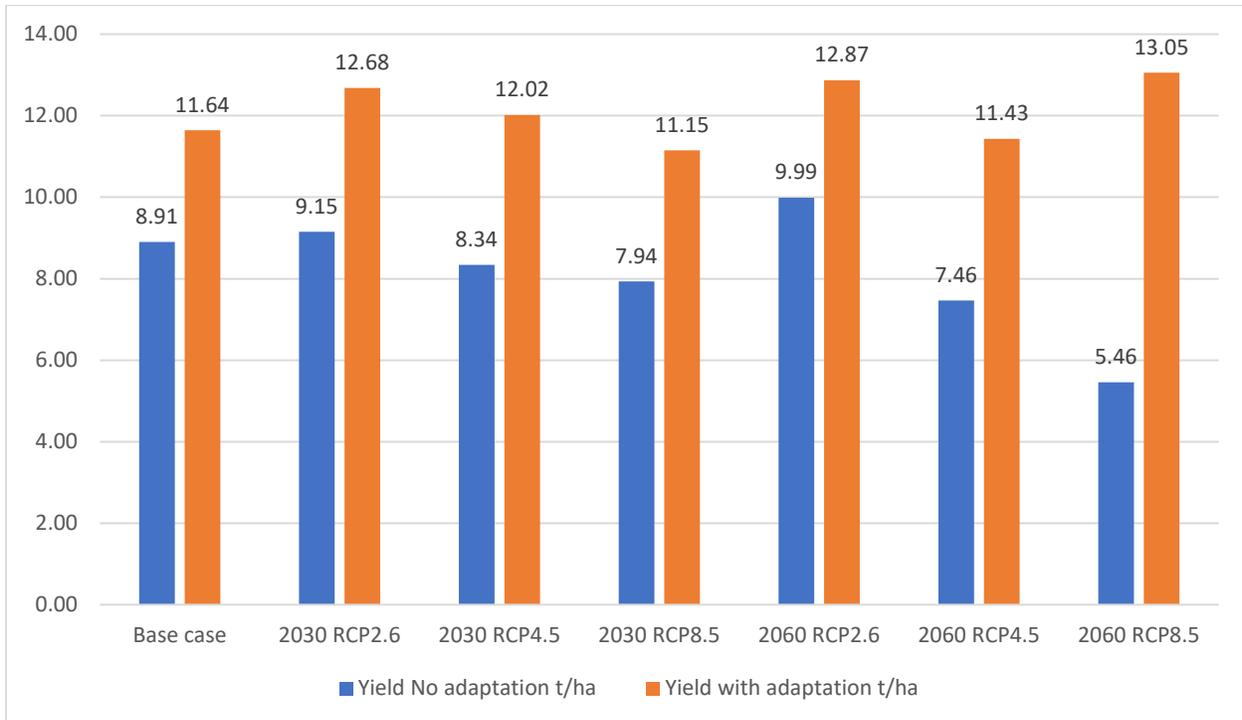
However, somewhere between 50 – 100 thousand hectares of irrigable land is not in use and can be rehabilitated. This is huge potential for increasing the irrigated areas in the country, but also to increase climate change resilience and to increase production and productivity. Moreover, the rehabilitation of these areas will contribute to the one of the most important targets of the national policy in agriculture, improvement of the competitiveness of the agricultural sector.

However, rehabilitation of irrigation systems is complex and costly activity that should consider the climate change, because the yields and the water required for irrigation of agricultural crops will change with time due to increased temperatures, changes in precipitation amount and precipitation pattern, CO<sub>2</sub> fertilization etc. Therefore, the design of the modeling activity conducted during the preparation of this report was to provide initial data for effects of irrigation on crop yield in the future climate and to predict water requirement for irrigation in the next period.

The model used was FAO AquaCrop as previously explained. The scenario developed was designed to assess the effect of irrigation on crop yield for 3 representative pathways (RCP2.6, RCP4.5 and RCP8.5) for 2-time spans in the future 2030 and 2060. The 30-years' time series, centered for the above-mentioned years was used (2016-2045, centered for year 2030 and 2046-2075 centered for year 2060). Data presented in this chapter is result of 30 years model runs. The crop used was maize, as one of the usually irrigated crops in the country. Maize belongs to the group of crops with C<sub>4</sub> photosynthesis pathway and as such is more tolerant to the higher temperature compared to the C<sub>3</sub> crops. Moreover, maize is quite tolerant to the water stress, particularly after the period of grain filling. However, the water shortage before the grain filling stage, particularly during the flowering stage can significantly reduce the yield. The results presented here result of the analyze for the five representative grids for maize growing in the country. In order to assess effects of irrigation in future climate no restriction related to the soil and management practices were designed. The soil used was uniform, deep sandy loam. Initial moisture of the soil was dry in the top layer and wet below the top. The irrigation scenario was fairly conservative, suitable for sprinkler irrigation. The irrigation event was triggered when soil moisture depletion will reach 80% of the readily available water, therefore the full irrigation scenario was used. However, there are possibilities to decrease water used amount by number of water saving options and implementation of deficit irrigation practices.

The following graph presents non irrigated and irrigate yield simulated by the AquaCrop model.

Figure 82. Average yield of maize non-irrigated vs irrigated in t/ha for different Representative Concentration Pathways (RCP2.6, RCP4.5 and RCP8.5) for period 2030 and 2060 compared to Base case (2000)



The very obvious and notorious facts that can be immediately seen from the graph is that irrigation is increasing crop yield. While yield fluctuation in non-irrigated case is huge (from 5.46 to 12.97 t/ha), irrigated yield is more stable and fluctuate from 11.15 to 13.5 t/ha.

However, the RCPs for the year 2030 are quite similar in CO<sub>2</sub>-equivalent concentration with RCP8.5 increasing faster than others. In 2060 there are significant differences and RCP2.6 show clear signs of reducing the concentration to below 450 ppm and RCP8.5 rising to the values higher than 700ppm. These concentrations influence the temperature changes creating different temperature regime and different rainfall pattern. The results presented in the figure above are following this pattern and in close future (2030) there is small differences in yield of not irrigated maize, and due to increased CO<sub>2</sub> fertilization even yield will be slightly higher. The Scenario RCP4.5 show similar results with RCP2.6 for the near future, but significantly decrease maize productivity in period of year 2060. The maize productivity in case of RCP8.5 (worst case) will decline rapidly. However, irrigation highly positive affect the maize yield and in 2060 the yield will be more than 50% higher if RCP4.5 will be actual or more than double compared with no adaptation in case of RCP8.5.

The results presented in the table below gives the simulated yield for tested scenarios (base case, RCP2.6, RCP4.5 and RCP8.5)

Table 23. Simulated yield and yield increase, simulated irrigation water use and water productivity for base case (2000) and climate change periods (2030 and 2060) for RCP2.6, 4.5 and 8,5

	Simulated Yield without adaptation t/ha	Simulated Yield with adaptation t/ha	Yield increase as result of adaptation t/ha	Yield increase as result of adaptation %	Simulated Irrigation water use in mm	Irrigation water productivity in kg/m <sup>3</sup>
Base case	8.91	11.64	2.73	30.70	229.8	1.18
2030 RCP2.6	9.15	12.68	3.53	38.56	365.43	0.97
2030 RCP4.5	8.34	12.02	3.68	44.12	303.22	1.21
2030 RCP8.5	7.94	11.15	3.22	40.52	246.5	1.30
2060 RCP2.6	9.99	12.87	2.88	28.86	225.9	1.28
2060 RCP4.5	7.46	11.43	3.97	53.23	236.1	1.68
2060 RCP8.5	5.46	13.05	7.59	139.01	241.9	3.14

The irrigation increases yield for about 31% in the year 2020 (base case), very similar to the increase in 2060 for the RCP2.6 scenario. Also, the same RCP resulted with smaller yield increase of about 39% in year 2030. Much higher increase in the yield is achieved when simulation was done using the weather data and Co<sub>2</sub> concentration for RCP4.5 scenario 44% in year 2030 and 53% in year 2060. The highest yield increase is achieved in the scenario that caused the highest yield reduction RCP 8.5. The yield increase as result of irrigation is almost 41% for year 2030 and maximal 139% of yield increase were achieved in the year 2030. This is somehow logical consequence of the yield reduction as result of the water shortage. The irrigation successfully compensates yield losses caused by water limitation, and in case of more severe yield reduction irrigation achieve better results. The important fact is simulated irrigation water use for different time span and different RCP's. In general, the smallest amount of water for irrigation is used in the base case (229mm), but also yield increase is smallest (only 2.73 t/ha). The interesting fact is that all 3 scenarios used more water for irrigation in year 2030 than in year 2060. This is probably result of the increased temperatures that shortened the growing period and more efficient water use by the crop in case of increased CO<sub>2</sub> concentration. Result is significant increase in water productivity in the period of year 2060 for scenarios RCP 4.5 and RCP8.5 to 1.68 and 3.14 kg of yield for each m<sup>3</sup> of water used. However, this water productivity is calculated only to the incremental yield increase and water amount used for irrigation to achieve that yield increase and is quite different of the normal understanding of the water productivity when calculation procedure considered total water used (from natural sources and for irrigation) versus total yield achieved. Our goal is to present important fact that in the base case for each m<sup>3</sup> of irrigation water used the yield will increase for 1,18 kg. However, the water productivity in the future climate will be more efficient and will rise to the values of 1.2 to 1.7 kg for each m<sup>3</sup> of water used for irrigation. The exception is the scenario of RCP9.5 in year 2060 when water productivity will rise to 3.14 kg for m<sup>3</sup> of water used for irrigation. Actually, the

conclusion is that irrigation water will become more productive in future climate and higher the impact of climate change will be, the water will bring higher benefits in term of production and productivity. Therefore, irrigation as adaptation have significant advantage with amplifying its positive effects as situation with climate change is worsening.

The rehabilitation of the irrigation systems as adaptation measure after this elaboration is even more powerful, because it can be done without worries that more water will be required for irrigating the crops in the future climate and irrigation systems will not be able to supply enough water. Moreover, the effects will be more and more positive as time will go on. The infrastructure for irrigation exist, the water use for irrigation purposes is regulated and there are not obstacles and challenges that building of new irrigation infrastructure is faced with. Therefore, the rehabilitation of the existing irrigation infrastructure should be set as highest priority in the crop production subsector and should start early enough to improve climate change resilience. However, there is important challenge associated with the cost of irrigation water. To keep irrigation profitable the cost for irrigation should not be higher than profit that can be achieved. Nevertheless, the benefit of the irrigation water in case of maize growing is between 1 to 3 kg of maize for 1m<sup>3</sup> of water. If water price rise above cost of the 1kg of maize for m<sup>3</sup> then there is not profitability and measure will be just losing the money for the farmers. However, the pressure over the water resources will rise in the future, almost all sectors will need more water and it is expected that price will increase. Therefore, the policy for maintaining the cost for irrigation in the future should be one of the highly ranked priorities for decision makers and for policy development in agriculture. However, policies for support of agriculture can contribute in reduction of the cost for irrigation by subsidizing the water cost as top up payment, introducing the agri-environmental measure for irrigation that will compensate farmers for the increased cost associated with irrigation, supporting the purchase of the modern water saving equipment for irrigation, developing of irrigation scheduling systems and many other measures can be implemented to keep farmers irrigating their fields.

The analyses of the situation in the agricultural sector and irrigation and drainage lead toward several important conclusions about the gaps determined, about several needs and about possible development directions that will lead toward improvement of the situation.

The yield gap, as result of the water limitation and some shortage of knowledge and somehow old-fashioned technologies applied in the crop production and in irrigation and drainage, reduces production and profitability. Moreover, in synergy with other structural constrains as small farm size, small plot size, low level of education of the farmers and some natural constrains as low fertile soils, unfavorable weather conditions, frequent water and heath stress and more frequent and more severe extreme weather events reduces the productivity to the level of lowest crop yields in Europe.

The irrigation infrastructure was constructed more than 50 years ago, and due to lack of maintenance, frequent changes in irrigation management models and number of other reasons the part oof the infrastructure is damaged to the level to be non-usable for supplying irrigation water to the farms. Moreover, the water losses in conveyance network, in distribution network and on the farm level increased and there is urgent need to rehabilitate the network and to reduce losses to the acceptable level.

The irrigation systems were designed for completely different social environment and present solutions are not favorable for irrigating the small farms and small plots with modern irrigation techniques. Moreover, farmers prefer to use drip irrigation for almost all crops suitable for this technique (orchards, vineyards, row crops, vegetable, green houses, plastic tunnels etc.). Therefore, the rehabilitation should be conducted with emphasis on the modernization of the network and suitability for microirrigation and sprinkler irrigation, therefore wherever possible gravity flow to be replaced with pressurised and to replace channels by pipes.

The water for irrigation is available, there are already constructed reservoirs that should be fitted with irrigation network. However, there are number of options for construction of the new dams, reservoirs, and irrigation systems and increasing the irrigation area should be based on both solutions: i) construction of the new irrigation systems and ii) rehabilitation the existing irrigation network. Moreover, the process of rehabilitation of the existing network and building of new irrigation systems should be conducted with participation of the end users and they should be consulted about their needs. This approach will help in building the trust between water management organizations and end users and will ensure higher level of utilization of the water in agriculture, therefor will contribute to the filling the yield gap, increasing the productivity and production, will contribute to the increasing of the competitiveness etc. Moreover, the consultation process should be merged with land consolidation activities and consolidated land and increased parcel size will reduce some of the important structural deficits and will boost effects of the irrigation.

Similarly, to irrigation systems, the drainage systems are old and rehabilitation is direction for improving of their functionality, thus to protect crops from excessive water and to boost productivity of agriculture. The big parts of the number of drainage systems are not functional, there are problems caused by processes of privatisation, closing the channels and drains, urbanisation, cadastral /property problems and number of other issues that should be addressed in the next 10 years period.

Adaptation options:

The adaptation should go in 2 directions

1. Rehabilitation of the existing irrigation and drainage systems, and construction of the new infrastructure in order to reduce losses in the conveyance and distribution network and to adapt irrigation distribution network to the modern irrigation techniques and farmer's needs.
2. Increasing the water use efficiency at the farm level in order to increase the productivity and production and to achieve higher water productivity (more crop per drop)"

## Analyze of the adaptation measures already tested in the country

The Rural Development Network (RDN) conducted project on “Adaptation to climate change in agriculture” supported by United States Agency for International Development (USAID) in the period 2012 – 2016. The project tested number of adaptation measures in Macedonian environment and determine some very suitable measures. The measures are presented below. Moreover, RDN conducted economic feasibility of each measure and promotional activities. Therefore RDN can be good source of information for implementation of the measures below.

### **Fruit Growing**

#### Use of anti-hail/UV protective nets in pear, plum, apricot and peach orchards

Trees covered/protected with UV nets provide significantly higher yield compared to uncovered trees which is in average 50% higher compared to uncovered trees. Analyzing the parameters related to fruit quality, it was noticed that the UV covered trees have slightly lower average fruit weight, higher amount of total soluble solids and better firmness of the fruits which improve fruit quality. Therefore, the measure is proven as very good adaptation option and should be continued in the Agriculture support program.

#### Use of drought tolerant apple, sweet and sour cherries rootstocks as an agricultural measure against lack of water in the soil

Experiments with sweet and sour cherry in the demonstrative orchards show that in arid conditions and in regions affected by climate change the most recommended rootstock is prunus mahaleb as trees grafted on this rootstock show better development of the trunk and productivity of the trees. In regards to evaluation of the apple rootstock trees grafted on rootstocks Suporter 4, M9 Emla and Pajam 2 have higher growth and the most productive are trees on M9 Emla and Pajam 2. These two rootstocks can be recommended for production of apple in more arid conditions and in regions more vulnerable to climate change. Therefore, the use of these rootstock should be supported in establishment of the new orchards as well as in form of support of production of seedlings.

#### Changes in planting depth of trees in apple and cherries orchards

Deeper planting of the trees has positive influence on the vegetative growth and productivity of the trees as it contributes for better absorption of available water in the soil. Deeper planted apple trees have between 20 to 33 % better growth of the trunk and an increase of over 28% in productivity, while deeper planted sour cherries have from 9 to 12% higher production compared with standard planted trees. Therefore the measure should be set as requirement in the support for establishing the new orchards.

#### Use of different materials (Trichoderma spp., Zeolit/Zeofit and Hydrogel) as a measure for water conservation in sour and sweet cherry orchards

Trees planted with usage of water conservation materials have better development, higher growth (up to 20% in cherries, up to 17% in sour cherry orchards) and survival of plants. This especially refers to zeofit, while hydrogel does not have significant influence on the plants. Trichoderma spp. boost the root

development. The measure needs further evaluation, while use of zeolite can be set as condition in establishing of new orchards support.

#### *Using the pruning techniques at peaches and apples as a measure for reduction of sunburns on fruits*

In warmer region, the negative influence of direct sun insolation is more evident and sun exposed fruits have sunburns on the fruits. Short pruning contributes to avoiding of the negative influence of high insolation. Results have shown that by implementing short pruning the vegetative growth of the trees is reduced and yield decreased (2,5%). However, the fruits are with better quality and some pomotechnical measures such as fruit thinning is easy to conduct and less costly (requires less labor). Fruits are with better quality, and in higher grading class which from economic point view is more profitable. Our evaluation concluded that short pruning is a recommended adaptive practice for regions prone to changing climate and high insolation. Therefore, the measure can be introduced in the support for maintaining the orchards as top up payment (due to yield losses) for warmer regions.

#### *Use of specific the protecting materials for preventing sunburns on apple and pear fruits*

The analysis of usage of specific protecting materials for preventing sunburns on pear and apple fruits are very positive as in all orchards where this measure was used damages on leaves and fruits caused by high insolation were not noticed. The most recommended protective material is **calcium carbonate**. In addition, it had positive influence on protection of trees against attack of pest psila pyri. The measure should be incorporated in the measure for support of orchards maintaining.

#### *Row space mulching in apple and pear orchards*

Trees grown under peat and sawdust mulching have the best productivity. Reduction of the soil temperature and conservation of water by using this type of mulching provide better soil condition for the trees, avoidance of the stress factors and thus uninterrupted pollination and fruit set which is resulting in higher yield ranging from 3,5 – 43% increase in productivity compared to orchard rows without mulch. With its introduction, an indirect influence on better water conservation in the soil and better uptake of water and nutrition of the fruit tress was achieved. The project results show that the effect of mulch material on water conservation varies from 5,1% to 27% in beneficiary pear orchard. In some fruit growing practices mulching can be also used as a measure for weed control. Therefore, measure should be introduced as top up payment (due to increased cot for establishing mulch cover) in annual payments for orchards maintaining.

### ***Vineyards***

The following measures were tested:

#### *Utilization and influence of T-pruning system application*

The data is not publicly available

#### *Utilization and influence of UV protective net*

The data is not publicly available

### Application of calcium carbonate

The measures proposed were evaluated in interaction, therefore the conclusions are not very clear on individual effect of each measure. However, the measures express impressive results and should be set as measures for CC adaptation in vineyards. Moreover, the proper advisory package should be developed on application of these measures separately or in combination.

## **Vegetable**

Measures:

### Implementation of *Trichoderma harzianum*

The measure expressed better seed emergence, enhancement of root growth at vegetable plants, faster plant growth, increased flowering and plant's increased capacity for improved water and nutrients uptake resulting with higher and better-quality yield. The plants had a height increase of over 12% followed with 28% growth in productivity. The benevolent fungus additionally influenced reduction of water consumption ranging from 3,7 to 4,2 %. The measure should be involved as top up payment in vegetable production, but proper advisory package is required.

### Utilization of UV protective nets

UV nets used in open field production as well as on plastic tunnels prevent damages from sunburns on vegetable plants, leaves and fruits and contribute to achieving better quality yield. Nevertheless, the farmers should receive proper instruction of the percentage of shading, appropriate color per specific crop as well as the timing and frequency of UV nets utilization. It is very important to use them only when sun radiation is very strong, especially the nets placed above plastic tunnels. If the shading nets are applied when sun radiation is weak, plants start to suffer from lack of light and become yellowish with long internodes, susceptible to diseases and with lower productivity. The percentage of shading of UV nets also depends on the growing system practice (open field or vegetable growing in controlled conditions). The UV nets with 30% of shading, which are placed in outdoor, open field production, gave satisfying results, while when placing UV net over plastic tunnels, the 15% of shading was enough to give suitable results. The productivity of the plants increases by 0.5 kg/plant. The plants which were growing under UV nets produced fruits without sunburns and perfectly matured. In addition, the UV nets showed excellent results in providing protection from hail. The measure should be introduced as CC measure in vegetable production, with proper advisory package for implementation of the measure.

### Use of plastic bags filled with soil mixtures

Plants grew faster, bigger, with better yield and enhanced quality. The main reason for better plant development was the higher temperature and better control of water and fertilizer in the growing medium (soil and turf mix) ensuing better root development than in the soil and resulting with over 50% increase in yield. The measure should be introduced as CC measure and advisory package to be developed. However, the measure has additional potential in irrigation water saving, fertilizers saving, reducing water pollution from agricultural sources etc., but further elaboration is required.

## ***Efficient Agricultural water management***

### *Irrigation scheduling on the basis of meteorological parameters from installed meteorological stations*

These activities were in correlation with the project purchased meteorological stations set up in Negotino and Skopje region together with the additionally installed soil moisture sensors. The initiative was developed to be site specific and to aggregate information collected on the wider region with information from the specific fields and to deliver a valuable decision-making tool for farmers to optimize irrigation for their specific field and crop they are growing. The main principle of this idea was to close the circle between the collected data from meteorological stations, soil moisture sensors and water-physical properties of the analyzed soils in the project region, in determining when to irrigate and how much water to apply.

As a whole, the realized activities provided resources and information to farmers not only to manage water more efficiently, but also to achieve highest benefit from the water simultaneously minimizing the negative impact on the environment. More than 60 weekly irrigation programs for irrigation of vineyards (Negotino) and corn crop (Skopje) were issued and were readily accepted by farmers.

### *Improvement of drip irrigation and drip fertigation practice for efficient use of water and fertilizer and soil water conservation*

Drip irrigation and drip fertigation is a common practice in modern agriculture in the world. In the Republic of Macedonia this technology is fairly spread, especially in vegetable, fruit and grape production. Anyhow, there is still problem of proper using of drip irrigation systems in the country. Namely, most of the farmers use own designed irrigation systems, which is in common different from real terrain conditions. For example, longer drip pipes instead of short pipes and vice versa, use of emitters (dripper or micro-sprinklers) with different discharge than soil water characteristics (infiltration rate, etc.), lower filter capacity (for water filtration) in large designed irrigation systems or vice versa, etc. Generally, these problems have influence on efficient water and fertilizer use in crop production. Additional problem related to efficient use of water and fertilizer, as well as for reduced yield and economic productivity is improper fertilizer application in farmer production. Namely, regardless of utilizing modern techniques for irrigation in the country, the farmers don't use injectors for regular application of fertilizers through the irrigation system. Most of the farmers in the country use drip irrigation, while fertilizers are applied by spreading on the soil.

When drip fertigation, water use efficiency is almost 25% higher in comparison with drip irrigation and traditional spreading of fertilizer and almost 50% higher in comparison with furrow irrigation and spreading of fertilizer. Also, the fertilizer use efficiency is almost 20% better in drip fertigation in comparison with drip irrigation and spreading of fertilizer. Therefore, the drip fertigation should be compulsory measure in all cases where drip irrigation is supported. The fertigation unit must be included in the drip irrigation system.

## Recommendation of the measures already presented as mitigation measures, with high adaptation potential

### *Biochar Application on low fertile land*

The high criteria for keeping temperature increase below 1,5°C requires quick and energetic actions and change of CO<sub>2</sub> emission reduction strategies toward “negative emission” technologies that withdraw CO<sub>2</sub> from the atmosphere. Realistic measures that deliver negative emissions are very limited. Options available to deliver negative emissions include sequestration in biomass and soil, and biomass energy with carbon (C) capture and storage (“BECCS”), enhanced weathering, ocean fertilisation and direct capture of CO<sub>2</sub> from air by “artificial trees” etc.

Conversion of biomass to biochar is a strategy for C sequestration that could contribute to “negative emissions”. The thermal conversion of biomass to biochar creates a product with much slower mineralization than the original biomass source; this delayed oxidation delivers long term C sequestration. Gases released during pyrolysis can be combusted for heat or power and could be captured and sequestered and used as energy source for pyrolysis of the biomass. Biochar offers additional mitigation benefits through a range of routes: besides delaying the mineralization of organic matter used as feedstock, it can (under certain conditions) reduce nitrous oxide (N<sub>2</sub>O) emissions from soil, enhance plant growth, thus sequestering more C, and may stabilise native soil organic matter, further increasing C sequestration. Additional mitigation can be delivered through reduction in GHG emissions, resulting from reduced fertiliser and irrigation requirements due to improved nutrient- and water-use efficiencies, and avoidance of GHG emissions from conventional disposal routes.

Biochar was included for the first time as a promising negative emission technology in the new IPCC special report “An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty” published in 2018. The inclusion of biochar is an important milestone for mitigating climate change and fostering research on pyrogenic carbon.

Biochar is defined as a solid material generated by heating biomass to a temperature in excess of 350°C under conditions of controlled and limited oxidant concentrations to prevent combustion. These processes can be classified as either pyrolysis (in which oxidants are excluded), or gasification (in which oxidant concentrations are low enough to generate syngas)

However, biochar can capture even 3 times more CO<sub>2</sub> compared to its weight, because of its high carbon concentration (about 60% when produced from straw, more than 80% if produced from wood). The biochar should be carefully introduced in the country, after some research for adopting the technology. The meta analyses show various effects on crop yield. The average yield increase is about 10% with higher effects in tropical than in temperate agriculture. The application rate is from 4t/ha to more than 20 tons, but most common from meta analyses is 8-10 t/ha. Even though maybe too early, we are including this technology as promising and potentially disruptive technology for carbon sink in agriculture, with significant positive effects on productivity.

### ***Photovoltaic irrigation***

The irrigation is well known measure for adaptation of the agricultural production to the climate change. However, there is possibilities to realise some mitigation effects by replacing the energy used for pumping the water (electricity, petrol) with renewable energy. Replacing the energy source by electricity produced from renewable is possibility to make irrigation mor environmentally friendly. However, the proposed measure is based on existing national legislation, the maximal discharge of the ground water without licence is 1 l/s. The pump will operate while there is production of the electricity by the sunshine. If classical irrigation techniques will be used with this system there is possibility to irrigate up to one hectare, with drip irrigation irrigated area can be doublet to two hectares if careful design of the on farm irrigation will be applied with particular attention on number of sets and their rotation in time. However, this design is very interesting because sunshine duration and intensity are somehow in accordance with the crop water requirement. At the beginning and at the end of the season day is shorter, the electricity will be produced in shorter period, but also the crop water requirement is lower. Also, there is similar logic within one day, in the hottest period with the highest sunshine, crop need more water that in the morning or before the night. Also, electricity production and water amount pumped will be smaller. However, the system we propose is not designed following this phenomenon, but it can be subject of future research.

The two cases are considered as mitigation practice, replacing the petrol pump with consumption of 0,3l petrol per hour (one of the most popular pumps in the country) with 3 phase AC pump and adding photovoltaic and replacing 1.1 kw electricity pump with 3 phase AC pump and adding the photovoltaic. The measure is suitable for already established on farm irrigation systems, but also for new establishing of the irrigation systems with on-farm water source. However, the last case is highly effective adaptation practice and will be considered as adaptation measure that will convert non irrigated agricultural land in irrigated and dry farming of low intensive crops will be replaced with intensive crop in in irrigated farming. Moreover, photovoltaic irrigation can increase the adaptive capacity of crop production sector by converting non-irrigated in irrigated land. Also, photovoltaic irrigation can be of significant importance for food security in energetic crisis, extreme events, disasters etc.

The measure is compatible with IPARD 2 measure “Production of energy from renewable resources for self-consumption, through processing of plant and animal products from primary and secondary biomass (except biomass from fishery products) for production of biogas and/or biofuels, use of solar energy, windmills, geo-thermal energy etc”. The measure provides up to 65% of co-financing and promoting of photovoltaic irrigation in the frame of this measure is feasible.

### **Risk of appearance of the new crop pest and diseases**

In recent years, there has been significant growth in the body of literature on how climate change is likely to affect plant diseases. The majority of these papers predict that plant diseases are likely to become more severe, epidemics will be more frequent and some pathogens will spread to new areas. This literature warns of the challenges for agricultural research which must respond to these predicted changes.

One of the reasons for the decrease in yield in agriculture throughout the last century is associated with invasive pests reaching new areas. Their access to potential sites can be related to the advent of globalization, especially the increasing interchange of people and products around the world. Generally,

the most important factors responsible for the outbreaks of crop plant diseases and spread into new areas are:

- global plant trade
- inadequate surveillance and quarantine,
- lack of resistance in the host plant,
- changes in virulence of the pathogen,
- changes in crop management methods and
- conducive weather conditions (including Climate Change).

Prevailing weather conditions are far more important than changes in climate in the short and medium term. Uncertainties as to where, when and if plant diseases will become more severe, causing greater crop losses and threatening future food production, particularly in the latter half of this century. Most papers conclude that there is a need for much more research and increased funding. Also, it is essential to generate new datasets required, improve monitoring and modelling tools.

The global uncertainty is even pronounced in the country, because very limited number of reports and papers are available. The research on effects of climate change on crop pests and diseases are not available. It is known that recent and significant example of this problem is the spread of the invasive pest *Tuta absoluta* to the mainland Europe, including Republic of North Macedonia. Even though papers elaborating spreading of the *Tuta absoluta* in the Europe, do not include North Macedonia as area affected, our experience and number of field visits prove that the pest is present in the country. However, *Tuta absoluta*, is known as the South American Tomato Pinworm, has been reported as a tomato pest in South America for more than 50 years. Therefore, the spreading of *Tuta absoluta* is going from West to East, and characteristic of climate change induced move of the pest and diseases is usually Northward. Therefore, there is number of papers that do not agree with assumption that climate change induce spreading of the pest Eastward. There are papers that analyse the global spreading of *Tuta absoluta* and reports that it can be associated with climate change and even predict future spreading of the insect to the other areas of the world, including some of the most important tomato growing regions globally.

However, the spreading of the insect and diseases from one region to the other can be associated with a lack or bad implementation of the phytosanitary measures and can be sign for improvement of the national phytosanitary systems. This is particularly important in the North Macedonia, because Phytosanitary monitoring is not operational and there is serious lack of information's, reports, publications and research activities on effect of climate change on spreading of the diseases and pests in crop production. Missing the basic data is creating this unfavorable situation and proper phytosanitary monitoring, increased transparency of meteorological and agrometeorological data, can influence increased interest of researchers toward the issue and stimulate modeling activities in order to assess how climate change will influence risk of new diseases and pests appearance in the country.

Nevertheless, decades of research on the global scale have generated considerable knowledge and greater understanding of the seasonal effects of temperature, rainfall and humidity on diseases affecting major food crops. However, long-term data sets on plant disease development under changing environmental conditions are rare. It is also clear that plant diseases respond to different climatic variables in different ways. The outcome for any given host–pathogen interaction under changing climate is not readily predictable. Furthermore, the lack of models with multiple climate change parameters adds another layer of uncertainty, as there could be significant interactions between these variables.

The many factors involved in determining plant health under a changing climate, their direct and indirect effects, interactions and feedback loops raise the question of whether a predictive understanding of these complex systems is achievable. It is therefore important to make clear the inherent uncertainty in models of plant disease development under climate change.

Two recent studies on wheat rusts illustrate this uncertainty. In one study in Europe, wheat leaf rust (*Puccinia triticina*) model scenarios using temperature and leaf wetness predicted disease onset would be one month earlier, due to rising temperatures during the latter part of this century. This effect was partly counter-balanced during the spring by lower leaf wetness frequency.

However, another study of several wheat leaf rusts noted that temperature rises had a beneficial effect on the pathogens' survival depending on availability of humidity and leaf wetness. On the other hand, increased levels of O<sub>3</sub> had a negative effect while the effect of increased CO<sub>2</sub> varied among susceptible cultivars. Without including temperature, leaf wetness, CO<sub>2</sub> and O<sub>3</sub> as parameters in the same model, it would therefore be difficult to predict whether wheat leaf rust would be more or less severe.

Well-developed models are available for major food crops. Models for plant diseases, however, are restricted to a few major pathogens. It is therefore not surprising that most modelling studies of plant diseases under changing climate are focused on major diseases of wheat and rice. In general, with the exceptions of potatoes and oilseed rape, the effects of climate change parameters on diseases of other food crops such as roots and tubers, sorghum and millets, legumes, oilseed crops as well as animal forage crops, have been neglected. Clearly more research is urgently needed on these crops and their diseases.

#### Actions required:

There are evident risk of appearance of new crop diseases and pests. Moreover, the changing climate can disturb the present pathogen to host interaction in favor of the pathogen and even increase problems associated with crop protection and yield losses. Therefore, the following actions are required:

- Rehabilitation/ new design and setup of the phytosanitary monitoring system based on the geospatial distribution of pests/diseases
- Investment in capacity building of the research and high educational institutions in establishing capacities for modeling of the crop diseases and pests including the effect of climate change
- Increase the availability of the meteorological/agrometeorological and other data and datasets required for crop/disease modelling

## **Adaptation measures resulting from the consultation meetings and presentation of the results**

The two workshops for presentation of the results and for the consultation with the stakeholders took place as follow:

1. Workshop on the results from the sectoral report for agriculture and forestry prepared for the needs of the IV national plan for Climate change, with representatives of the farmers, farmer's associations, extension experts and representatives of the business sector in agriculture that took place on 13 and 14 October 2021
2. Presentation of the results of the sectoral report for agriculture and forestry prepared for the needs of the IV national plan for climate change with representatives of the ministries, academia and international donors that took place on 29 October 2021.

During the Workshop with representatives of the farmers, farmer's associations, extension experts and representatives of the business sector in agriculture the intensive discussion was developed. The discussion emphasized three major problems farmers are facing with:

- Low level of participation in policy creation and in decision making in the sector
- Low access to the financial resources for investing in the adaptation practices
- Problems related to irrigation (damages of the distribution network, water not available when required etc.)

The presentation of the result for the representatives of the ministries, academia and international donors also was followed with fruitful discussion. The representative of the Ministry for agriculture, forestry and water economy pointed out the insurance of agricultural production as one of the important measures for farmers resilience to climate change.

The MAFWE plan to revise the current measure for financial support for co-financing the insurance of agriculture. The present measure covers 60% of the cost for insurance, but the measure was not widely accepted by the farmers. However, the insurance is wise measure in agriculture. With climate change the extreme weather events will increase (by number, duration, frequency and severity). The insurance should be first choice for addressing the risks of climate change, because farmers will be compensated for damages they will have on their fields. The most important benefit from the insurance will be that agricultural producers will be able to use compensation received from insurance companies to cover damages and to survive until the next harvest. Such benefit will provide more resilient farming community, rural population will be able to remain in rural areas and keep doing important roles they have, as food production, ensuring the food sustainability in the country, maintaining the rural landscaping and number of other less visible roles. Insurance can significantly contribute to achieve de-risking of the agricultural sector. However, number of adaptation measures reduce risk. The adaptation measure usually addresses the most prominent one or several risks. Nevertheless, number of other risks remain and still jeopardize agricultural production. These residual risks can be covered by insurance. The most important is to treat insurance as de-risking tool that cannot replace adaptation to climate change.

The revision of the measure considers the increasing of the cost coverage. Moreover, the idea is to revise the whole system of insurance in agriculture. The intention is to move from named peril to multiple peril and to all raise coverage. Moreover, the final goal is to move to the index-based insurance and reinsurance in due time. Therefore, the completely new design of the insurance in agriculture is

required, from main principles of the models used to the development of the advanced indexes that should be regularly MAFWE will be institution responsible for implementation of the new insurance system in agriculture. monitored.

Therefore, the proposed adaptation measures are amendment with 4 new measures resulting from consultation process:

- Increase farmers participation in policy development and decision making processes
- Improve access to the financial assets for the farmers and small agricultural enterprises
- Improve maintenance of irrigation systems
- Revise the insurance measure with new, modern and farmers appreciated practices

### **Recommendation for the increased level of implementation of the national policies/documents related to climate change in agricultural sector**

One of the essences for successful creation of the long-term policy for climate change in AFOLU sector is to improve the cooperation between environmental and agricultural sectors and responsible institutions. However, the Ministry of Agriculture, Forestry and Water Economy (MAFWE) should be considered as most important stakeholder in this process. The present attitude that MoEPP is preparing national documents without participation of the MAFWE did not contribute to the development of the Climate Change mitigation/adaptation in agricultural sector. In present the MAFWE policy in this mater is fully synchronized with the TNC and TBUR, and the number of the instruments of MAFWE (Direct Payments, National rural development programe, IPARD...) will be programmed to contribute to the realization of these measures presented in the TNC and TBUR Moreover, it is important:

- To ensure mutual transparency of information, including development of an integrated database for data and research driven policy making including data collection, monitoring and evaluation framework. and the tools for awareness raising, knowledge transfer and common training modules;
- To establish operational vertical and horizontal cooperation (inter-institutional, inter-entity); where feasible transfer from individual farm approaches to management in bigger scale operations, such as watershed or commune level management, can be more efficient.

Including the mitigation measures in the Agri-environmental policy (AEP) is probably one of the best solutions for North 's Macedonia's agri-food sector. The Agri-environmental policy often has to serve two goals: one is to ensure to enable agricultural activities and decrease abandonment of agricultural land; this is often the case in marginal regions, where frequently extensive forms of farming are in place. These systems provide highly valued services to the public, for example maintained cultural landscapes and biodiversity, as well as cultural identity. Sustainable provision of these services is one goal of agri-environmental policy. On the other hand, the pressure for economic improvement of agriculture, increase of production, and growth of farms generates challenges for keeping the development on an agroecological pathway. This is where AEP should ensure, aside of regulatory prescriptions and laws, the

design of a framework for effective support of environmentally friendly farming practices and approaches. The EU Commission defines Agri-environmental measures (AEM) as a key element for integration of environmental concerns into the EU Common Agricultural Policy. The AEM are designed to encourage farmers to protect and enhance the environment on their farmland. Farmers commit themselves to adopt environmentally friendly farming techniques that go beyond their legal obligations (set by cross compliance). In return, farmers receive payments that provide compensation for additional costs and income foregone resulting from applying those environmentally friendly farming practices in line with the stipulations of agri-environment contracts. However, the AEP covers more than just on-farm measures for improvement of environmental impact of agricultural activities. Thus, AEP strives to influence laws, programs, political instruments, and measures in agricultural policy to ensure that positive impact from agriculture on the environment is strengthened, and negative impact is minimized. Therefore, the climate change mitigation and adaptation should become one of the key components of the national AEP, following the new EU CAP. Moreover, the mitigation measures are costly and even though the choice of the measures in this report put emphasis on the measures with clear co-benefits and yield increasing potential, frequently farmers cannot afford such investments and supporting them to move towards carbon farming can increase the respective use of the measures. Moreover, mitigation measures in AFOLU sector need to be designed on the base of sound information and scientific understanding. Only if the goals of mitigation measures are defined and agreed with national agri-environmental policy, and their impact is monitored, the success of an implementation can be evaluated. It is important to carefully implement a monitoring and evaluation system also calling upon independent evaluators.

- Increasing the awareness on all levels for the need and the potential benefits of mitigation measures is essential for their successful implementation. It is advised that all stakeholder groups understand the objective and need of the mitigation measures and are involved in their development. This refers to farmers, consumers, public, decision makers, advisory services, researchers. Government bodies and NGOs that should be linked for joint activity projects.
- Capacity Building is essential for a successful further development and expected growing importance of mitigation measures in AFOLU sector. Therefore, it is necessary to improve the staff capacity in responsible institutions in terms of number and knowledge, as well as improving technical capacities for: i) program development; ii) monitoring and evaluation; iii) control and administration of mitigation measures; iv) training, advisory services, and education.
- The investment in a system for research on national emission factors and other data required for proper modelling of the emission and effect of mitigation measures, as well as training of research staff, is essential for making the step toward implementing the higher Tier level, important for moving a step forward in designing the mitigation measures.
- Education and vocational training of farmers and also administration/institutions as well as of inspection bodies (capacity building) are needed to spread up to date knowledge and exchange experiences.
- Establishing demonstration farm (farms) for testing and piloting the mitigation measures and activities for the national circumstances would support the knowledge transfer and exchange of experiences.
- Establishing regular training of staff in relevant institution and advisory services and ensure participation e.g. through a certificate is also of great importance.

- Conducting the project on biomass productivity, production and utilization in the AFOLU sector, in order to estimate biomass availability, biomass requirement in the sector in present and future to ensure sustainable supply for advances in biomass turnover in the sector, as prerequisite for establishing a target for joining the “4 per 2000” initiative.

Frequently adaptation measures and intervention are considered as on-farm measures for adapting crops/animals for improved productivity in future climate. These measures are really important for sustainability of food production, food security, rural population welfare etc. Such type of measures was tested and elaborated during the USAID supported project on adaptation of agriculture. However, the other direct for adaptation interventions in related in adaptation of the whole system. Such measures are directed in adapting the whole system, increasing the adaptive capacities and resilience of the agricultural system. The intervention that should be considered for the strategic period are related to:

- Increased level of knowledge and know how in agricultural sector including increasing the level of education of agricultural producers and employees in agricultural enterprises
- Increased access to the services for decision making support on the farm level by implementation of climate smart agriculture,
- Improvement of agrometeorological network by number of stations, news services, personalization of the services for specific conditions prevailing on farm, including, soil, fertilization, crop protection, irrigation, etc
- Improved access to agro-meteorological services for all stakeholders, particularly small farmers, through innovative approach suitable for level of knowledge and education prevailing in the sector
- Improvement of agricultural water management by large scale soil water monitoring, irrigation scheduling, water saving, fertigation etc.
- Improvement of the advisory system, development of the proper advisory packages for climate change related issues
- Increased investment in research and innovation, including development of the center for innovations and climate change that will develop, test and adopt mitigation and adaptation scenarios and measures and serv as dissemination center
- Improved quality and spatial distribution of all datasets, development of the new datasets required for CC research, allow access to the data sets based on open data policy
- Development of indicators for CC, vulnerability, mitigation and adaptation that will be regularly updated and used for assessment of the progress in climate change policy and practice
- Implement of Phyto-sanitary capacities for monitoring of the economically important diseases and pest and for monitoring eventual appearance of ne ones due to changed climate
- Compulsory implementation of the cross compliance for all farms using subsidies and implementation of agri-environmental measures
- Capacity building for climate change issues at institutional level

## **ECONOMIC ASPECTS OF THE VULNERABILITY TO CLIMATE CHANGE (Soil and Crops)**

Climate change can have a wide range of effects in agriculture, forestry and land use in general. For instance, climate change has a direct impact on agriculture by altering crop growth development and yields as a result of variations in rainfall and temperature patterns, and more intense, more frequent extreme weather events. On a local and global scale, the indirect second-round effect of these productivity changes can have significant ramifications for agricultural market developments, farm incomes, the environment, and, ultimately, food security in the region (Nelson et al., 2014). In order to formulate effective responses to these challenges, both at production level, on one end, but also at policy level, on the other end, it is necessary to examine the economic ramifications of the biophysical impacts associated with changing climate. The adaptation of the agricultural sector to climate impacts is therefore key for its survival. From the findings presented in the previous chapters, two case studies involving economic aspects emerge: (1) promotion of sustainable irrigation as an effective adaptive strategy, analyzed through the projected vulnerability of maize production; and (2) implementation of smart climate strategies to increase productivity while improving adaptability, with cover crops as a one of the most promising conservation practices. Both cases emphasize the role of including different climate change scenarios as a vital element in relevant policy authorities' decision making processes. In addition, raising awareness towards the actual need for more intensive support to research investigating climate change effects (from various aspects, including the economic effects) is of utmost importance, especially stemming from data derived from applied research and field experiments in local context.

### ***Vulnerability of maize production - sustainable irrigation CBA case study***

Various economic and financial analytical and forecasting tools are used to evaluate the response to climate change and tailor specific measures to adapt to these effects (Bedzek et al., 2018). Cost-benefit analysis (CBA) is a common approach for such evaluations. It is an economic tool that helps determine if the benefits over the lifetime of an intervention exceed its costs, and if not, determine the partial difference that can be subsidized by the government, in order to compensate for the additional cost incurred, which in turn, would bring environmental and societal gains. Full description of the techniques of cost-benefit Analysis (CBA) is seminally explained in Irwin (1978) and Gittinger (1982).

This case study considers the cost-benefit relation of irrigated versus non-irrigated maize production in the context of North Macedonia. The cost-benefit analysis (CBA) is applied, as a decision-making tool for obtaining the economic and profitability of an investment (in on-farm irrigation equipment) by means of a comparison among costs and benefits resulting from the

different proposed measures. In the case of irrigation practice in maize production, CBA is used for choosing between these different options, by comparing the net benefits of each option, that is, the total benefits minus the total costs. To simplify the calculations, only the differences in costs and benefits are compared (using a partial budgeting approach). All other agricultural and technical parameters, output and input quantities and prices are considered *ceteris paribus*, hence the focus is on the difference in the costs between the options.

The economic analysis evaluates the influence of the main variable affected (i.e., net return and irrigation water consumption) over the profitability indicators, net present value (NPV) and internal rate of return (IRR), under different future scenarios of maize production water demand. The net present value (NPV), returns the net value of the cash flows and sums the total present values less the cash outlay required. The NPV greater than zero indicates justifiability of the project. The internal rate of return (IRR), is the annualized rate of return that equates the present values of costs and benefits; it should be greater than the set discount rate for acceptable projects. In addition, the period for return of investment (ROI), indicates the number of years after which the initial investment is returned and it should shorter than the investment life span. The combination of these indicators provides grounds for assessment of the feasibility of the proposed interventions. A standard interest rate of 6% and the amortization periods associated with the life of the 15 years for the irrigation equipment are considered to obtain the amortization annuities. The discount rate is the current rate used in IPARD projects in North Macedonia. The average annual inflation rate is also determined using the CPI index and estimated at optimal 1.5% at annual level.

The cost-benefit analysis is based on the simple premise of extra benefit gains, as result of extra income over extra costs from maize irrigation. The hypothesis of the baseline scenario (Scenario 0) takes into consideration extra benefits generated from extra income as result of increased yield with irrigation and an average price of maize of 9.38 MKD/kg<sup>4</sup>.

Additional costs are generated primarily as a result of water costs (irrigation as a variable cost in case of water paid per cubic meter consumption, and irrigation as a fixed cost when paid per hectare basis), and additionally costs of energy (fuel) are considered, in case of pump irrigation. Furthermore, this scenario compares extra costs in two potential types of irrigation, comparing drip irrigation system, on one side, with sprinkles irrigation system, on the other side (assuming extra 25% consumption on the basic water irrigation normative). The basic scenario presumes that sources and off-farm systems of irrigation exist and no additional capital investments are required.

Using Scenario 0 as a baseline, two more scenarios are evaluated. Scenario 1 hypothesis tends to evaluate feasibility to invest in drip irrigation and sprinklers systems, presuming an investment

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<sup>4</sup> Average maize prices 2018-2021, Agriculture Market Information System, [www.zpis.mk](http://www.zpis.mk)

value in drip irrigation system of 227,550 MKD and sprinklers with 61,500 MKD per hectare, respectively. The operating costs include 2% annual maintenance (based on the investment value), which accounts for regular repairs and personnel costs during the equipment lifespan.

Scenario 2 builds upon Scenario 1 and further intends to identify the maximum level of investment i.e. the level of support/subsidies required, justified by the extra benefit generated with investments in on-farm irrigation. All cost-benefit scenarios are performed based on one hectare of land with maize production.

The model input data were derived from the AquaCrop modelling tool, as an estimation of the non-irrigated versus irrigated maize yields, and the quantity of water required for irrigation. The scenarios cost-benefit evaluation is performed on the three crop-water productivity models (AquaCrop RCP2.6, RCP4.5 and RCP8.5) to assess the effect of environment and management on crop production. AquaCrop simulates the biomass and yields response to irrigation and water amounts in period from year 2021 to 2075.

**Scenario 0. Cost-benefit analysis of irrigated versus non-irrigated maize production without investment.** RCP2.6 example is illustrated in Figure , and the comparison across different RCPs is given in Table 30.

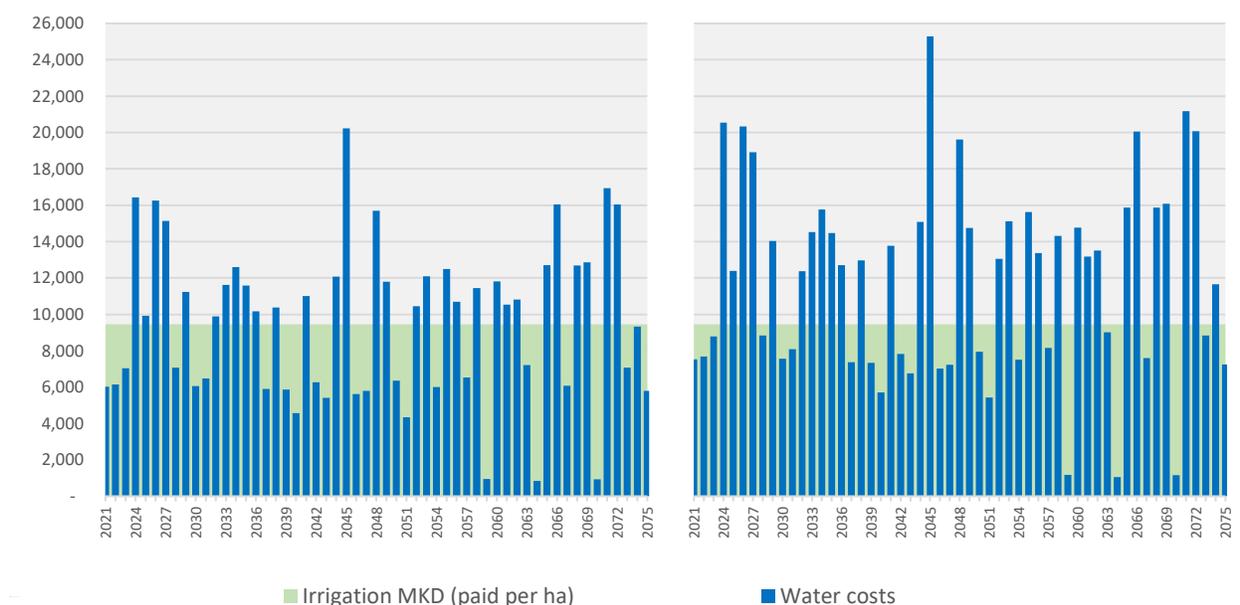


Figure 83. Irrigation water costs drip irrigation (left) and sprinklers irrigation (right) RCP2.6

In average, for the period 2021-2075, in RCP2.6, 9,516 MKD will be extra annual costs for irrigation in case of using drip irrigation system and 12,004 MKD will be annual average costs in case of using sprinklers system, based on charges per cubic meters. The annual costs for

irrigation water are 9,453 MKD per hectare, if charged as fixed based on area (hectares).<sup>5</sup> The irrigation water costs have huge annual variation, which ranks from 841 MKD annually, up to maximum 20,223 MKD annually in case of drip irrigation system. In case of sprinklers, the variation is from 1,051 MKD up to maximum 25,279 MKD annually. The variation is lower in RCP4.5 and RCP8.5.

Table 24. Cost-benefit analysis elements, based on different irrigation systems and water charge models, 2021-2075 (MKD/ha)

	Extra income	Irrigation (per ha)	Drip irrigation				Sprinklers				
			Water costs	Fuel cost	Extra benefit (irrigation per m <sup>3</sup> )	Extra benefit (irrigation per ha)	Water costs	Fuel cost	Extra benefit (irrigation per m <sup>3</sup> )	Extra benefit (irrigation per ha)	
<b>RCP2.6</b>	Total	1,642,071	519,907	523,363	411,880	706,828	710,284	654,203	514,851	473,017	607,314
	Average	29,856	9,453	9,516	7,489	12,851	12,914	11,895	9,361	8,600	11,042
	Max	118,727	9,453	20,223	15,915	82,589	93,359	25,279	19,894	73,554	89,380
	Min	-28	9,453	841	662	-12,647	-15,023	1,051	827	-17,786	-16,415
	Variation	118,755	-	19,382	15,253	95,236	108,382	24,227	19,067	91,340	105,796
	St.dev	30,987	0	4,299	3,383	25,776	28,555	5,374	4,229	24,676	27,978
	No + years					30	29			25	28
	No - years					25	26			30	27
<b>RCP4.5</b>	Total	1,569,364	519,907	503,730	396,430	669,204	653,027	629,663	495,538	444,163	553,919
	Average	28,534	9,453	9,159	7,208	12,167	11,873	11,448	9,010	8,076	10,071
	Max	115,735	9,453	16,375	12,887	89,846	94,881	20,468	16,108	83,374	92,031
	Min	-	9,453	-	-	-19,221	-17,214	-	-	-24,340	-19,469
	Variation	115,735	-	16,375	12,887	109,067	112,095	20,468	16,108	107,714	111,499
	St.dev	32,184	0	3,894	3,064	28,017	30,222	4,867	3,830	27,154	29,761
	No + years					25	25			24	24
	No - years					29	30			30	31
<b>RCP8.5</b>	Total	1,846,957	519,907	537,538	423,036	886,383	904,014	671,923	528,795	646,239	798,255
	Average	33,581	9,453	9,773	7,692	16,116	16,437	12,217	9,614	11,750	14,514
	Max	115,735	9,453	16,375	12,887	89,846	94,881	20,468	16,108	83,374	92,031
	Min	-38	9,453	862	678	-19,221	-17,214	1,077	848	-24,340	-19,469
	Variation	115,773	-	15,513	12,209	109,067	112,095	19,391	15,261	107,714	111,499
	St.dev	32,930	0	4,320	3,400	27,936	30,591	5,400	4,250	26,890	30,038
	No + years					29	30			26	28
	No - years					26	25			29	27

In addition, if the irrigation cannot be performed by gravity, costs for pump use and energy (fuel) are calculated as extra costs. For instance, for the period 2021 - 2075, 7,489 MKD are annual additional costs for fuel used for irrigation and pumping water in case of drip irrigation use in

<sup>5</sup> The average prices per hectare of 9,453 MKD and 4.10 MKD per metric cubic are calculated based on the prices officially published in the Pricelist of JSC Water Economy of Republic of North Macedonia and Public Enterprise for Water supply Strezevo - Bitola 2021. The JSC Water Economy of Republic of North Macedonia is responsible and has different prices for own subsidiaries and branch offices: Radovishko Pole - Radovish, Crn Drim - Ohrid, Bregalnica - Kochani, Prilepsko Pole - Prilep, Tikvesh - Kavadarci, Kumanovsko-Lipkovsko Pole - Kumanovo, South Vardar - Gevgelija, Bitolsko Pole - Bitola, Polog - Gostivar, Berovo - Berovo, Strumichko Pole - Strumica and Skopsko Pole - Skopje. The cost of irrigation water depends on the supply type (gravity or pump) and significantly differ between branch offices, depending on the supply system. The price varies from 28,160 MKD/ha in case of Valandovsko pole (system pumps) to only 5,141 MKD/ha in Radovsiko pole when the irrigation is done by gravity and furrows. Also, there is a significant variation between prices per cubic meter, starting from 0.5775 MKD/m<sup>3</sup> in Prilep (Desovo 1 and 2, and Brailovo), up to 8.046 MKD/m<sup>3</sup> in Valandovsko pole.

RCP2.6, while fuel costs for the sprinklers system in average reach 9,361 MKD on an annual basis.<sup>6</sup> The average annual extra benefit in both systems is positive, however with very high variation and both positive and negative individual years values. Nevertheless, an overall observation is that as result of higher extra costs for irrigation with sprinklers system, stemming from the higher water requirements (25%) in comparison with the drip irrigation system per hectare, the drip irrigation system has higher results and extra benefits (Figure 125). This is the case in all RCPs.

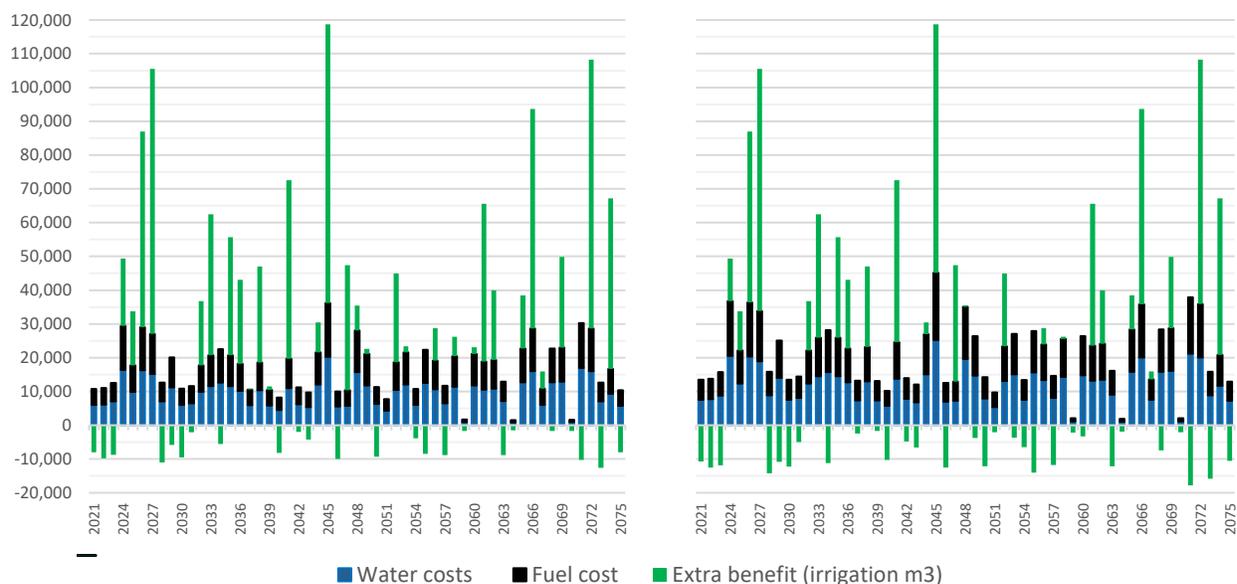


Figure 84. Cost-benefit drip irrigation (left) and sprinkles irrigation (right) RCP2.6

**Scenario 1. Cost-benefit analysis of irrigated versus non irrigated maize production with investment in drip irrigation and sprinklers system.** This scenario takes into consideration an investment in equipment for drip irrigation (227,550 MKD) or sprinklers system (61,500 MKD). The assumption is that the extra income from extra yields and extra costs for irrigation water and pump fuel are on the same level as in Scenario 0.

In case of drip irrigation system, in RCP2.6, the annual costs for depreciation are 15,170 MKD and 4,551 MKD extra costs respectively for system maintenance. As result of the investment, the total additional costs as result of investment are 19,721 MKD, which increases the annual average extra costs on 36,725 MKD (36,732 MKD in case of irrigation water paid per hectare). These costs are much higher than the extra income (average annual 29,856 MKD), which results with negative average annual benefit of -6,870 MKD or -377,827 MKD for the whole period from 2021 to 2075. The finding is similar with the payment of irrigation water per hectare, where total negative benefit is -374,371 MKD or on average -6,807 MKD annually.

<sup>6</sup> Fuel costs are calculated based on the required fuel to pump the recommended irrigation water (0.048 l fuel for 1 m<sup>3</sup> water) and 67 MKD per liter fuel.

In case of sprinklers, the annual costs for depreciation are expectedly lower at 4,100 MKD and 1,230 MKD extra costs for system maintenance. The total additional costs as result of investment are 5,330 MKD, which increases annual average extra costs on 26,586 MKD (24,144 MKD in case of irrigation water paid per hectare). Even though these costs are lower than the extra income and results with average annual benefit of 3,270 MKD and 5,712 MKD in case when payment of irrigation water is per hectare, still they cannot justify investment as the negative NPV and negative flows are noticed (unless a portion of the investment is subsidized, as treated in Scenario 2). Corresponding findings are also found in RCP4.5 and RCP8.5.

**Scenario 2. Break-even analysis of cost-benefit scenario for maize irrigation and maximum value of investment.** The Scenario 2 aims to deliver a break-even analysis based on the investment intervention presented in Scenario 1 (using the calculated NPVs). This break-even calculation actually provides an estimation of the ration between the affordable own on-farm investment and the portion needed to be covered by external funding, that is, the level of support/subsidies required, as compensation to cover the full irrigation equipment investment amount. The scenario also takes in consideration discount rate of 6% and average annual inflation rate at 1.5% on annual level, which are applied on all extra income, costs and investment values used in Scenario 1.

In RCP2.6, in the case of drip irrigation systems, the maximum value of investment that is feasible is 63,714 MKD or 28% of the original value of the system. This means that 72% should be subsidized in order to break-even. In the case of the sprinklers irrigation system, the maximum value of investment that is feasible is 36,285 MKD or 59% of the original value of the system, meaning that 41% of the value should be subsidized. In RCP4.5, the break-even point for policy support is at 18% of the original investment value for drip irrigation, i.e. 25% for sprinkles system. In RCP8.5, the break-even point for policy support reaches 31% for drip irrigation, or 69% for the sprinkles system. Even though the whole exercise is constructed on several assumptions on average values of equipment, water costs and maize prices, it suggests that investments in on-farm irrigation systems should be considered for policy support. Also, photovoltaic systems are a good alternative to fuel pumps used for irrigation water pumping, which should be considered for policy support. Of course, a key requirement is that the whole off-farm irrigation infrastructure is properly rehabilitated and maintained.

### ***Soil conservation practices – cover crops economics case study***

Cover crops are one of the most promising conservation practices, simultaneously promoting many aspects of soil and water sustainability (Chatterjee, 2013). Since the primary farm management objective is to maximize profits, adding environmental considerations requires accurate and flexible understanding of expected income, production costs and changes in farm

operations that may affect revenue and costs when introducing sustainable practices, in for instance, soil management (Bergtold et al., 2019).

To determine the economic effect of a change in soil management practices in empirical studies, data are typically collected through direct surveys with farm operators that manage production systems with and without an intervention such as introduction of cover crops. Partial budgets are often compiled as a tool to assess the net economic returns to cover crop use. Partial budget analysis is a farm management analytical method where the net economic effect of only specific proposed changes between comparative productions is determined. The partial budget methodology quantifies the changes in production costs associated with adoption of soil health management systems. For example, converting from conventional production without cover crops to no-till production with cover crops will remove field activities that impact associated costs with tillage. A partial budget analysis will account for the cover crop seeds costs as well as the associated costs with planting and terminating the cover crop, specific to the change of adding cover crops to the management system (Flanders, 2021).

A summary of potential linkages between changes in practices associated with the use of cover crops and changes in income and costs is presented in Tale 31, as identified by Plastina and Liu (2016). It is important to note that different combinations of different input costs and income increases/decreases are likely, with possible opposite effects, depending on the specific farm and farming environment context.

Table 25. Potential changes in revenues and costs associated with cover crops (adapted from Plastina et al., 2018)

COSTS		INCOME	
Expected increases	Expected decreases	Expected increases	Expected decreases
Cover crops seeds and planting	Herbicide savings, fertilizer savings	Higher yields	Lower yields
Equipment, labor and herbicide for termination	More efficient nitrogen use	Grazing or forage	
Extra insecticide, herbicide and nitrogen	Reduced tillage	Cost share	
Extra soil analyses	Reduced costs for repairing soil erosion	Change to more profitable crops (e.g. wheat with maize)	
More management	Lower principal crop planting population		

In that regard, different studies obtain different results in terms of net farm return, depending on the local context, soil and climate conditions, crop structure and farm management practices. For

instance, in the United States, based on a survey of farms producing maize and soybeans, Capellazzi et al. (2021) argue that the majority of farmers who have who have made the switch and adopted no-till, reduced tillage or cover crops demonstrated increased yield resilience in challenging years and an overall decrease in inputs costs, and hence overall achieved a positive change in net farm income (85% of surveyed farmers). The maize farmers in their study reported average cost reductions of \$67.1 per acre, added costs of \$46.4 per acre, increased income of \$32.5 per acre; and decreased revenue averaged \$1.64 per acre, or aggregated, the average change in net farm income with the adoption of soil health management practices in maize was positive with \$51.6 per acre. On the other hand, Plastina et al. (2018) found the average net returns to cover crops terminated with herbicides followed by maize to be negative, while the net results were positive in the case of cover crops terminated with herbicides followed by soybeans. The determined that the largest cost drivers are cover crop seeds and planting costs. The authors suggest that cost-share payments are a critical incentive to support this practice and should be sufficient to cover the additionally incurred costs to be covered by the farmers. Bergtold et al. (2019) found negative net returns in cover crops systems in Kansas on dryland, but marginally positive on irrigated land which The potential for profitable application of cover crops can differ substantially by location, management and weather, but nevertheless positive returns to cover crops for producers are seen as a definite possibility, especially if the cover crop replaces a fallow period as opposed to a cash crop. The broader effect is seen in promoting long-term sustainability, even if the immediate financial returns are not positive.

In the context of North Macedonia, in absence of specific cover crops field trials involving economic implications, a cost budget was estimated for three cover crops options: oilseed rape, fodder peas and grass mix. Oilseed rape and fodder peas can be planted in late autumn crop rotation, enabling soil coverage between regularly planted major field crops, while grass mix is an option as a row intercrop in vineyards and fruit orchards. The estimated cost budget is calculated on annual basis and is presented in Figure 126. The benefit from the use of cover crops has both economic effects (for instance, in terms of savings in major crops' fertilizer, pesticides and tillage costs, as well as enhancing the major crop yield levels and crop quality), but more importantly, it provides soil health improvements and other multiple potential agroecosystem benefits.

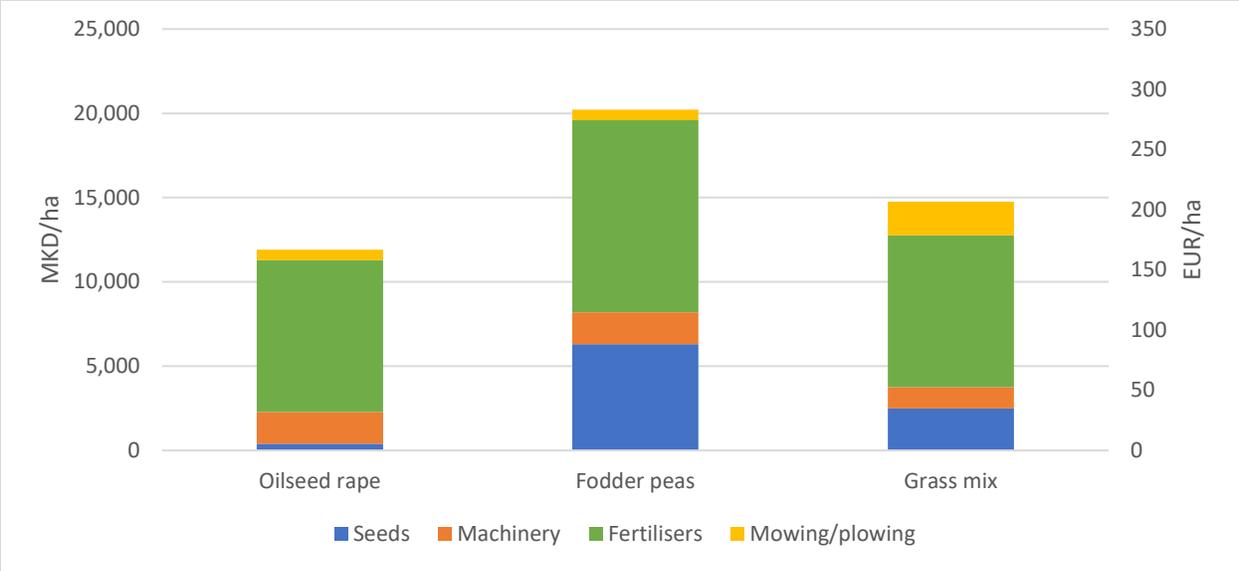


Figure 85. *Estimated cost structure for different cover crops*

Farmers employing cover crops should not expect immediate beneficial results since, in the beginning, as they will have increase in expenditures from the newly introduced practice, on one side. On the other side, the desired significant increases in the major crop yields will occur after the long-term use of cover crops in crop rotations due to the time needed to improve both soil fertility and organic matter storage. Nevertheless, the adoption of soil health management systems requires development of a new soil management practices, and that in turn requires time and learning. In this regards, better understanding of the system, enhanced through field trials and location specific information should provide grounds for determining the change in costs and income when switching to the new system and the possibilities to increase farm income over time. Technical support, knowledge and skills acquisition and transfers are also vital to successful introduction of soil health management systems.

## Vulnerability in Livestock

### *Introduction*

Animal production as a part of the agriculture sector has not been assessed in line with the predicted changes of temperature and precipitation as part of the vulnerability assessment of the agriculture sector to climate change. However, climate change has a severe negative effect on the livestock's productivity and welfare, reflecting in frequent and prolonged heat stress (Martinson et al., 2012; Collier et al., 2019). The heat stress is even more substantial on modern high-productive breeds than local breeds adapted for ages to the local environment.

All animals have a thermal comfort zone, which is a range of ambient environmental temperatures that are beneficial to physiological functions. During the day, livestock keeps a body temperature within a range of  $\pm 0.5$  °C (Henry et al., 2012). When temperature increases more than the upper critical temperature of the range (varies by species type), the animals begin to suffer heat stress. Animals have developed a phenotypic response to a single source of stress, such as heat called acclimation (Fregley, 1996). Acclimation results in reduced feed intake, increased water intake and altered physiological functions such as reproductive and productive efficiency and a change in respiration rate (Nardone et al., 2010). Heat stress on livestock is dependent on temperature, humidity, species, genetic potential, life stage, and nutritional status. Livestock in higher latitudes will be more affected by higher temperatures than livestock located in lower latitudes because livestock in lower latitudes is usually better adapted to high temperatures and droughts (Thornton et al., 2009). Confined livestock production systems that have more control over climate exposure will be less affected by climate change. Heat stress decreases forage intake, milk production, the efficiency of feed conversion, and performance. Warm and humid conditions cause heat stress, affecting behavior and metabolic variations on livestock or even mortality. Heat stress impacts on livestock can be categorized into feed nutrient utilization, feed intake, animal production, reproduction, health, and mortality.

Addressing the negative consequences on livestock systems requires access to many technical solutions that care used to affect the farms' air physical parameters. The technical solutions approach increased ventilation, air conditioning, air recirculation, and insulation to influence climate parameters such as air temperature, velocity, humidity, and conditions for radiation heat exchange. For the optimal outcome of those approaches, it is essential to know how the animals would respond to the changing thermal environment and how the different air physical parameters protect animals from heat stress. Beckett (1965) proposed using an effective temperature (ET) in livestock to express the combined influence of air temperature and humidity and defined the effective temperature to be equal to room temperature if the relative humidity was 50%. Several models were built, tested, and utilized to describe the optimal comfort zone of the animals and describe different levels of heat stress. The most suggested and used approach (NRC, 1971, Igono et al., 1985; Igono and Johnson, 1990; Ravagnolo and Misztal, 2000; Bouraoui et al., 2002; St-Pierre et al., 2003, Bohmanova et al. 2007, Carabano et al., 2016, Pinto et al., 2020)

in the one for Temperature Humidity Index (THI), expressing the relative significance of air temperature and humidity on heat stress among confined ruminants, pigs and poultry.

Environmental conditions, such as solar radiation, high air temperature, and relative humidity, are the main stress factors for livestock. The etiology of heat stress consists of failure to maintain the core body thermo-neutrality with increasing ambient temperature and humidity. An animal may start to show signs of heat stress beginning at a THI of around 68 (Zimbelman et al., 2009). In dairy, exposure of dairy cows to a thermal environment is a major risk factor for decreased milk production, especially in high-yielding cows than low-yielding ones due to combined accumulation of heat gained from the environment and metabolic heat (Rhoads et al., 2009). When dairy cows are under heat stress, accumulated heat exceeds the body capacity for heat loss by radiation, convection, and conduction. To reduce the heat load of dairy cows rearing under high ambient temperatures, accomplished with the higher metabolic heat production, additional cooling measures during the season of thermal stress are required. For better acclimatization in hot environments, high-producing dairy cattle need environmental improvements, such as thermal comfort zone inside barns.

Physiologically pigs can be more tolerant to lower than higher temperatures because they are homeotherm animals and can maintain their body temperature and cannot sweat. The cooling is done by excessive ventilation through breathing when water evaporation is happening. The particular problem is cooling when the air temperature exceeds 30 °C in combination with high air humidity when the process of water evaporation is more difficult. The aim of the housing is to ensure optimal inside air temperature and humidity, taking into account the exchange of the air through ventilation. Low temperatures are overcoming with the installation of the heating devices, while the high temperature is mainly solved with high air exchange through the ventilation system. However, the ventilation has limitations since airspeed and air volume should not exceed certain limits (e.g., more than 1 m/s).

On the other hand, ventilation is working on differences in temperature in and out of the houses, and if the difference is small, then the system is not functional. Farms are practicing intensive ventilation on days when the outside temperature is higher than 25 °C since animals are also radiating heat and the indoor temperature is above optimal range. Heat stress is provoked on pigs when exposed to higher than the optimal temperature for a longer period. In the case of adult categories, heat stress occurs when the air temperature is 2-4 °C higher than the optimum range.

### ***Characteristics of the livestock sector***

National livestock production has been predominantly organized on small farm, and it is characterized with intensive production systems in dairy cattle, pigs, and poultry.

Dairy cattle production currently is under ongoing decreasing in number of farms and process of enlargement of farm size. In 2019, the average farm size was 9.3 heads, while 47% of all dairy farms have less than 20 heads. In last decade the total national population size is also decreasing. According to NSFARR 2021-2027, predominantly in the population are crossbreeds of local Busha breed and exotics (58%), while Holstein breed accounts for 38%. Local Busha breed accounts for 3%. The challenges in the dairy production are 1) lack of investment in farm modernization (milking, manure management, animal welfare), 2) improved feeding, 3) limited access of land area for own forage production, 5) providing milk quality, since in 2019 only 20% of the annual production was in accordance for the national regulation for milk safety and milk quality.

Pig production provides national self-sufficient in fresh pork meet. It is organized on several large farms (40% of all hogs) that are applying intensive and modern production system, based on genetically superior animals. In pig farms the investments are continuous in modernization of the technology, feeding and biosecurity. The sector is growing but challenged by diseases spreading and market instability.

Layers are the most dominant in poultry production. The production of eggs is intensive and national demand self-sufficient. Broiler production is very limited (only 2% of national market). The layer population size decreased for 29% from 2014 to 2019. Sector is under pressure of instability of the market and trends.

Intensive production systems required genetically superior animals, strictly controlled nutrition, and optimal ambiantal environment (narrowly controlled temperature, humidity and ventilation).

Production systems in beef cattle, sheep and goats are less intensive, and closely related to near farm pastures. Beef production mainly is organized on rural areas and provides about 20% of national demand for beef meat. It is mostly based on crossbreeds, kept extensive, exploring natural pastures and alternative feedstuffs. Sheep and goat production is extensive, traditionally exploring mountain pastures. It has never been intensified, and due to national socio-economic trends, the population size is constantly decreasing (from 740.457 in 2014 to 684.558 in 2019). In last 5 years the average farm size was increased by 20%. Sheep production is base don local sheep breeds and their crosses, while in goat production locally adapted breeds are predominant.

The less intensive production systems possess higher adaptive capacities to severe weather events, due to exploration of locally adapted breeds (local, imported or crossbreeds between locals and imported ones) and its higher tolerance to nutrition requirements (diverse feeding regime, feed components, less selective to different feeds, etc.). It has been proven that the locally adapted breeds can much easily adapted to future climate change then imported ones.

Due to climate change, the vulnerability of intensive livestock production systems will be comparably higher. In the last decade, it has been noticed changes in technology applied on larger dairy, pig, and poultry farms, adopting technologies resulting in higher productivity. In order to maintain high production levels over the seasons, farms are forced to provide an optimal

environment, ideally, within the comfort zone for specific species, physiological status, and production level, maintain temperature, humidity, and ventilation. Due to the mixture of influence of the continental and Mediterranean climate in the country, the producers are faced with cold winters and hot summer periods. Since intensive livestock farming incorporates a controlled microenvironment, buildings and facilities are constructed according to specific requirements, ensuring additional heating during the winter periods and excessive ventilation and cooling in the summers.

### ***CC and livestock diseases***

Climate change could have an impact on diseases outbreaks in livestock. The occurrence of diseases can be directly on animals exposed on extreme weather conditions, or indirectly by the presence of vectors which spatial distribution is usually very dependent of climatic condition.

The direct influence of climate change is one of the preconditions of the livestock environment, that can be observed through disturbance in feeding, availability of water, and water quality, but also ensuring favorable conditions for the occurrence of many parasites and diseases. All those diseases, generally do not have an impact on health status in the country, but significantly influenced the economic profitability of farming. However, some contiguous diseases are transmitted by vectors or by wild animals, and the spreading of those vectors can be enhanced with climate change. Such diseases Bluetongue, Rift valley fever, West Nile fever, African horse sickness, African swine fever, etc. are important for determining the health status in the country. However, the occurrence of other diseases like Avian influenza is not transmitted by vectors, but they can be also related to climate change due to the change of the routes of the migratory birds. An example was in 2006 in Europe, when due to very cold weather in some regions caused frost on the open waters and lack of food for migratory birds. Consequently, seeking feed, wild birds changed their usual route of migration, so there was an outbreak of highly pathogenic Avian influenza. Increased movement of wild animals seeking feed and water also influenced the transition and spreading of contiguous diseases. There are examples of the spreading of Avian influenza, Rabies, Classical swine fever, etc. Perhaps the best examples of the influence of Climate Change on speeding the diseases in livestock are Bluetongue and West Nile fever. About 15 years ago, according to World Organization for Animal Health (OIE), each country lying above the 40th parallel north, was assumed that is free from Bluetongue disease. That was adopted based on the spread of the vector of the Bluetongue disease, the *Culicoides* mosquito. Accordingly, the disease had never been registered nor reported by the vast majority of the European continent, except in some very south parts. Since 2006 the disease has been speeded almost over the whole continent including Great Britain, The Netherlands, and Sweden.

The influence of climate change on frequent outbreaks of contiguous diseases that are already present, but also rather new diseases in the regions was the reason why OIE took initiative for global research on the subject. Out of 126 member countries in OIE, 71% reported a high level of concern for the expected effects, and out of them, 58% reported at least one disease that was assumed was related to climate change. The most frequent were 3 diseases, e.g., Bluetongue,

Rift valley fever, West Nile fever. Therefore, the OIE initiated the strategy for support of the national veterinary services in readiness for the outbreak of the diseases.

The country was already faced with Bluetongue disease in 2014, and Lumpy skin disease in 2016. Hence, it is of vital importance to investigate the risks and vulnerability of the livestock to outbreaks of diseases that can happen due to climate change. It means to take action towards adopting farm management and technologies in preventing outbreaks, but also preventing further spreading. Also, it will influence the way of animal movement (wild animals and livestock in grazing). Veterinary service needs to be trained to make early diagnose of the diseases, prevent the risk of spreading, and eradicate. However, those activities need to be applicable, effective, appropriate, and economically reasonable. Mainly all actions will be:

- Preventive supportive measures to farmers to keep breeds with higher tolerance of diseases, and increased animal immunity, which is not always economically profitable.
- Direct measures against the pathogen and disease transmitter or vector.
- Environmental measures that prevent spreading diseases like farm biosecurity, controlled movement of animals, etc.

Current structure of national livestock production, suggest that the most vulnerable to climate change will be dairy cattle, pig and poultry. So far, globally the methodological approaches have been widely applied in dairy cattle and pigs, but less in poultry. Therefore, this report aims, for the first time to assess two THIs for dairy cows and pigs over three different scenarios for three periods of 30 years, for 249 centralized points in RNM.

### ***Approach***

Data source and data description are the same initial data used for this report, described as a daily minimum, maximum, and average temperature and precipitations, for all points (~12x12 km) over the period from 1970 to 2100, under three scenarios (RCP 2.6, RCP 4.5 and RCP 8.5). In addition, three periods were extracted from the whole data, e.g., P1: 1986-2015; P2: 2016-2045 and P3: 2046-2070, aiming to represent past, present, and future. Finally, the daily meteorological data for all points were used for calculation of the daily Thermal Humidity Index (THI), following the formula for Cattle (Bohmanova et al., 2007) and pigs (Zumbach et al., 2008).

$$THI_c = ((1.8 T_{max}) + 32) - ((0.55 - 0.0055 RH) * (1.8 T_{max} - 26.8))$$

$$THI_p = ((1.8 T_{max}) + 32) - ((0.55 - 0.0055 RH) * (1.8 T_{max} - 14.5))$$

where:  $THI_{dc}$  and  $THI_p$  are THIs for cattle, and pigs, respectively,  $T_{max}$  is the daily maximum temperature in  $^{\circ}C$ , RH is the relative humidity in percentage. Since the relative humidity was not available in the data set, their approximative values were calculated following the instructions given by Alduchov and Eskridge (1996), based on Magnus approximation. In the formula, relative humidity is derivated from dew point (TD) assumed as daily minimum temperature ( $T_{min}$ ), as explained by Parsh and Putman (1977) and daily maximum temperature  $T_{max}$ .

$$RH = 100 * (\text{EXP}((17.625 * TD) / (243.04 + TD))) / (\text{EXP}((17.625 * T_{max}) / (243.04 + T_{max})))$$

The approximation to RH by daily  $T_{min}$  and  $T_{max}$  is far from ideal, but it was acceptable for the purpose of this report, where a lot of uncertainties were considered, too.

Daily TDI for both dairy cattle and pigs was then summarized in annual THI load, representing the number of days above thresholds for more than 2 consecutive days, assuming body tolerance in the first two days (West et al., 2003). THI threshold value of 72 in dairy cows recently was determined as alert phase (Pinto et al., 2020). Due to uncertainty in the approach applied, the higher threshold values of 74-78, 78-83, and 83+ were used as categories for alert, emergency, and dangerous THI load, respectively (Polisky et al., 2017). All annual THI loads were averaged for the three periods under three scenarios.

**Dairy Cattle:** Specific cattle THI, as expected, are different over the periods and scenarios. The most optimistic scenario, RCP 2.6, assumes that the temperature will rise until 2040 and later would beginning to decline. The same trend can be observed in the average annual THI load, wherein P2, all thresholds had maximum value. The estimated average annual THI load in P2 for the alert, yellow phase with THI between 74 and 78 was 35 days, in an emergency, orange phase with THI between 79 and 83 - 25 days, and in dangerous, red phase THI over 83 – 9 days. Overall average annual exposure of the cattle in phase over emergency would last above 67 days for the period from 2016 to 2045. The average annual THI load would be 40% and 5% higher than in P1 and P3 in the same period.

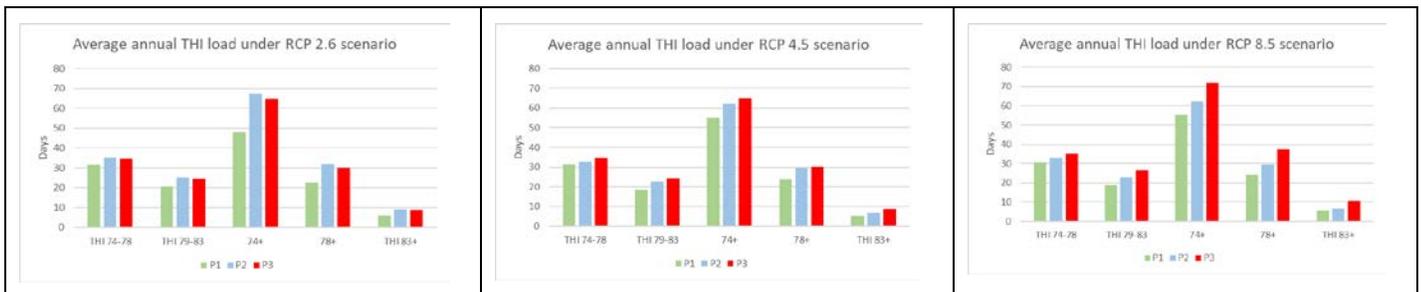


Figure 86. Average annual THI load in ranges 74 to 78, 79 to 83, above 74, 78, and 83 in days for cattle under RCP 2.5, RCP 4.5, and RCP 8.5 scenarios.

For RCP 4.5 and 8.5 scenarios, the maximum average annual THI load in all periods had been estimated in P3 (2046-2075). The highest annual THI load over the emergency phase would last 64 days in scenario RCP 4.5, while in PCR 8.5 - 72 days. However, the spatial distribution of three different THI loads over the country would not be equally distributed (Appendix 1). Therefore, it is a noticeably increased number of days where THI over the emergency phase would increase over time. Under all scenarios, the emergency phases would be more prominent along Vardar River, Pelagoina, and the regions of Kumanovo and Strumica. However, under the scenario RCP 4.5, the emergency phases of over 50 days could also be expected in Ovcepole, Kochani, and Radovich. However, the most extreme scenario (RCP 8.5) would affect all low lands in the country except Polog, where a THI load of over 50 days should be expected for P2.

Attention is paid to how the THI load would be changed over the above alert phase (74+ THI). The country average THI load under RCP 2.6 in P2 was estimated to 67 days, followed by a decrease of 2% in P3. In RCP 4.5 and RCP 8.5, the maximum country average 74+ THI load should be expected in P3, where the load will be higher for 4% and 16. However, the highest 74+ THI loads would be expected in the central and southern parts of the country, mostly in low lands (Appendix 2). It is noticeable that the above alert THI loads in cattle would be mostly above 120 days, with prolongation for each P2 and P3 for additional 12 days. Of particular interest is the fact that the 74+ THI load of over 50 days can also be expected in higher lands, except for the country's west mountainous area. Under the RCP 8.5, the 74+ THI loads of over 2 months could be expected in most of the lower lands in the country in the period 2016-2045.

### ***Case study - cattle***

According to the State Statistical office (2020), about 23% of the total national cattle population was kept in Pelagonia region. Hence, this region was deeply studied for the vulnerability of the cattle production, particularly the low land area, including 23 points from N 40.91, E 21.61 to N 41.46, E 21.28. Therefore, for simplification, the reference point will be P2 and THI load 74+ in all three RCPs.

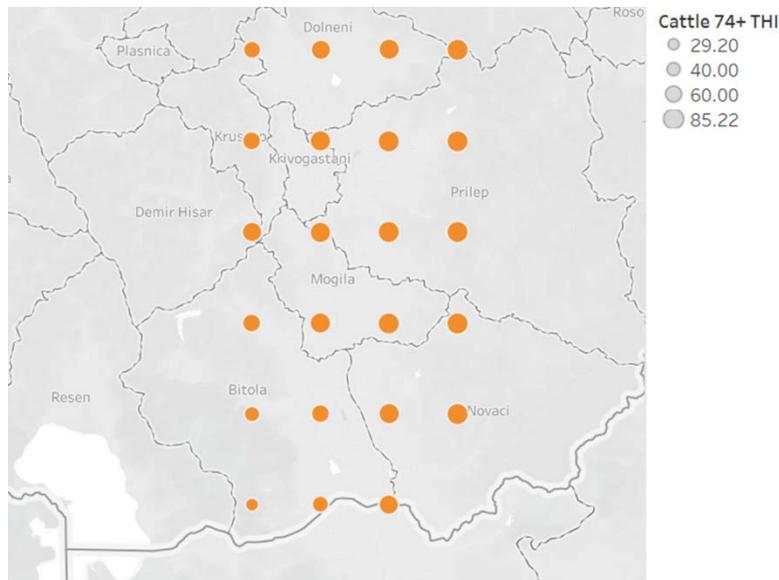


Figure 87. Spatial distribution of the points used in the case study for cattle in Pelagonia (days of 74+ THI load in P2 under RCP 4.5)

The RCP 2.6 scenario is the most desirable but at the same time the most unlikely where the maximum average annual 74+ THI load would be reached in P2 (84 days), which is an increase for 22 days from P1, while in P3, the load would decrease for 3 days. However, it means that in the period from 2016 to 2045, the farmers should expect that cattle would be on average annually exposed to above emergency for 84 days, expecting about 8 days of dangerous phase (83+ THI). According to the scenario RCP 4.5, on average, the greatest annual 74+ THI load should be expected in P3 (81 days), when also about 6 days of dangerous phase (83+ THI) should be expected. The worse scenario (RCP 8.5) would result in, on average, the highest annual 83+ THI load of 11 days in P3, and overall 74+ THI load in the same period would be 85 days. Thus, even though all three scenarios count for different increases in temperature, it is evident that cattle production in Pelagonia would be faced with an annual 74+ THI load of over 70 days with dangerously THI load for over 6 days.

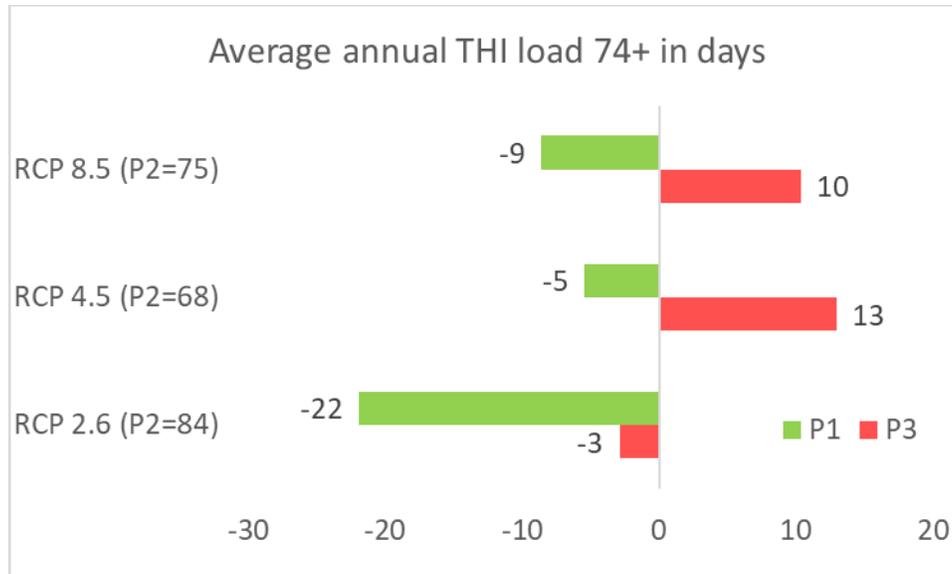


Figure 88. The deviations in P1 and P3 from P2 for the average annual 74+ THI loads for cattle in the low land area in Pelagoina under three RCP scenarios

For the dairy cow, it has been found (West et al., 2003) that at an increase per unit in THI beyond 72, a 0.2 kg reduction in milk yield was recorded. The cost of the decrease in daily milk yield in US dairy farms was US\$ 2.5 per day (St-Pierre et al., 2003). Additionally, it was estimated annual loss due to early culling, mainly due to failure in regular reproduction cycles, of US\$ 15 per animal. Hence, if those economic values are used for farms in Pelagonia, then it can be expected annual direct loss due to failure of productivity would be up to US\$ 190 per dairy cow.

*Pigs:* Specific pig THI loads, should be different over the periods and scenarios. Under scenario RCP 2.6, the average annual THI loads in all three phases (yellow, orange, and red) for all periods would be similar. However, the average annual THI loads of 74-78 in P1 would be 19 days, while after P1, it would last 1 day longer. In all three periods, the average annual THI loads of 79-83 would be about 10 days, while 83+THI loads would be around 3 days, with a slight decrease in P3.

The THI loads under the other two scenarios (RCP 4.5 and RCP 8.5) had different projections. Namely, the THI loads for all classes would be the lowest in P1 and would increase in P2 and P3. However, in the RCP 8.5 scenario, the THI loads the increase over periods would be more dramatic than as they were under RCP 4.5.

Under RCP 4.5, the estimated average annual THI load in P2 for the alert, yellow phase with THI between 74 and 78 would be about 20 days, in an emergency, orange phase with THI between

79 and 83 - 10 days, and in dangerous, red phase with THI over 83 – 3 days. Thus, the average annual THI load would be 22% higher than in P1 and 25% less than the load in P3 (43 days).

For RCP 8.5 scenarios, the maximum average annual THI load in all periods had been estimated in P3 (2046-2075). Therefore, the average annual 74-78 THI load in P2 would last 2 more days than the other two RCPs. The increase for 1-day would also be expected for 79-83 THI and 83+ THI loads in RCP 8.5 compared to RCP 4.5. Also, in P3, the highest 83+ THI average loads of 6 days annually would be expected.

The spatial distribution of three different THI loads over the country (Appendix 3) suggested an increased number of days where THI over the emergency phase will increase over time. Additionally, the increases in low lands more evident. Under all scenarios, the emergency phases would be more prominent along Vardar River, in the regions of Kumanovo, Ovchepole, Radovich, and Strumica, while in Pelagoina will be less evident. Furthermore, under scenario RCP 4.5, the emergency phases of over 30 days could be expected. Finally, the most extreme scenario (RCP 8.5) would affect all low lands in the country, where THI loads will be increased by 10% in P2 and P3, compared to RCP 4.5.

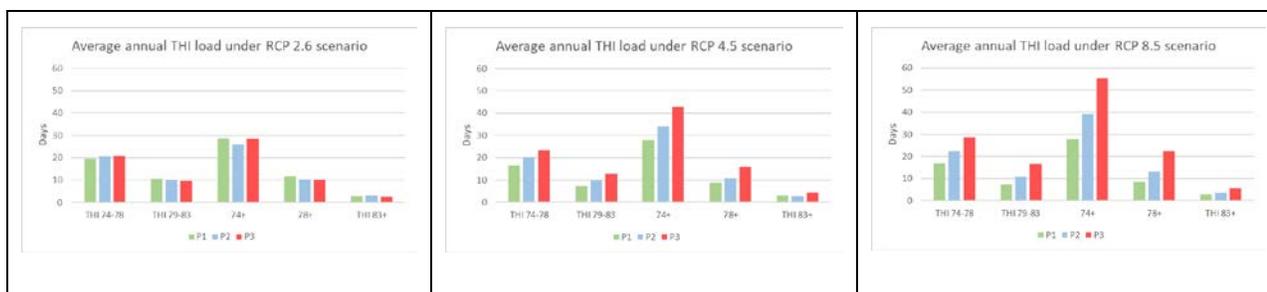


Figure 89. Average annual THI load in ranges 74 to 78, 79 to 83, above 74, 78, and 83 in days for pigs under RCP 2.5, RCP 4.5, and RCP 8.5 scenarios.

The lowest country annual average, 74+ THI loads, was estimated under RCP 2.6, almost 30 days in all periods. In all three periods, similar average annual 78+ THI loads of 10 days were estimated. However, on average dangerous THI load (83+) could be expected for 3 days in all periods. Thus, the country annual average 74+ THI loads under scenarios RCP 4.5 and RCP 8.5 would be increasing over periods, reaching the highest value in P3. Under RCP 4.5, the annual average 74+ THI loads were estimated to 34 days, 7 days more than in P1 and 8 days less than in P3. Those differences are even more prominent under RCP 8.5 when the annual average 74+ THI load in all periods would be 28 days in P1, 39 days in P2, and 55 days in P3.

Attention is paid to how the THI load has been changed over the periods in terms of the above alert phase (74+ THI) and how that would be reflected in different parts of the country (Appendix 4). The evident rise of average annual 74+ THI loads would be expected under RCP 4.5 and 8.5. It is noticeable that the above alert THI loads in pigs would be mostly between 60 and 90 days in

the central, southern, and south-eastern parts of the country. Under the RCP 2.6, the highest above alert THI load would be expected in P2 (2016-2045). Under the RCP 4.5 and RCP 8.5, the 74+ THI load would be increased for additional 10-15 days for each P2 and P3. In addition, for these two scenarios, the 74+ THI loads would be expected along Vardar River, in the regions of Kumanovo, Ovchepole, Kochani, Radovish, Strumica, and Pelagoina. However, the highest 74+ THI can be expected in the central and southern parts of the country, mostly in low lands.

According to the State Statistical office (2020), most pig farms are located in the central area. Hence, this region was deeply studied for the vulnerability of the pig production, particularly the Veles – Gradsko, and Ovchepole. In total, 15 points were considered, avoiding all points in Krivolak (since no pig farms are located there but could influence the results). The boundaries of the assessed area are located from N 41.46 E 22.16 to N 41.90 E 21.94. For simplification, the reference point will be P2 and THI load 74+ in all three RCPs.

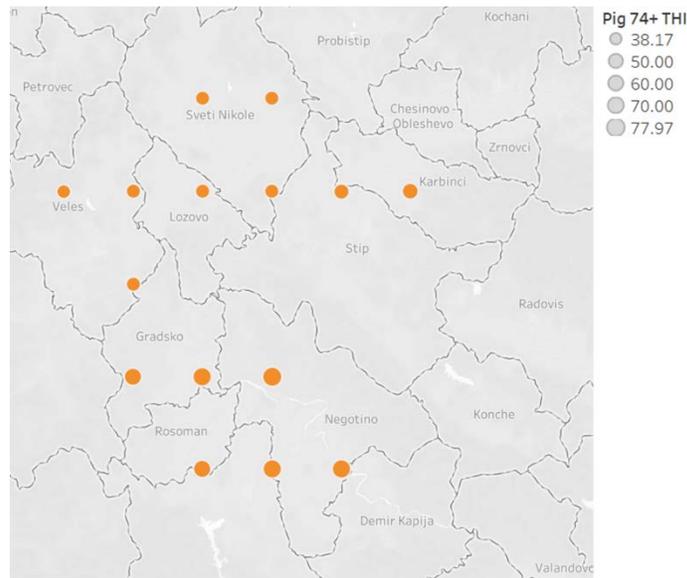


Figure 90. Spatial distribution of the points used in the case study for pigs in the central part of the country (days of 74+ THI load in P2 under RCP 4.5)

The RCP 2.6 scenario is the most desirable but at the same time the most unlikely where the average annual 74+ THI load would be 64 days in P2, which is an increase for 12 days from P1, while in P3, the load would last longer for additional 4 days. Thus, from 2016 to 2045, the farmers should expect that pigs would be on average annually exposed to the above emergency for 64 days, expecting about 5 days of dangerous phase (83+ THI). According to the scenario RCP 4.5, on average, the greatest annual 74+ THI load should be expected in P3 (60 days), when also about 3 days of dangerous phase (83+ THI) should be expected. Finally, the worse scenario (RCP 8.5) would result in, on average, the highest annual 83+ THI load of 5 days in P3 and overall 74+ THI load of 69 days in the same period. Therefore, even though all three scenarios count for different

temperature increases, it is evident that pig production in the central part of the country would be faced with an annual 74+ THI load of over 60 days with a dangerously THI load for around 4-5 days.

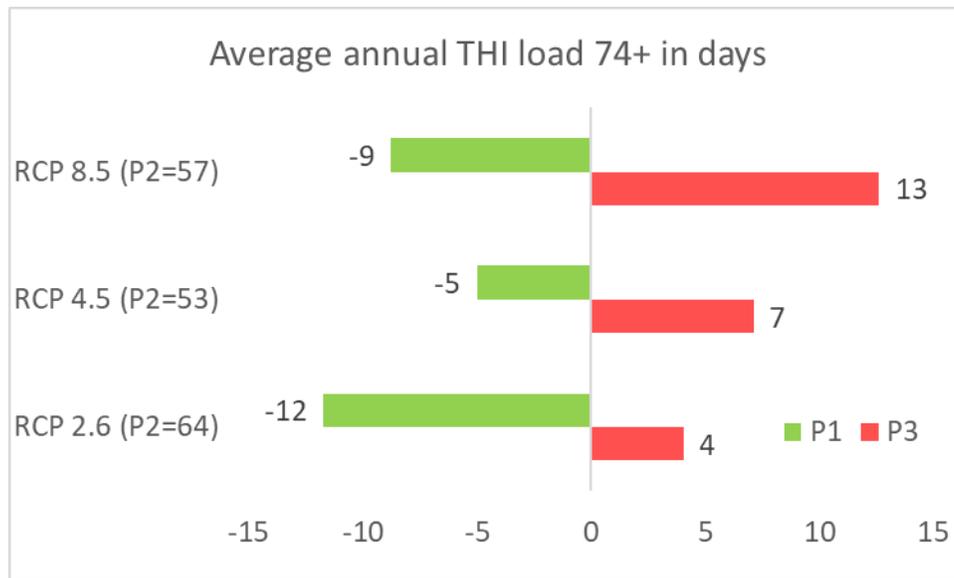


Figure 91. The deviations in P1 and P3 from P2 for the average annual 74+ THI loads for pigs in the central area under three RCP scenarios

The RCP 2.6 scenario is the most desirable but at the same time the most unlikely where the average annual 74+ THI load would be 64 days in P2, which is an increase for 12 days from P1, while in P3, the load would last longer for additional 4 days. Thus, from 2016 to 2045, the farmers should expect that pigs would be on average annually exposed to the above emergency for 64 days, expecting about 5 days of dangerous phase (83+ THI). According to the scenario RCP 4.5, on average, the greatest annual 74+ THI load should be expected in P3 (60 days), when also about 3 days of dangerous phase (83+ THI) should be expected. Finally, the worse scenario (RCP 8.5) would result in, on average, the highest annual 83+ THI load of 5 days in P3 and overall 74+ THI load of 69 days in the same period. Therefore, even though all three scenarios count for different temperature increases, it is evident that pig production in the central part of the country would be faced with an annual 74+ THI load of over 60 days with a dangerously THI load for around 4-5 days.

In pig farming, a lot of investment has already been made in housing, providing optimal ambient atmosphere (temperature, humidity, air exchange, etc.) for the animals with different physiological statuses. The impact of increased THI load on the animals will cause a reduction in their performance. This depression was quantified as loss of 5% to 10% gross margins

(Schauberger et al., 2021), where the economic impact of decreasing reduction of body mass at the end of the fattening period, dry matter intake, and the increase of the mortality, would lead to the probability of a return period of 10 years resulted in a growth of the economic risk from 0.27 € annually in 1980 to 5.13 € annually in 2020 per animal place. Another report (Grootaers, 2020) estimated a loss of 20 € per sow annually due to heat stress in the Netherlands. In the study of the heat waves in the RNM (Andonov, 2013), the decreases in live-born piglets and weaned piglets per sow were 2.1% and 1.7%, while the weaning to conception period was prolonged by 3%.

### Recommendations:

Climate change scenarios suggest the occurrence of high seasonal temperatures with heatwaves and rapid weather change. In such cases, it is realistic to expect that intensive pig production in RNM located in the regions that would be the most vulnerable to climate change, losses in production level will happen. Wide expert society is aware of the possible developments and is mobilized in searching for possible solutions. However, there is limited knowledge and experience on a national level and should focus on research regarding adaptation measures.

#### *Proposed adaptations options:*

- Genetically heat-tolerant breeding animals. Such a process has been started and breeding organizations worldwide, but the process is slow, and the heat tolerance of the animals should be proven in local conditions. Namely, heat-tolerant genetic animals, one should be aware that the breeding programs worldwide take into account genotype-environment interaction. Therefore, with the specific climatic conditions, the genotype-environment interaction has to be proven, and even better, the specific genetic combination to be produced locally. Hence, the breeding program toward robust and high productive livestock is an adaptive measure with a long-term cumulative effect.
- Adoption of special feed and feeding techniques in the period of excessive heat should be considered. Since in excessive heat, the needs of the live animal would change dramatically, the conventional feed compositions need to be upgraded to specific conditions of ambient and animal category. On the other hand, the feeding techniques need change to increase feed efficiency and digestibility.
- Improvement in housing conditions by adopting proper ventilation, in-house conditioning, and cooling systems installation would be required. These adaptive measures need investment in installation and energy. However, to meet the criteria of energy-efficient proper thermal insulation and use of renewable energy are needed.
- The Introduction of continuous monitoring is needed to follow the farms' productivity level concerning heat waves and high temperatures. That can ensure data collection for precise loss calculation. The results can be used to determine the threshold loss level to balance lost income and investment.

*Adaptations measures:*

*Implementation of cooling systems in livestock production*

**Dairy cows:** The measure improved milk performance of lactating Holstein cows, and lessen the severity of heat stress during summer months. However, evaporative cooling has been showing to improve the environment of cows housed in these climatic conditions better than using just the system of fans.

The measures resulted with a 10,52% reduction of milk yield drop in dairy farm with installed ventilation and a 24,12% reduction of milk yield drop in dairy farm with installed ventilation and fogging system (evaporative cooling). The measure should be adopted as CC measure in livestock production.

**Pigs:** Installation of window cooling pads (evaporators) and the system of low pressure ventilation successfully reduces high temperature in the pig farms therefore almost eliminate heath stress, Achieved results show: 10.8% reduction of conception rate depression in pigs; Number of live born piglets increased by approximately 0,1-0,3 piglets per litter; Mortality rate (%) of piglets during the lactation period is decreased by approximately 5-8%; MMA syndrome (Mastitis, Metritis and Agalactia) is fully minimized; Piglets diarrhea during the lactation period is also fully minimized; Growth of piglets during the lactation period is improved. Therefore, installation of window cooling pads and low-pressure ventilation should be introduced as CC adaptation measure in pigs breeding.

**Poultry:** The measure “installation of the ventilation equipment and modified vitamin mineral premixes was tested”. Interventions in increased ventilation capacity and proper ventilation, followed by modification (enrichment) of the vitamin mineral premix are recommended tools for lowering the negative effects during the high environmental temperatures. Implemented interventions resulted in: 37.64% reduction of negative effect of high temperatures on egg production in floor egg layer production system and 27.26% reduction of negative effect of high temperatures on egg production in cage egg layer production system; Measure should be introduced as CC measure in poultry breeding in the country

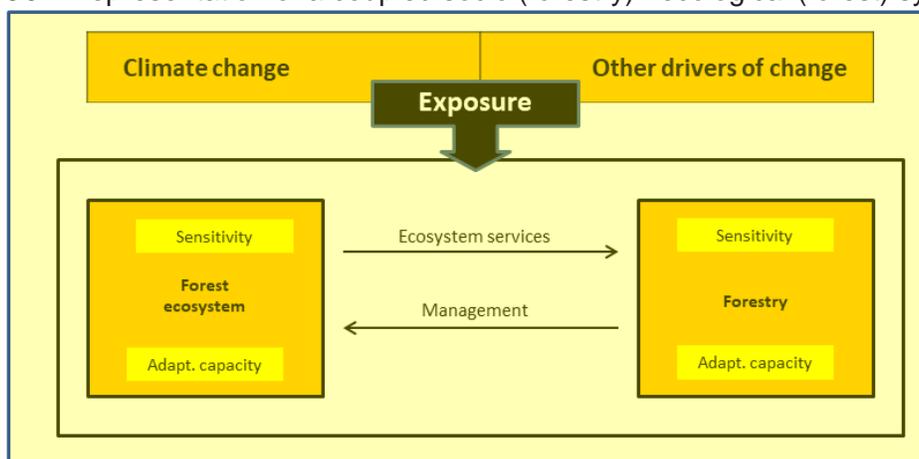
Nevertheless, precise economic calculation is needed to determine the threshold when is the most appropriate time to invest in the farm. Perhaps incentive measures can boost the implementation of adaptation measures to decrease production loss due to global warming.

## Vulnerability Assessment in Forestry Sector

### Introduction

According to IPCC, the three main components of vulnerability are exposure, sensitivity and adaptive capacity. Exposure is external to the system, while sensitivity and adaptive capacity are internal. As an example, the three factors E, S and AC explaining vulnerability of forest growth to temperature changes could be, respectively, the increase in temperature, the sensitivity of tree dynamics to temperature, and the changes of ecosystem composition following changes in tree dynamics. This report focuses on coupled sectorial-ecological systems, defined as integrated and complex systems in which ecosystems and sectors interact. As the provision of ecosystem services influences the vulnerability of society (different sector such as forestry) and as society (different sectors) affects positively or negatively the vulnerability of ecosystems, adaptation policies should aim at reducing the vulnerabilities of both ecological and sectorial systems at the same time. Vulnerability assessment should consider the links between these two systems, in our case forest and forestry (see figure 92).

Figure 92. Representation of a coupled socio (forestry) –ecological (forest) system



### Climate change and forestry sector

Tacking into considerations the results from the previous NC of CC, data and experiences from the forestry sector its self, it is obviously that Macedonian forestry is already faced with the climate change. The forestry is trying to deal with these changes but although there are isolated actions,

still there is a lack of a national program or strategy for adaptation of the forestry sector to climate change.

### Vulnerability of the forestry sector

Generally, a vulnerability assessment should answer the question “what (or who) is vulnerable to what?” (Gitz and Meybeck, 2012).

The first “what” (or who) to be identified describes the social or ecological system that is to be evaluated and which aspects of that system may be at risk. Describing “what is vulnerable” can be done by answering the following general questions:

- Which species and processes are vulnerable?
- Where are the vulnerable systems located?
- Who or what will experience the greatest consequence because of their vulnerability?
- Where and for whom might climate change result in opportunities and benefits?

The second “what” describes the aspects of climate that create risk.

Clarifying both parts of “what is vulnerable to what” is essential to determine the scope and focus of a vulnerability assessment. Within that scope, the vulnerability assessment will evaluate the system’s potential exposure to the climatic risk that was identified, the sensitivity of the system to that climatic risk, and the system’s capacity to adapt to the climate risk.

In theory, assessment of vulnerability to climate change should take into account both the evolution of the system and the pressures and risks with which it will be confronted.

This raises complex methodological issues.

The climate changes themselves may be relatively easy to predict (albeit with a level of known uncertainty) using projection models based on historical meteorological information. It is much more difficult to project the future vulnerability of a complex system such as a forest and forestry, given the number of parameters that must be taken into account. Some of these parameters change slowly, such as the optimal conditions for a species or even for a particular type of ecosystem. However, all parameters of vulnerability that are driven by human activity, institutions, economy, social organization and even forest management can change dramatically in 30 years. Most of these changes are difficult to model or predict with accuracy. Indeed, one of the main purposes of a vulnerability assessment is to orient these changes in order to reduce vulnerability. The vulnerability of a system to a specific risk can be determined by one factor or, more often, several combined. Forest fires provide a good example. Drought increases the risk of forest fires. The vulnerability of the forest will depend on the amount of dead biomass, which in turn depends on the way the forest is managed, the amount of dead trees resulting from previous droughts and/or pests, the spatial organization of the forest (e.g. the presence of buffer strips and fire breaks), which could facilitate or constrain the spread of the fire, and the openness of the forest to human activities. Finally, its vulnerability will depend on the means of preventing and monitoring fires and addressing them at an early stage. The importance of potential impacts is determined by a combination of biophysical, economic and institutional factors which can either augment or limit one another. Landscape, community and institutions can all buffer the consequences of hazards, thus helping to reduce the vulnerability of households. Analysis of such combinations is particularly important in determining areas of action; it can lead to the identification of links among different vulnerabilities and risks, and can also shed light on some broad contextual factors that

may cause vulnerability to most risks. For instance, forest degradation and deforestation increase the vulnerability of a forest to many of the impacts of climate change.

Having all this on mind, all complexity of the relation forest-forestry, the vulnerability assessment of the forestry sector will be done.

### *Climate change adaptation in forestry sector*

Adaptation in forestry is sustainable forest management that includes a climate change focus. Climate change over the next 100 years is expected to have significant impacts on forest ecosystems. The forestry community needs to evaluate the long-term effects of climate change on forests and determine what they might do now and in the future to respond to this threat. Management can influence the timing and direction of forest adaptation at selected locations. Adapting to climate change in the face of the uncertain timing of impacts means we must have a suite of readily available options. A high priority will be coping with and adapting to forest disturbance while maintaining the genetic diversity and resilience of forest ecosystems. In the same time forestry should provide certain products from the forest and finances.

### *Overview of in sector forestry*

#### Characteristics of sector forestry

According to the data from the project “TCPF Assessment of the methodology for implementation of the forest inventory (TCP/MCD/3604)” the total area of forest, forest land and barren land (estimated in 2017 year) is 1.122.258 ha out of which 1.001.489 ha are forest, 109.126 ha forest land and 11.643 barren land. This generally is in line with the official data from the State Statistical office, Forestry management plans (PE “Macedonian forests”, other subjects that manage forests and Ministry of Agriculture, forestry and water economy). But according to the findings of the project TCP/MCD/3604 in the period of 2009 to 2017 year about 43.252 ha of other wood land are changed to forest. This process of land cover changes (especially from other land cover to forest) is very important for planning of measures of mitigation and adaptation on climate change.

In terms of the ownership around 90 % of the forests are state owned and the rest are private forests. This means that the planning and conduction of measures of mitigation and adaptation on climate change mainly will be through the state owned forests and forest land.

## ***Methodology, Tools and Indicators for climate change impact assessment of the forestry sector***

Forests and forestry are influenced with a great variety of factors that are product of climate change. This specter of factors is not influencing this sector separately, but with great interaction and can be noticed in the various forest management neighborhoods as physical environment, forest growth, utilization of forest resources, market changes, etc. Those different areas of influence need different approach and models of estimation the climate change impact on all those areas, as well as integrating those different models from different disciplines.

There are different ways of integrating cross-disciplinary impact assessments, such as linking, coupling and integrated modeling. The review of the existing experiences emphasizes the problem of complexity and the need to simplify disciplinary approaches. There have been a lot of discussion about the scaling issues that are important for impact assessment modeling in forestry sector, including the consequences of heterogeneity in site conditions (important variable for forest growth and renewal), influence of the extreme events on ecosystem and economic sector, as well as the difference between temporal and spatial scales over sources of uncertainty in forest impact assessment modeling.

## ***Vulnerability assessment of climate change impact on forest and forestry sector***

As the provision of ecosystem services influences the vulnerability of forestry and as forestry affects positively or negatively the vulnerability of forest, vulnerability assessment will consider the links between these two systems (see figure 92).

### **Climate change impact on forest health condition**

As a continuation of the presentation of the climate change impact on forest health condition in Macedonia given in the previous national communications and presentation of the current situation the updated results of IPC forest's tree assessment will be given. Then, using these results as a current forest health condition status and using the different scenarios of climate change for Macedonia in different periods we will assess influence of the climate change on the forest. The main parameters from this methodology will be crown transparency and Water availability for the trees.

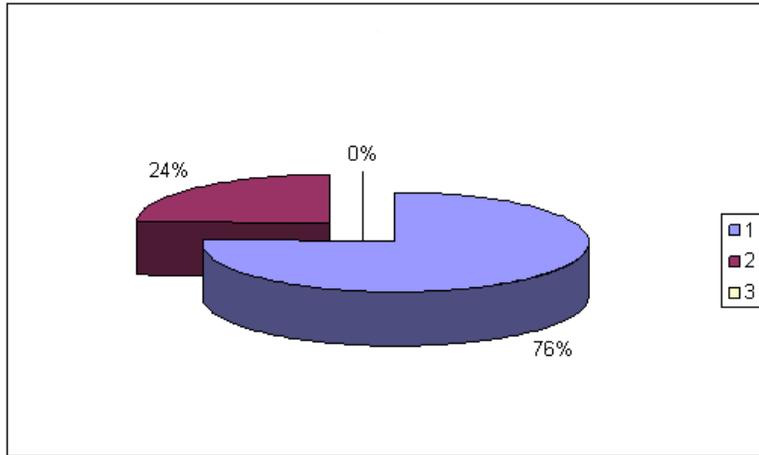
The crown transparency is divided in five classes, which are:

Class	Scale of loss of needles/leaves	Percentage of loss of needles/leaves
0	no loss of n/l	from 0 – 10 %
1	small loss of n/l	>10 < 25 %
2	moderate loss of n/l	>25 < 60 %
3	high loss of n/l	> 60 %
4	dead tree	100 %

Table 26. Crown transparency

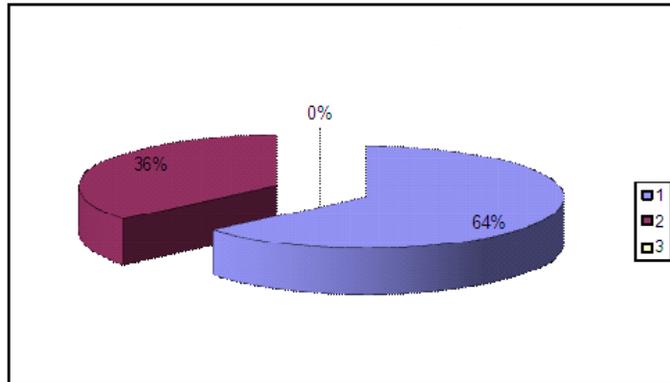
Year of assessment	Scale of loss of needles/leaves	Class	Percentage of assessed trees
2008	no loss of n/l from 0 – 10 %	0	<b>42,1%</b>
	small loss of n/l >10 < 25 %	1	<b>34,2%</b>
	moderate loss of n/l >25 < 60 %	2	<b>19,9%</b>
	high loss of n/l > 60 %	3	<b>3,1%</b>
	dead tree 100 %	4	<b>0,7%</b>
2009	no loss of n/l from 0 – 10 %	0	<b>53,7%</b>
	small loss of n/l >10 < 25 %	1	<b>25,8%</b>
	moderate loss of n/l >25 < 60 %	2	<b>17,2%</b>
	high loss of n/l > 60 %	3	<b>2,7%</b>
	dead tree 100 %	4	<b>0,6%</b>
2011	no loss of n/l from 0 – 10 %	0	<b>50,1%</b>
	small loss of n/l >10 < 25 %	1	<b>27,3%</b>
	moderate loss of n/l >25 < 60 %	2	<b>19,1%</b>
	high loss of n/l > 60 %	3	<b>2,8%</b>
	dead tree 100 %	4	<b>0,7%</b>
2018	no loss of n/l from 0 – 10 %	0	<b>45,2%</b>
	small loss of n/l >10 < 25 %	1	<b>33,5%</b>
	moderate loss of n/l >25 < 60 %	2	<b>16,7%</b>
	high loss of n/l > 60 %	3	<b>3,2%</b>
	dead tree 100 %	4	<b>1,4%</b>
2019	no loss of n/l from 0 – 10 %	0	<b>45,5%</b>
	small loss of n/l >10 < 25 %	1	<b>33,5%</b>
	moderate loss of n/l >25 < 60 %	2	<b>15,9%</b>
	high loss of n/l > 60 %	3	<b>3,5%</b>
	dead tree 100 %	4	<b>1,6%</b>

Figure 93. Water availability for the trees – 2008 year



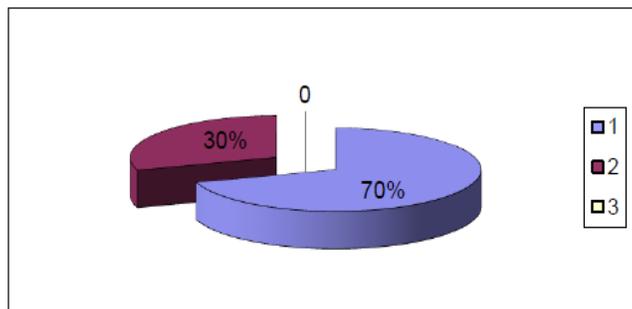
1-Insufficient 2-Sufficient 3-Excessive

Figure 1. Water availability for the trees – 2009 year



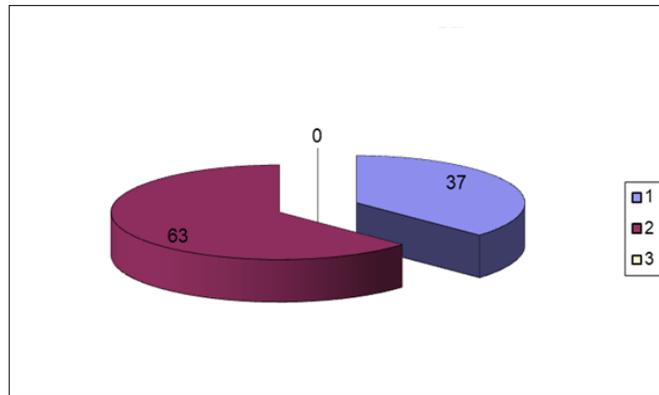
1-Insufficient 2-Sufficient 3-Excessive

Figure 94. Water availability for the trees – 2011 year



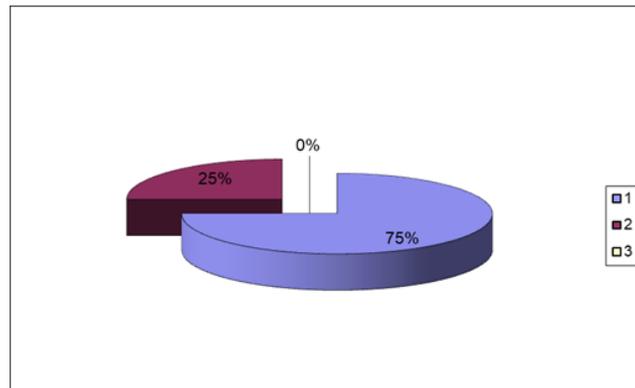
1-Insufficient 2-Sufficient 3-Excessive

Figure 95. Water availability for the trees – 2018 year



1-Insufficient 2-Sufficient 3-Excessive

Figure 96. Water availability for the trees – 2019 year



1-Insufficient 2-Sufficient 3-Excessive

In order to estimate the climate change impact and most vulnerable segments of the forest and forestry certain analyses of climate change scenarios of Macedonia will be done. For this purpose will use the Report on climate change projections and changes in climate extremes for Macedonia (V. Djurdjevic, 2019). Focus will be placed on three future twenty-year long periods: the nowadays / near-future period 2016-2035, the middle of the twenty-first century 2046-2065, and the end of the twenty-first century 2081-2100, which are selected to be compliant with the analysis in the Fifth Intergovernmental Panel on Climate Change.

In order to find correlation between climate change, forest and forestry all of these scenarios will be analyzed with the spatial distribution of the most represented forest types in Macedonia oak and beech forests on two different soil's substrats-carbonat and silicate ( Fig.9). These types of trees (oak and beech) in some areas are mixed with other trees such are pine, fir or some less

represented broadleaf or coniferous that means with this map are spatially presented almost all forest types in Macedonia except afforestation.

Figure 97. Spatial distribution of the most represented forest types in Macedonia (oak and beech forests) on two different soil's supstrats-carbonat and silicate

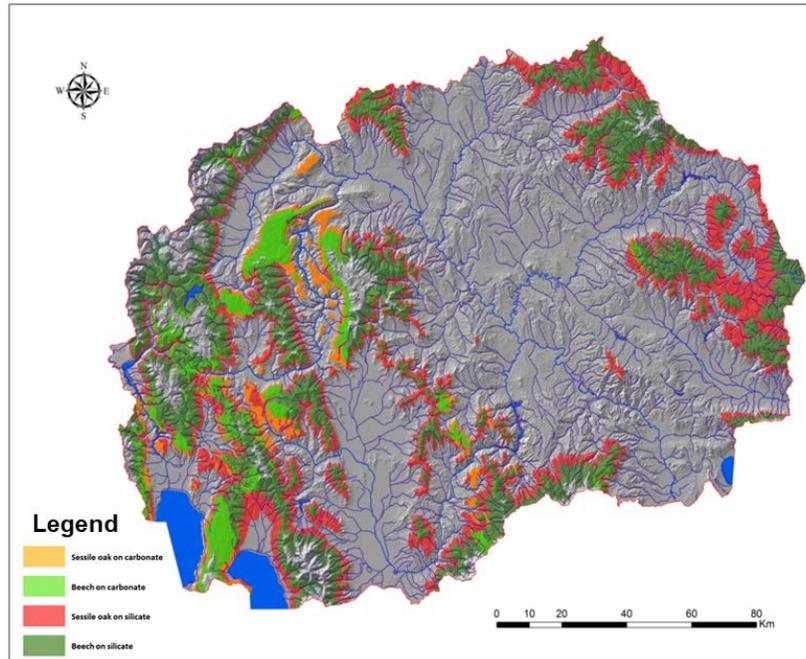
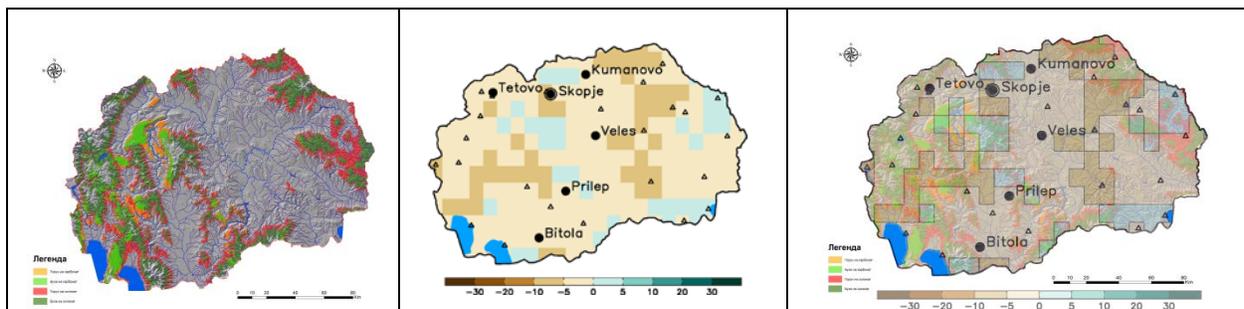
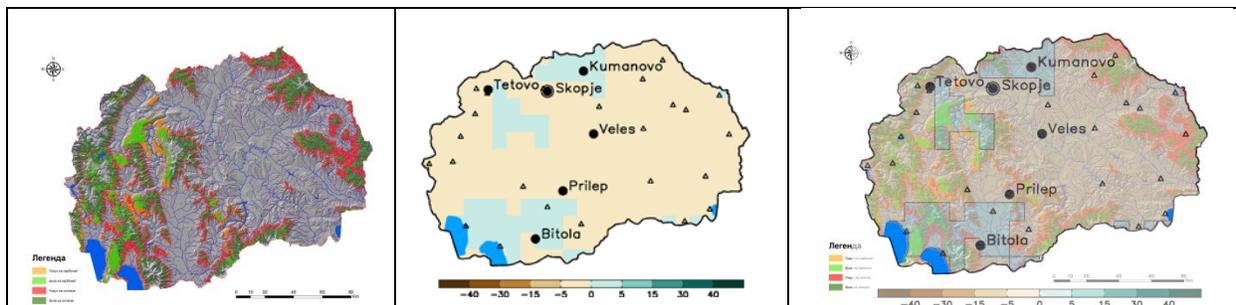


Figure 98. Spatial distribution of the average annual precipitations in Macedonia in the period 2016-2035: a) according the CC scenario 2.6 b) according the CC scenario 4.5 and c) according the CC scenario 8.5

**a) 2016-2035\_rr\_2.6**



**b) 2016-2035\_rr\_4.5**



c) 2016-2035\_rr\_8.5

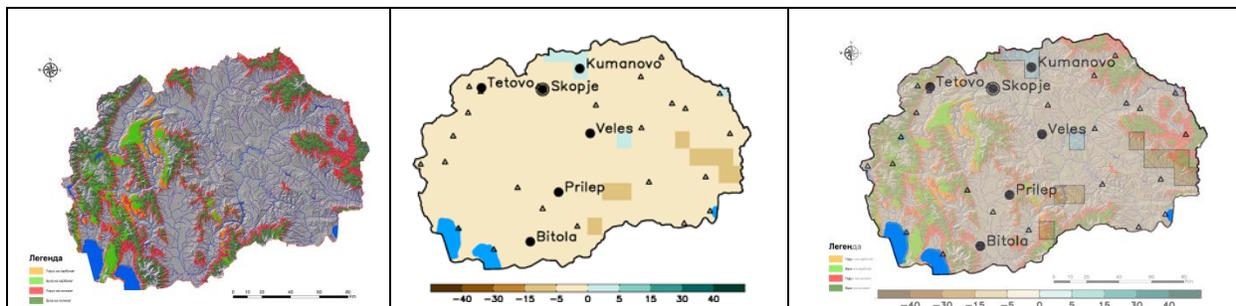
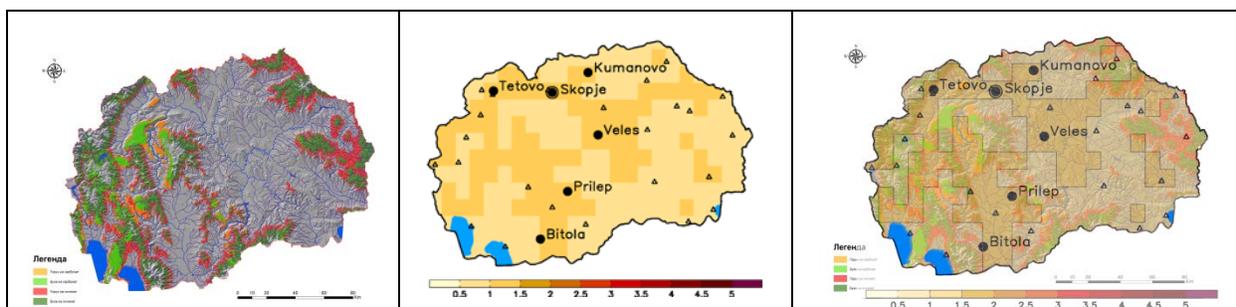
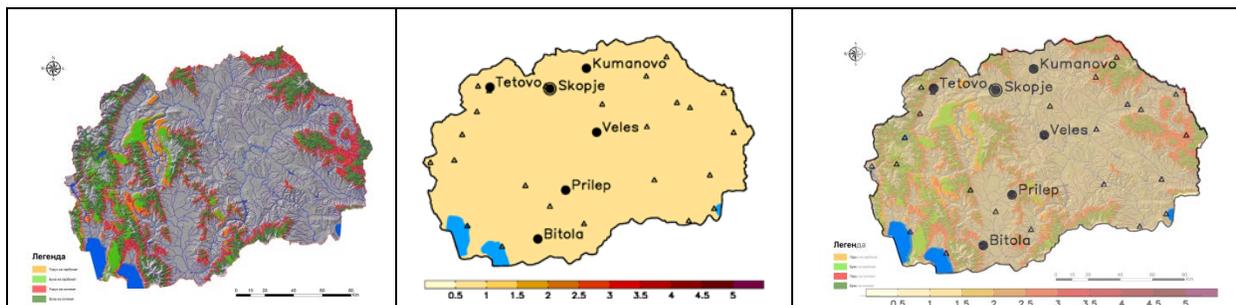


Figure 99. Spatial distribution of the average annual air temperature in Macedonia in the period 2016-2035 a) according the CC scenario 2.6 b) according the CC scenario 4.5 and c) according the CC scenario 8.5

a) 2016-2035\_tg\_2.6



b) 2016-2035\_tg\_4.5



**c) 2016-2035\_tg\_8.5**

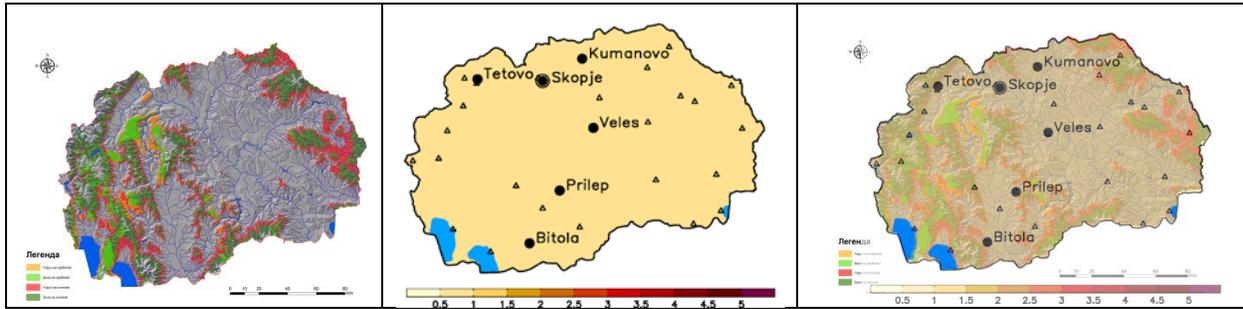
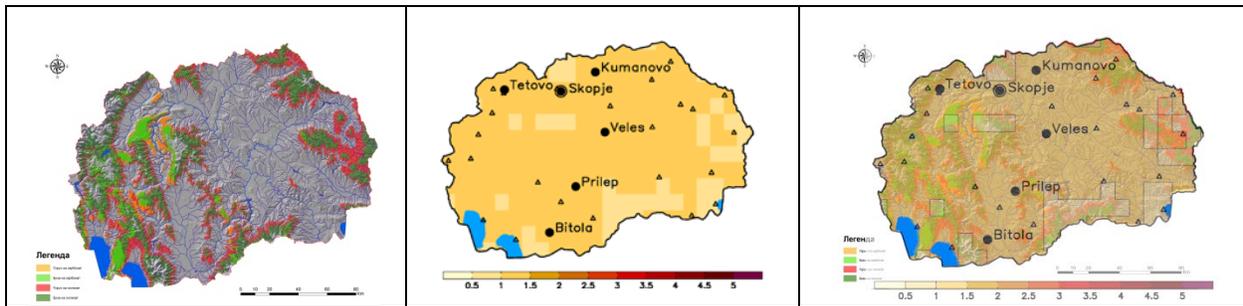
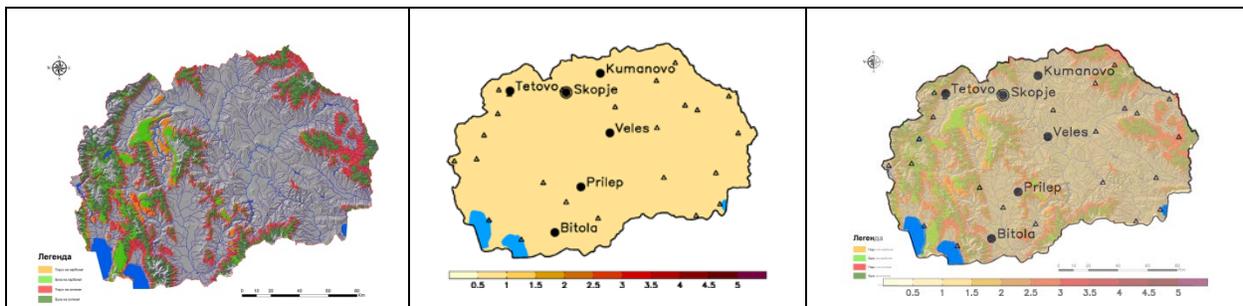


Figure 100. Spatial distribution of the average maximum air temperature in Macedonia in the period 2016-2035 a) according the CC scenario 2.6 b) according the CC scenario 4.5 and c) according the CC scenario 8.5

**a) 2016-2035\_tx\_2.6**



**b) 2016-2035\_tx\_4.5**



**c)2016-2035\_tx\_8.5**

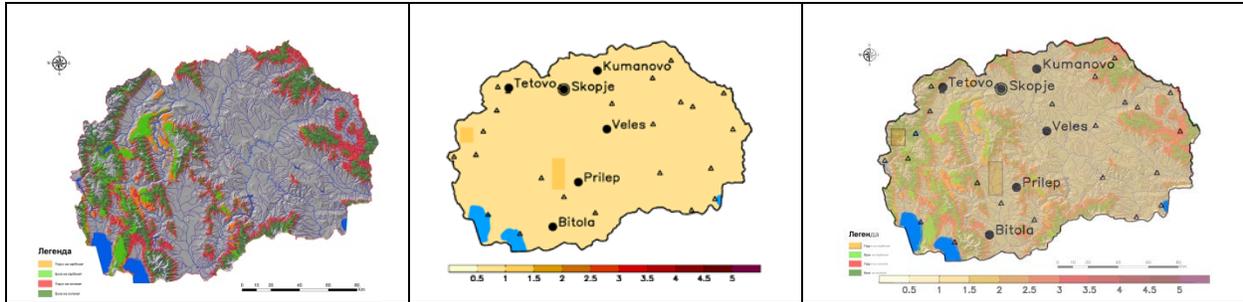
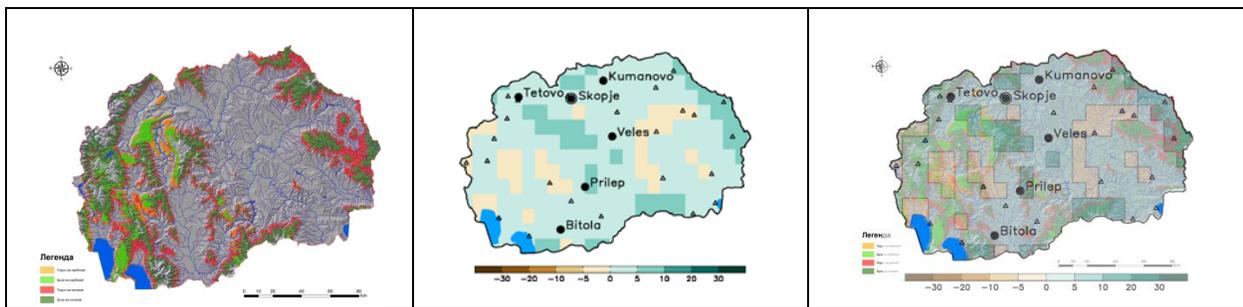
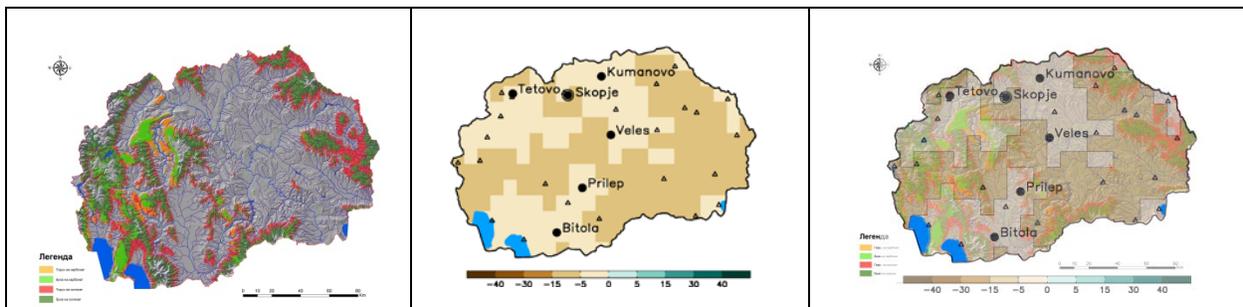


Figure 101. Spatial distribution of the average annual precipitations in Macedonia in the period 2046-2065 a) according the CC scenario 2.6 b) according the CC scenario 4.5 and c) according the CC scenario 8.5

**a) 2046-2065\_rr\_2.6**



**b) 2046-2065\_rr\_4.5**



**c) 2046-2065\_rr\_8.5**

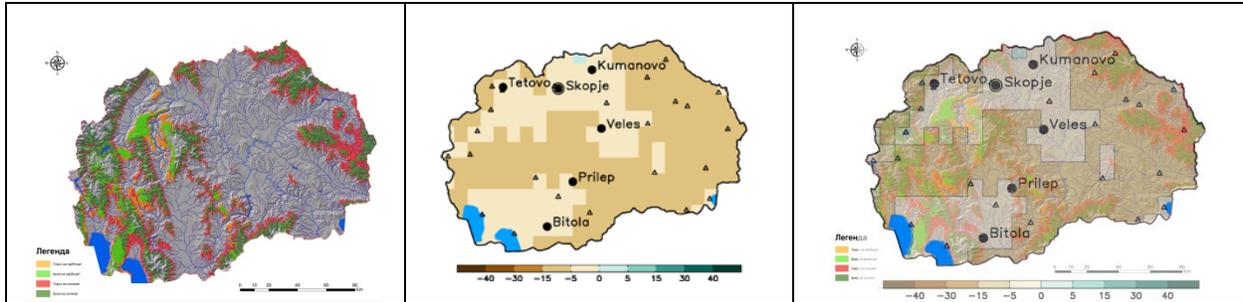
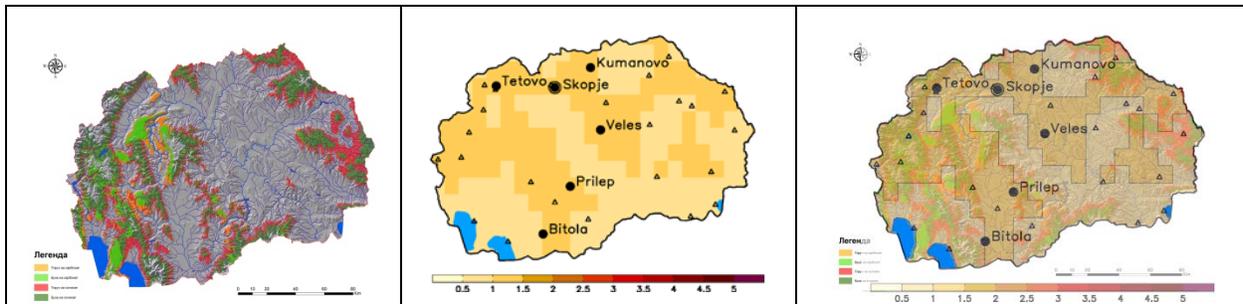
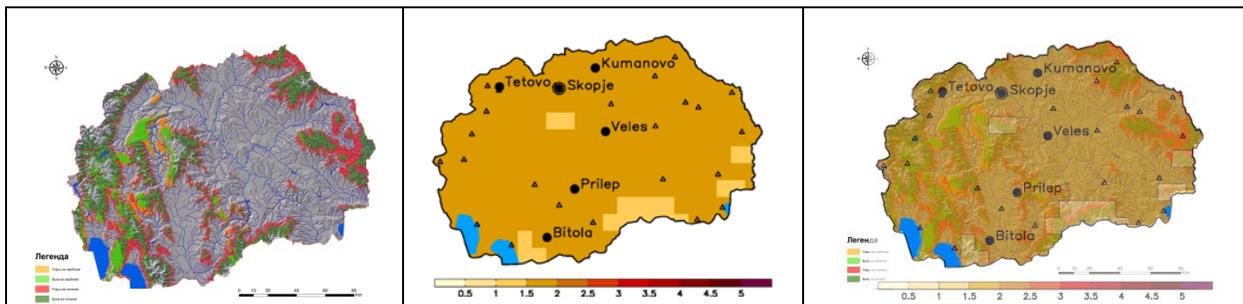


Figure 102. Spatial distribution of the average annual air temperature in Macedonia in the period 2046-2065 a) according the CC scenario 2.6 b) according the CC scenario 4.5 and c) according the CC scenario 8.5

**a) 2046-2065\_tg\_2.6**



**b) 2046-2065\_tg\_4.5**



**c) 2046-2065\_tg\_8.5**

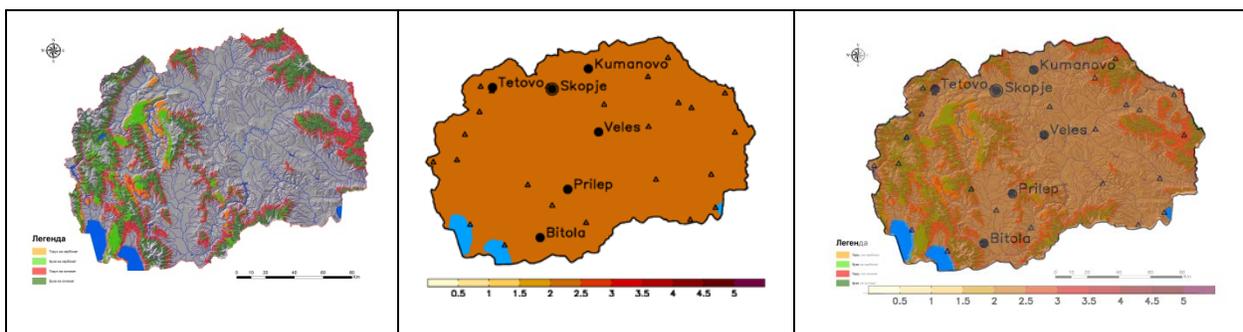
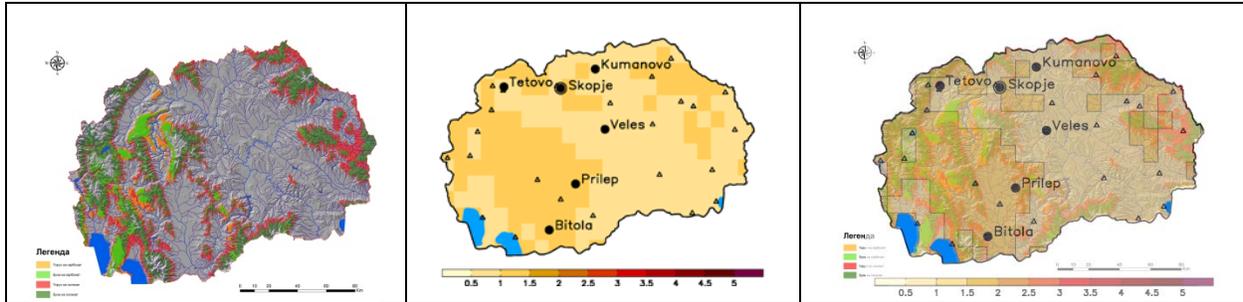
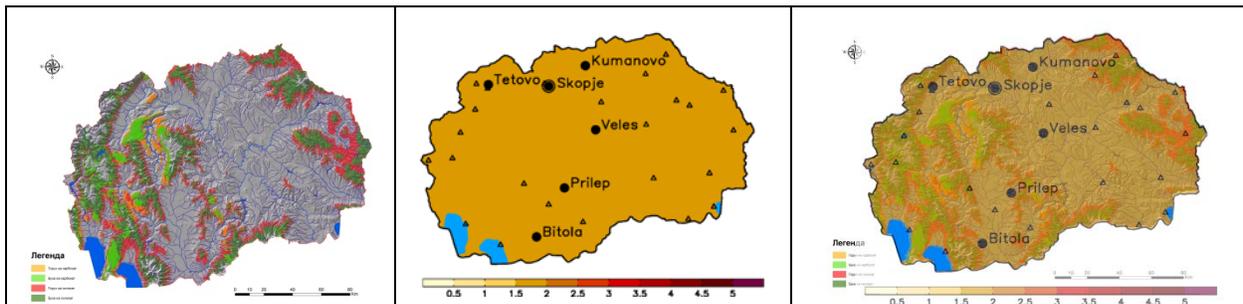


Figure 103. Spatial distribution of the average maximum air temperature in Macedonia in the period 2046-2065 a) according the CC scenario 2.6 b) according the CC scenario 4.5 and c) according the CC scenario 8.5

a) 2046-2065\_tx\_2.6



b) 2046-2065\_tx\_4.5



c) 2046-2065\_tx\_8.5

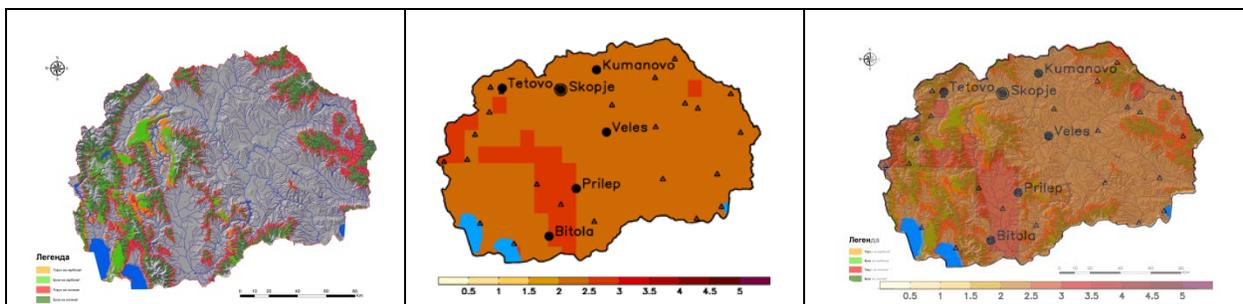
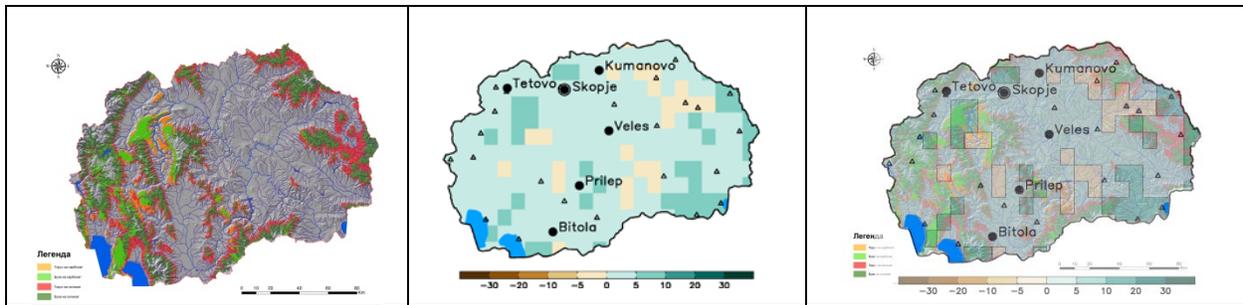
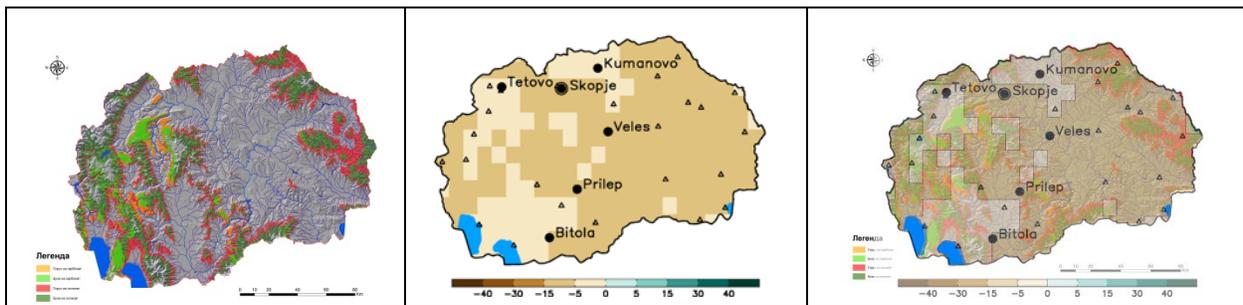


Figure 104. Spatial distribution of the average annual precipitations in Macedonia in the period 2081-2100 a) according the CC scenario 2.6 b) according the CC scenario 4.5 and c) according the CC scenario 8.5

a) 2081-2100\_rr\_2.6



**b) 2081-2100\_rr\_4.5**



**c) 2081-2100\_rr\_8.5**

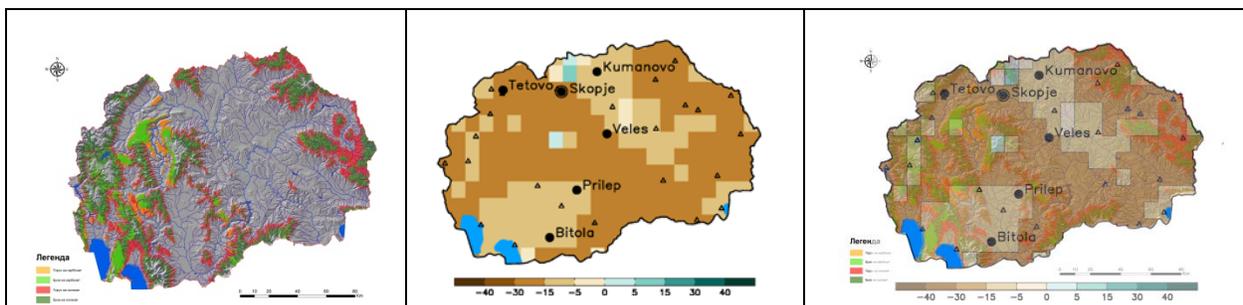
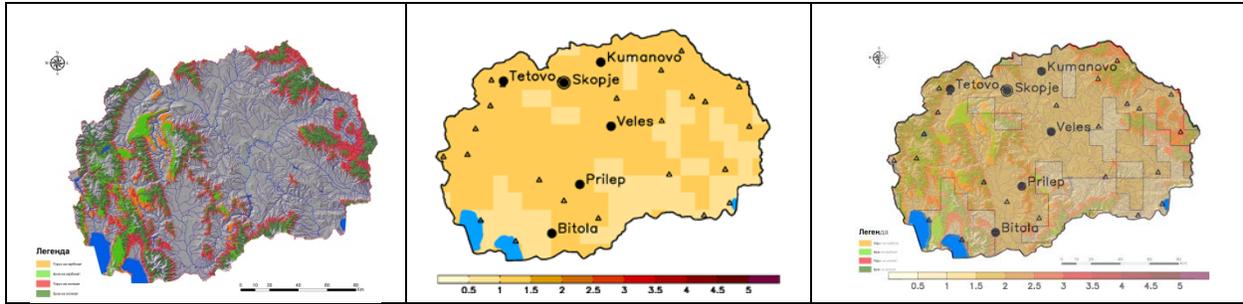
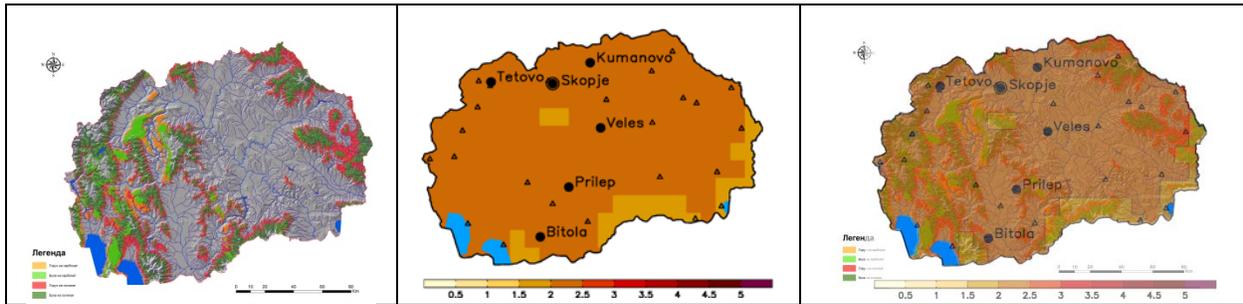


Figure 105. Spatial distribution of the average annual air temperature in Macedonia in the period 2081-2100 a) according the CC scenario 2.6 b) according the CC scenario 4.5 and c) according the CC scenario 8.5

**a) 2081-2100\_tg\_2.6**



**b) 2081-2100\_tg\_4.5**



**c) 2081-2100\_tg\_8.5**

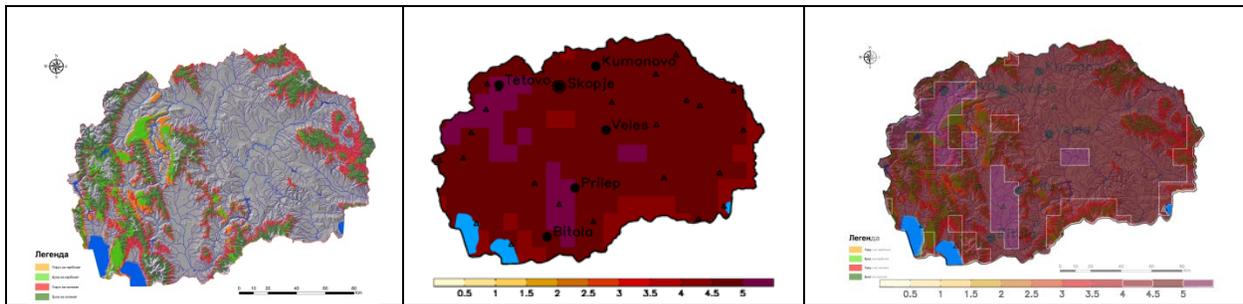
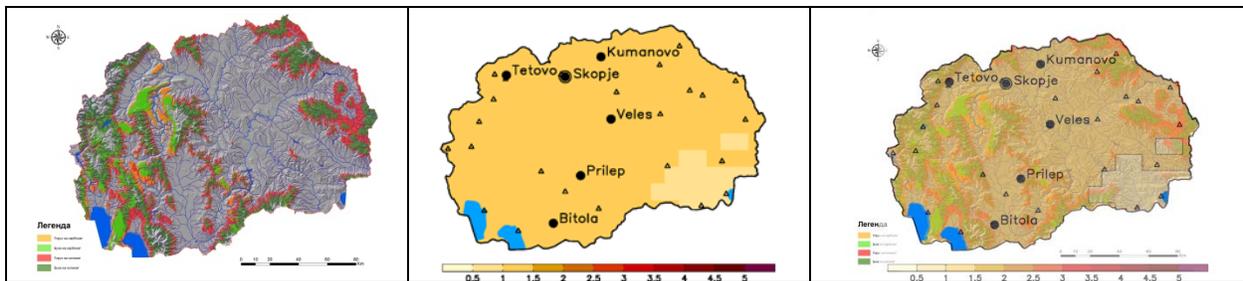
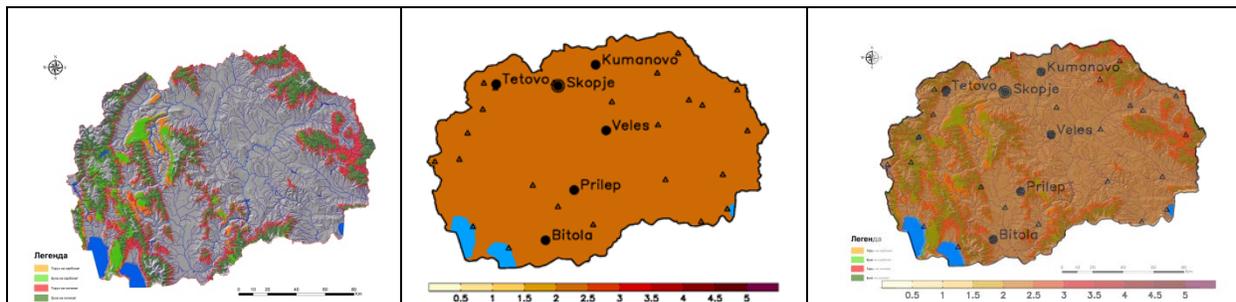


Figure 106. Spatial distribution of the average maximum air temperature in Macedonia in the period 2081-2100 a) according the CC scenario 2.6 b) according the CC scenario 4.5 and c) according the CC scenario 8.5

**a) 2081-2100\_tx\_2.6**



**b) 2081-2100\_tx\_4.5**



**c) 2081-2100\_tx\_8.5**

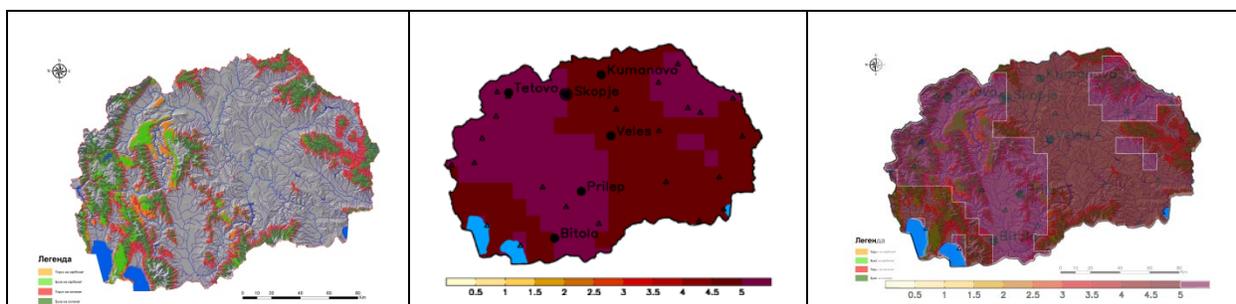
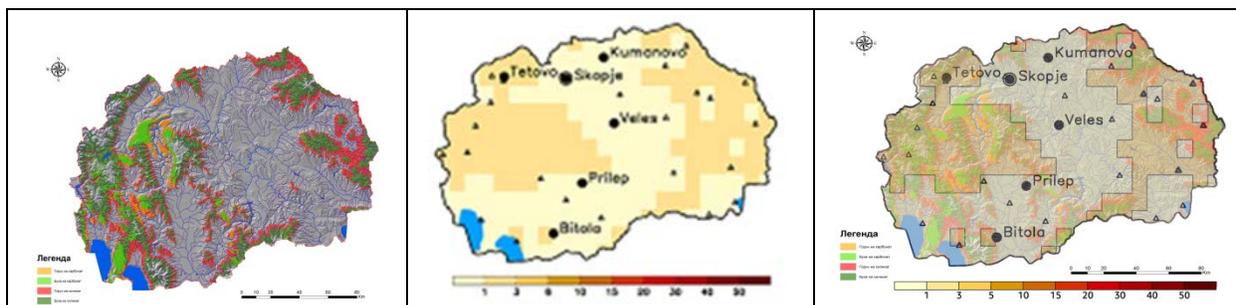


Figure 107. Spatial distribution of the future annual change in extreme heat waves (WSDI), for three future periods: a) 2016-2035, b) 2046-2065 and c) 2081-2100 with respect to the period 1986-2005 for the RCP8.5 scenario. The heat wave duration change is presented trough frequency of the heat waves (number of events in 20 years period).

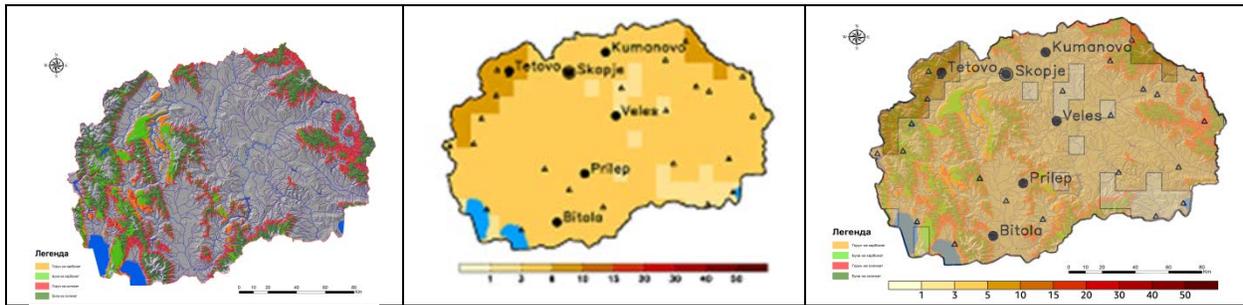
WSDI - Warm spell duration index: Annual count of days with at least 6 consecutive days when TX > 90<sup>th</sup> percentile (extreme heat waves).

ACEHW - annual change in extreme heat waves

**a) 2016-2035 ACEHW**



**b) 2046-2065 ACEHW**



**c) 2081-2100 ACEHW**

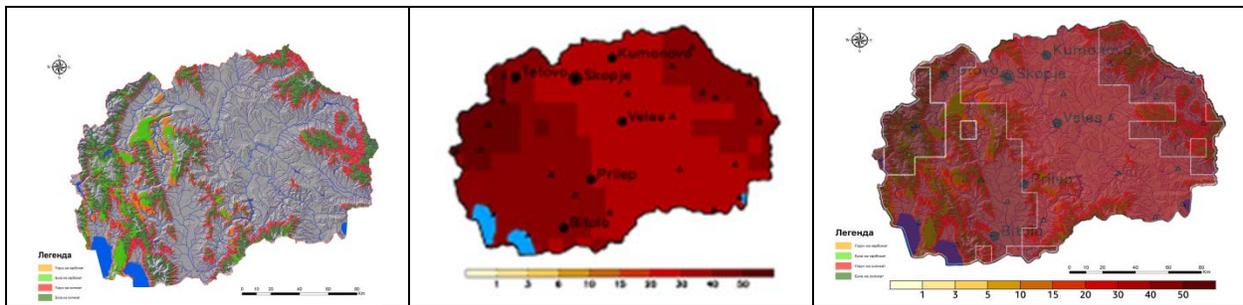
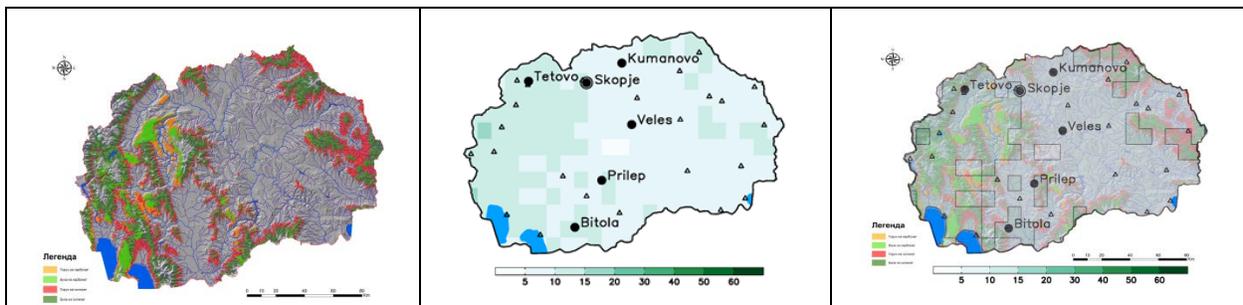
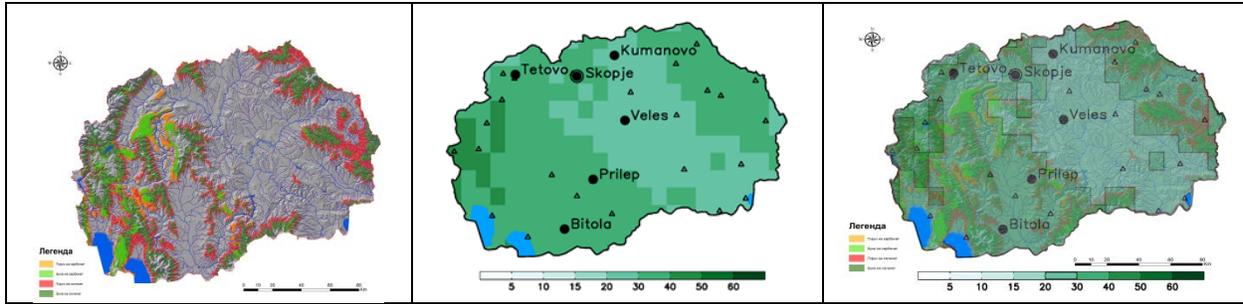


Figure 108. Spatial distribution of the future annual change growing season length (ACGSL), for three future periods: a) 2016-2035, b) 2046-2065 and c) 2081-2100 with respect to the period 1986-2005 for the RCP8.5 scenario.

**a) 2016-2035 ACGSL**



**b) 2046-2065 ACGSL**



**c) 2081-2100 ACGSL**

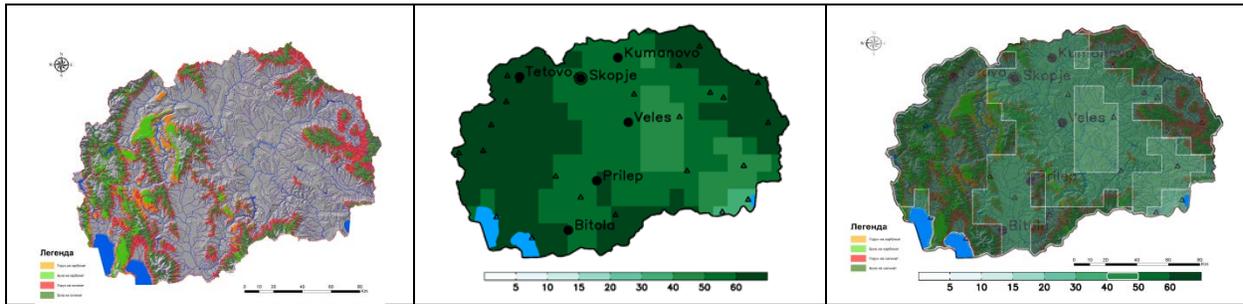
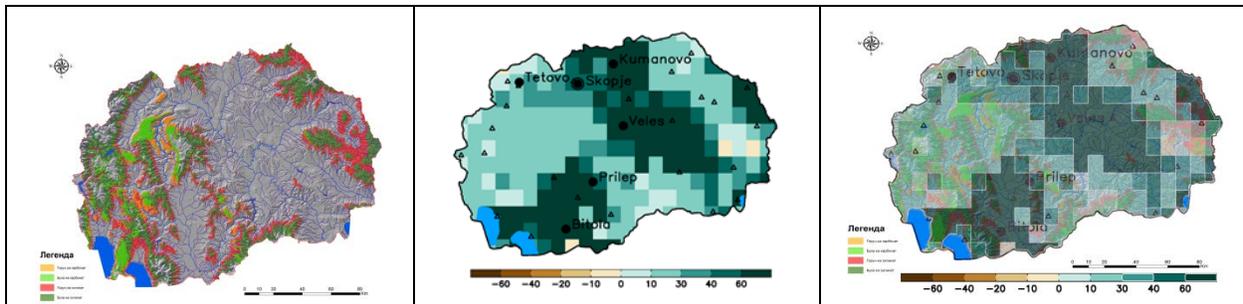


Figure 109. Spatial distribution of the future annual change in number of extreme precipitation events (RR40), for three future periods: a) 2016-2035, b) 2046-2065 and c) 2081-2100 with respect to the period 1986-2005 for the RCP8.5 scenario

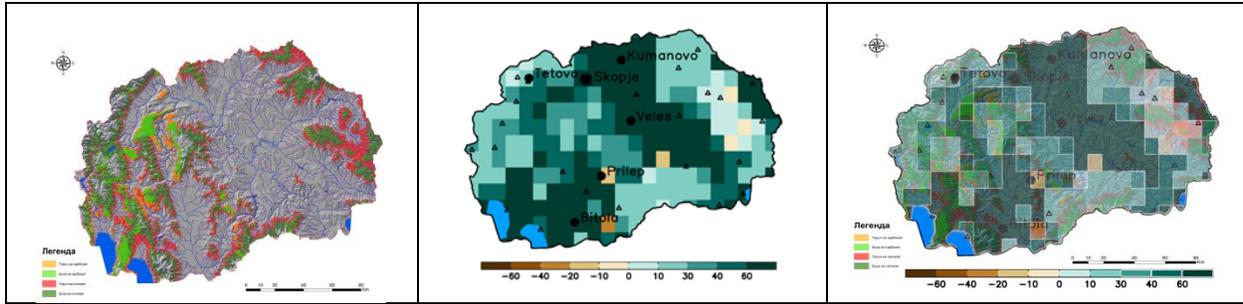
RR40 - Annual count of days when daily precipitation  $\geq 40\text{mm}$

ACNEPE - Annual Change in Number of Extreme Precipitation Events

**a) 2016-2035 ACNEPE**



**b) 2046-2065 ACNEPE**



**c) 2081-2100 ACNEPE**

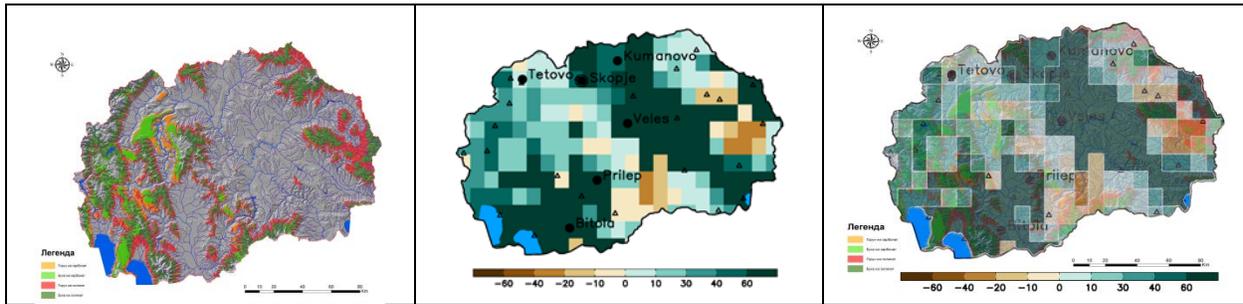
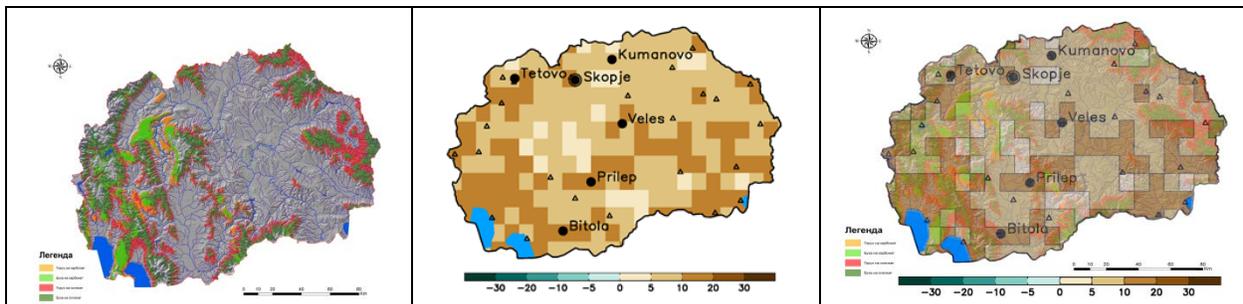
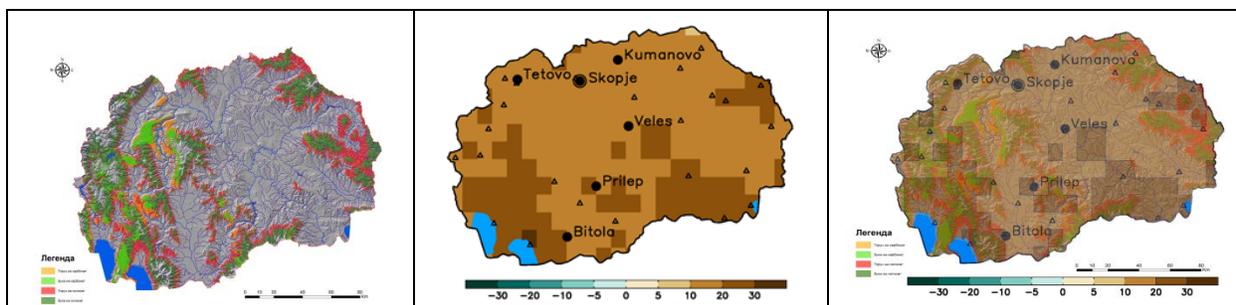


Figure 110. Spatial distribution of the future annual change in consecutive dry days (ACDD), for three future periods: a) 2016-2035, b) 2046-2065 and c) 2081-2100 with respect to the period 1986-2005 for the RCP8.5 scenario

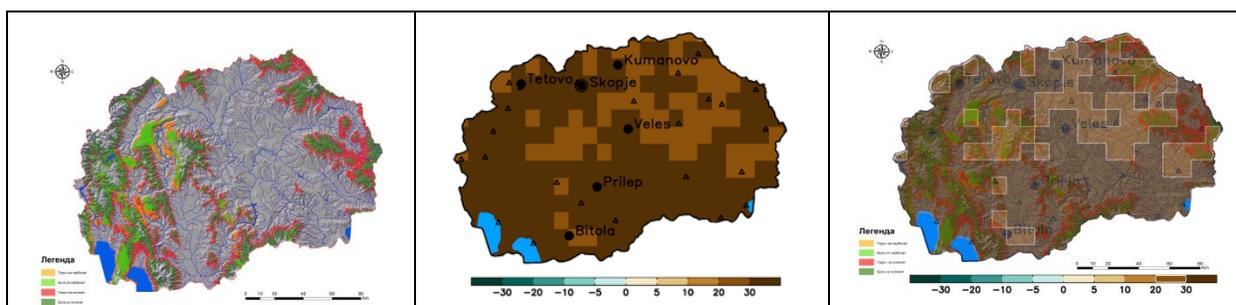
**a) 2016-2035 ACDD**



**b) 2046-2065 ACDD**



### c) 2081-2100 ACCDD



Looking the period of 2016-2035 and scenario 4.5 (as “a least dramatic”, positively or negatively, of all scenarios (including 6.0) we can make some general conclusions.

We are already faced with a decrement of the average annual precipitation (from 0 to 5 %) at the almost whole territory of Macedonia with exception of the region of Skopje, Kozjak and two lakes- Ohrid lake and Prespa lake (increment of 0 - 5 %) – Figure 10b). The average annual air temperature is in increment and will be higher from 0.5 to 1 °C at the whole territory of Macedonia (Figure 11b). It is the same situation with the average maximum air temperature (Figure 12b).

In the period of 2046-2065 and scenario 4.5 in the eastern, southern and some western parts of Macedonia the average annual precipitations will be less from 5 to 15% than in the period 1986-2005, and in the rest of the territory from 0 to 5% (Figure 13b). The average annual air temperature is in increment and will be higher from 1.5 to 2 °C on the almost whole territory of Macedonia (Figure 14b). It is the same situation with the average maximum air temperature (Figure 15b).

All of these changes almost without exceptions influence the forest in the above described regions of Macedonia.

In order to predict the extreme negative influence of climate change some elements of RCP 8.5 scenario were considered as well.

The frequency of heat waves (annual change in extreme heat waves-WSDI) in the western and eastern parts of Macedonia will be from 1 to 3 cases more in the period 2016-2035 (Figure 19 a). In the period 2046-2065 it will be from 3 to 6 cases more in the almost whole Macedonia with exceptions in western-north and eastern-north part of Macedonia where WSDI will be from 6 to 10 cases more (Figure 19b).

The length of the growing season is expected to increase in comparison to 1986-2005 period. For the period of 2016-2035 expected decrease is between 10 and 15 days (in the west of the country near to 15), and for the period 2046-2065 it is about 30 days on the east and west of the country (Figure 20a and 20b).

The number of extreme events (days with daily precipitation above 40 mm) is expected to increase in comparison to 1986-2005 period. Due to the warmer atmosphere that can hold more water vapor, the increase in many parts of the country is around than 60% more. In the period 2016-20135 this increment is concentrated in the central part of Macedonia (following the Vardar river), and in the period 2046-2065 wider in the whole territory (Figure 21a and 21b).

The length of consecutive dry days is expected to increase in comparison to 1986-2005 period. In the period of 2016-2035 length will increase from 5 to 20 days and in the period 2046-2065 from 10 to 30 days indicating higher risk for drought onset (Figure 22a and 22b).

According to the data in the Table 1 we can conclude that the health condition of the forest in the period between last National Communication on climate change and this one (2014-2021 year) is a bit worse. Generally, there are no significant changes in terms of the percentage of the crown transparency but there is noticed small transition from lower to higher categories. More precisely, in the year 2011 the amount of 50% of the assessed trees that didn't have signs of crown transparency in the 2018 and 2019 this number is around 45%. Also, there is increment of the second class of trees from around 27 % in 2011 on around 33,5% in 2018 and 2019. It is sign that the health condition of these trees shows negative trend. Finally, the tree mortality is higher, too. In 2011 the percent of dead trees had been 0,7 % and in 2019 is more than double, 1,6% from the estimated trees.

The other parameter is the water availability for the trees actually soil moisture (Figures 3, 4, 5, 6 and 7). It can be seen that in the year 2019 around 75% of the assessed trees are almost in drought condition.

Looking this and data from the scenarios for the period 2016-2035 (nowadays) we can see reactions of the trees on the above described climate changes.

Following this logic and seeing the data for some parameters of climate change especially for the period 2046-2065 it is obviously that health condition of our forest will be worsen with more significant dieback process and higher % of tree mortality. Because of weak health condition of the trees this process will be followed and accelerated by insects and fungi infestation.

In addition, in order to assess use of new technologies for monitoring and assessment of climate change impact on forest health condition we tested a drone as a basic toll for this.

This was provided by the SenseFly company from Skopje, mainly using the model SenseFly eBee Plus RTK. The drone has two modules to cover different type of service: survey mapping with very high precision (from 2 to 5cm), second is multispectral sensor facing the plants captures the light they reflect in four separate parts: green and red lights and two infrared bands invisible to the human eye. In addition, a different drone with thermal camera was used as well.

For this purpose as a testing area was chosen the mixed forest (native oak stand and pine afforestation) near to Makedonska Kamenica. The basic idea was to make different types of

photos/maps then determine characteristics of health or dead trees, conifer or broad leaf, what type of conifer is etc. Two already dead trees (on different locations) were selected to be used as markers ( Photo 3)

Figure 111. Testing area near to Makedonska Kamenica



Figure 112. View on a part of the testing area



Figure 113. One of the marker trees - a) from the ground b) from the air

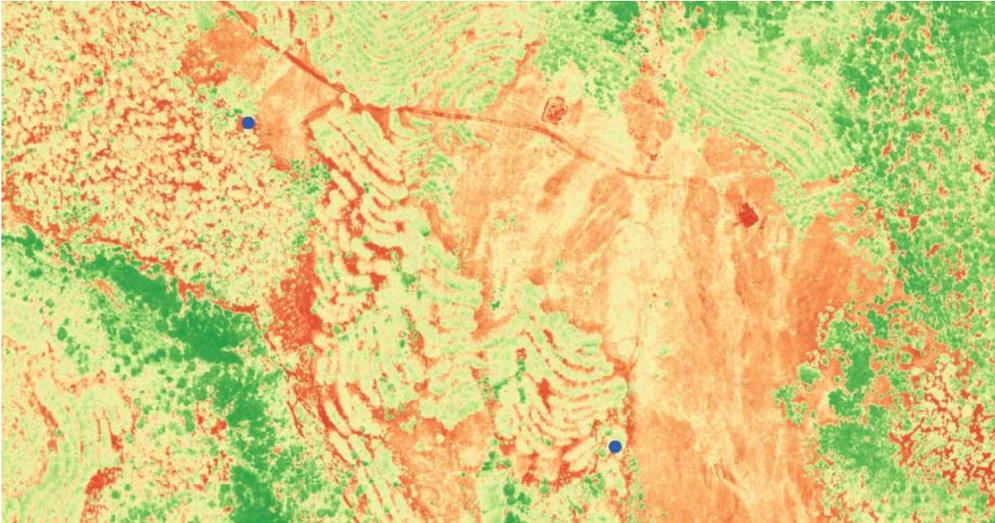


a)



b)

Figure 114. Multispectral Index HQ - with points (marker trees)



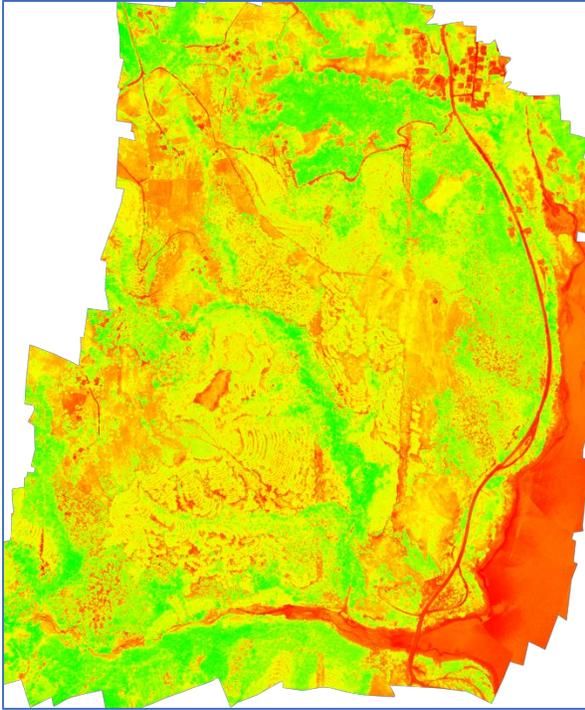


Figure 115. Index NDVI – Red Green

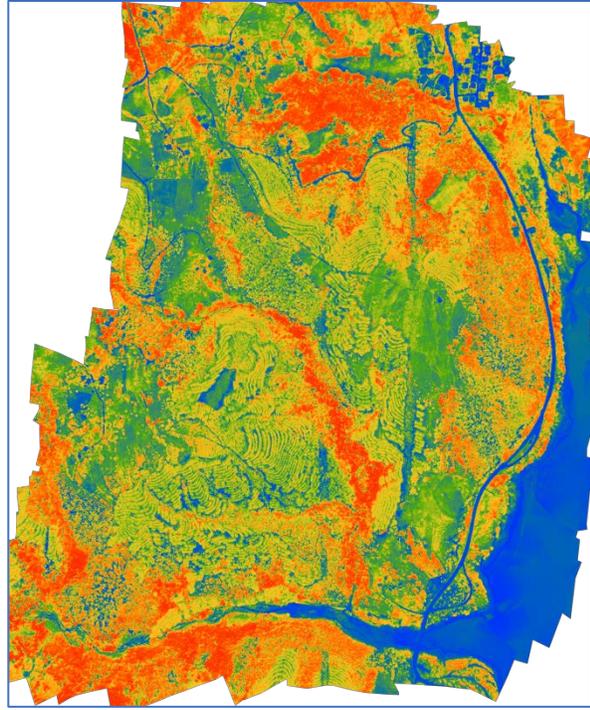


Figure 116. Index NDVI – Spectral

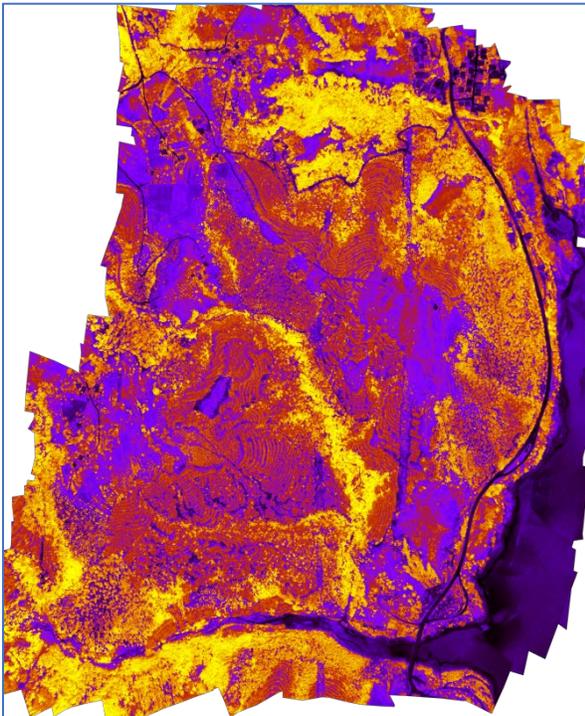


Figure 117. Index NDVI – Thermal

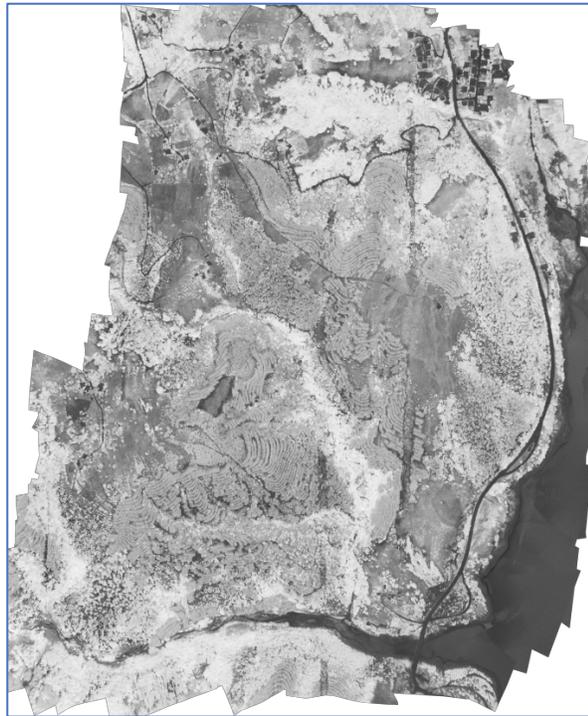


Figure 118. Index NDVI – Grayscale

The preliminary results of the testing shows that the drones are very suitable and efficient to be used as a tool for monitoring of the health condition of the forests (especially tree mortality, variation of the color of the crowns as a health condition indicator etc.). The drones may be use also for determination of the fuel, fuel condition and distribution in terms of forest fires that will help in design of the measures of prevention and preparedness.

It must be stressed because of COVID-19 pandemic the scope of the planed field activities was reduced.

### **Forest fires**

Table 27. Forest fires in Macedonia for the period 1999-2021 year

Year	Number of fires	Burned area ha	Burned wooden mass m <sup>3</sup>	Total costs	
				MKD	EUR
1999	69	2.414,80	1.905	105.837.151	1.720.929
2000	476	46.235,73	711.782	969.852.057	15.769.952
2001	161	6.263,30	88.260	610.814.677	9.931.946
2002	65	1.186,30	24.661	18.531.939	301.332
2003	144	1.068,88	10.987	15.594.691	253.572
2004	94	892,05	4.322	91.083.591	1.481.034
2005	182	1.368,00	1.063	25.287.638	411.181
2006	138	2.085,95	12.978	148.712.782	2.418.094
2007	652	35.248,06	617.678	1.311.167.722	21.319.800
2008	249	7.411,70	35.653	280.083.235	4.554.199
2009	61	1.990,60	1.551	29.746.064	483.676
2010	106	2.239,45	2.033	30.635.825	498.143
2011	302	17.812,84	55.743	355.053.834	5.773.233
2012	367	16716	102.160	181.927.609	2.958.173
2013	160	5.069,26	15.268	109.500.306	1.780.493
2014	109	818,04	19.152	24.655.527	400.903
2015	194	5.766,32	32.494	1.282.348.110	20.851.189
2016	150	3.585,15	17.574	213.596.388	3.473.112
2017	364	13.316,01	82.981	1.911.308.151	31.078.181
2018	129	2.822,99	5.786	69.368.610	1.127.945
2019	472	15.675,00	95.938	808.669.316	13.149.095
2020	102	1.233,92	8.138	81.071.150	1.318.230
2021 (till October)	192	12.042,74	487.038	2.342.637.539	38.091.667

<b>Total:</b>	<b>4.938</b>	<b>203.262,66</b>	<b>2.435.145</b>	<b>11.017.483.912</b>	<b>179.146.079</b>
17-21	252	9.018	135.976	1.042.610.953	16.753.024
<b>99-21</b>	<b>215</b>	<b>8.837</b>	<b>105.876</b>	<b>479.021.040</b>	<b>7.788.960</b>

Source: P.E. National forests

Over the past 2 decades, an increase in frequency and intensity of forest fires has been recorded worldwide, including our country. In the period of 1999-2021 each year, an average area of 8837.0 ha has been affected by forest fires in Macedonia with average damage estimated around 7.8 million EUR. In the period of 2015 to 2019 the average number of forest fires and damage caused by them are in increment and average burned area is around 3 % higher.

Most important is fact that the fire regime (frequency of the severe fire season) in the las five years (2017-2021 year) is changed in Macedonia. In this period each second fire season is severe in contrast to the previous almost two decades where each fifth fire season was severe. This is strongly related with the climate changes and behaviour of the people. Also, it is related with change of land use and weak fire protection capacities.

### *Forest ecosystem services*

#### Productivity

Analyzing the CC scenarios for the period 2016-2035 (especially RCP 4.5) it is very difficult to assess relation between forest productivity and climate change. From one hand, it is obviously that there is trend of growing season length increment and average annual air temperature. On the other hand, precipitations are around "no significant changes" and frequency of heat waves in the western and eastern parts of Macedonia will increase.

Generally, because of growing season length increment and average annual air temperature we can expect higher productivity of the forest but in the regions (western and eastern parts of Macedonia) where heat waves will be more frequent the forest productivity will be lower.

But, on the end of this period and during the next period 2046-2065 the forest productivity will decrease more significantly. The process of the forest productivity decrement will be accelerated by the insects and diseases.

The spatial distribution and time period, on "micro" or regional level, of these changes and their relation with the oak and beech forest are shown above.

#### Carbon storage and sequestration

The forest productivity mainly depends of ecological conditions (mostly climate) and way of forest management. In terms of the climate change and according to the above described, in the next

decade we can even expect higher productivity of our forest in general. But in relation with way of forest management there are two cases: legal forest management and illegal logging. With all difficulties and consequences of the long period of transition of our country the forestry sector is still able to follow the modern trends of sustainable forest management. On the other side the illegal activities especially illegal logging has a significant negative influence of the forest productivity.

Generally there is a trend of increment of forest area in Macedonia but there are two main negative factors that influence this, and they are illegal logging and forest fires. The first one is closely related with social, economic and political circumstances in the country and mainly depends by the strong political will in order to be solved. The second except socioeconomic conditions strongly depends of forest management and climate change. The both have strong negative influence of the carbon storage potential of our forest.

Although in the previous NC on CC were presented the principals and methodologies for evaluation of the carbon stock potential of our forests it is not done yet. It is connected with the national forest inventory that is still in process of preparation.

### ***Climate change impact on forest management and most vulnerable segments***

According to the review of the negative factors that influences forest, related with climate change, the forest fires still remains the biggest concern of the forestry sector in Macedonia. It can be seen by the damage caused of fires (UER/year) and burned area. Also the fire regime is changed, actually period between two severe fire season is shorten more and more.

But in line with the already recorded changes in the forestry and climate change scenarios the Macedonian forestry till 2035 also will be faced with: higher mortality of the trees, insects and fungi infestation, larger number of heavy rain days and more forest fires.

As a proof of this, in the last couple of years some extreme events were already recorded. In the summer period of the 2019 year many of the water springs into the forest area in the region of Shtip were dried up. The same was noticed in other regions. It was accompanied with strong attack of fungi and insects of the conifer forests and afforestation (reported in annual report for health condition of the forests in 2019). For sanation of this situation forestry is seeking additional financial support from the state because it is beyond of its capacities. On the other side in 2018 year forest management activities of the forestry sector were significantly interrupted because of heavy rain days. It caused decrement of the wood production but also additional financial costs for road network maintenance.

Consequently, the most vulnerable segments of the forestry till 2035 will be the same as in previous NC of CC:

1. Forest management planning: Although it is clear that the forest management planning (10 years management plans) must be adjusted with the climate change reality and especially future scenarios, there are still no significant activities in that direction.

2. Forest harvesting: As we said, there is already disturbances caused directly by climate change (heavy rains) and indirectly (insects, fungi, fires etc.). These disturbances will become more intense till 2035 and will make more difficult harvest operations.

3. Forest protection: To protect the forest, physically (forest fires) or its health (insects, fungi, dieback process etc.), will be a real challenge for the forestry. Great capacities (financial and human) will be engaged in this. Especially a great challenge will be to maintain the existing monitoring of the forest and establishment of a new in line with the climate change.

4. Silviculture: Many of forest management activities and technics are long term activities (for 20 to 60 years period, sometimes more). It means that they have to be changed and harmonized with the new conditions due to the climate change (species selection, silvicultural methods, etc).

5. In the last decade, especially in the last five years, there is a trend in Macedonia for proclamation of new protected areas (different level of protection) even new National Park, such is NP Shar Planina. Certainly, this is a positive trend toward nature protection including forests. But, potentially, excluding these forests out of the forestry management system is a possible exclusion of them out of the measures of climate change mitigation and adaptation. This is important especially for the measures of protection and silviculture.

## Action Plan

<b>Action</b> (adaptation measures that maximizes the economic benefit and minimize the climate change impact per sector)	<b>Type</b> Policy Legislation Capacity building	<b>Stakeholders</b> (Clear distinction of responsibilities among the relevant stakeholders)	<b>Timeframe</b> Short term/long-term	<b>Financing</b> (Financial means for implementation of the measures) – Euro-	<b>Constrains</b> (identification of possible barriers and risks, including legal arrangements, institutional management, financial and technical aspects)	<b>Sectorial/institutional relationship</b>
1. Develop a program for adapting forestry to global climate change	Policy, Capacity building	HEF, MAFWE, PENF	Short term	150 000	Capacity, finance, sector coordination	Forestry, Agriculture, Environment, Energy,
2. Education/training for the climate change of the engineers on PE National forest	Capacity building	HEF, MAFWE, PENF, MOEPP, UHMR	Short term	250 000	finance, sector coordination	Forestry, Agriculture, Environment,
3. Education/training for climate change of the engineers in the Sector for design, planning and hunting in the PE National forests (as a precondition for adaptation of the management plans in the forestry in agreement with the climate change)	Capacity building	HEF, MAFWE, PENF, MOEPP, UHMR	Short term	50 000	finance, sector coordination	Forestry, Environment, Energy,
4. Develop a program for improvement of the forest road network in line with the climate change scenarios, case study PENF “Babuna”-Veles		HEF, MAFWE, PENF, UHMR	Short term	1 000 000	Lack of finance	Forestry, Local self-governance, Agriculture, Environment, Energy
5. Adaptation of the Management plans in the forestry in agreement with the climate change	Legislation, Capacity building	FFS, MAFWE, PEMF	Long term	300 000	Law of forestry, education of staff, lack of finance	Forestry, Environment, Energy

6. Purchasing of drones for monitoring of the forest condition and climate change	Capacity building	HEF, MAFWE, PENF,	Short term	600 000	Financial and technological	Forestry, PENF, Environment
7. Introduction of technologies for efficient biomass using in the forestry	Legislation, Capacity building	HEF, MAFWE, PENF	Long term	1 000 000	Educational, financial, technological, legal	Forestry, Environment, Energy,
8. Introduction of the Landscape fire management concept , case study PENF Berovo and Kavadarci	Legislation, Capacity building	HEF, MAFWE, PENF	Midterm term	1 000 000	Different Laws, Financial	Forestry, Local self-governance, Environment, Agriculture,
9. Develop educational (training) center for sustainable forest utilization	Capacity building	HEF, MAFWE, PENF	Short term	500 000	Financial and technological	Forestry, Environment
10. Promotion of the possibilities for production of "green " energy	Promotion, Legislation,	HEF,FASF, MAFWE, PENF, MOEPP	Long term	100 000	Financial, institutional	Forestry, Energy, Environment
11. Implementation of pilot project for renewable energy production from forest and agricultural biomass	Legislation, Capacity building	HEF,FASF, MAFWE, PENF MOEPP	Long term	10 000 000	Financial, institutional, technological, legal,...	Forestry, Environment, Energy, Agriculture
12. Forest inventory (last one was done in 1977)	Capacity building	HEF, MAFWE, MOEPP	Short term	1 500 000	Financial	Data needed for higher Tier calculations: annual biomass growth (all types of forests, grasslands, croplands), DOM, Carbon fraction of biomass, Fraction of biomass oxidized Fraction of biomass burnt on-site and off-site, Fraction of biomass left to decay, harvest of industrial round wood (logs) and fuel wood, production and use of wood commodities, and establishment and operation of forest

						plantations as well as planting of trees in urban, village and other non-forest locations
13. Introduction of new environmentally friendly technologies for forest harvesting  (electric saw chains, electric harvesters, forwarders, case study NP "Mavrovo" sustainable management zone, and PE National forest – Berovo)	Capacity building	HEF, MAFWE, MOEPP	Short term	1 500 000	Financial, institutional, technological,	New technologies of forest harvesting are developed, and it should be introduced in the country. Forestry, Environment

#### Abbreviations

IPCC	Intergovernmental Panel on Climate Change
FASF	Faculty for Agricultural science and Food
HEF	Hans Em faculty of Forest Sciences, Landscape Architecture and Environmental Engineering
MAFWE	Ministry of Agriculture, Forestry and Water Economy
MOEPP	Ministry of Environment and Physical Planning
NC of CC	National Communication of Climate Change
PENF	Public Enterprise National Forest
RCP	Representative Concentration Pathway
UHMR	National Hidrometeorological Service

**Remark:** Actions number 1, 5, 7, 9, 10 and 11 were proposed within the previous action plan developed for the TNC, however, due to the very low level of implementation same actions are proposed again.

## Climate vulnerability assessment through the Livelihood Vulnerability Indices

The Intergovernmental Panel on Climate Change (IPCC) characterizes **climate vulnerability** as the propensity or inclination of a system to be adversely affected and the lack of capacity to cope and adapt accordingly (IPCC, 2019).

The understanding of vulnerability is acquiring increased complexity as a multidimensional concept. Studies suggest that climate impacts could slow down or reverse past development achievements; hinder global efforts on poverty reduction; and lead to human and environmental insecurity, displacement and conflict, maladaptation, and negative synergies (in IPCC, 2014: Jerneck and Olsson, 2008; Boyd and Juhola, 2009; Barnett and O'Neill, 2010; Ogallo, 2010). Key risks and risk levels vary across regions and over time, given the different socio-economic development pathways, vulnerability and exposure to hazards, adaptive capacity, and risk perceptions (IPCC, 2014). Vulnerability and its determinants are system and location specific and can diverge over time (Smit and Wandel, 2006; Adger et al., 2007). Different factors can influence different systems and make it vulnerable to the effects of climate change, depending on the system structure and characteristics and the type of effect (Brooks et al., 2005). Stronger adaptive capacity moderates the potential impact of exposure and sensitivity, and hence reduces vulnerability (Figure 2).

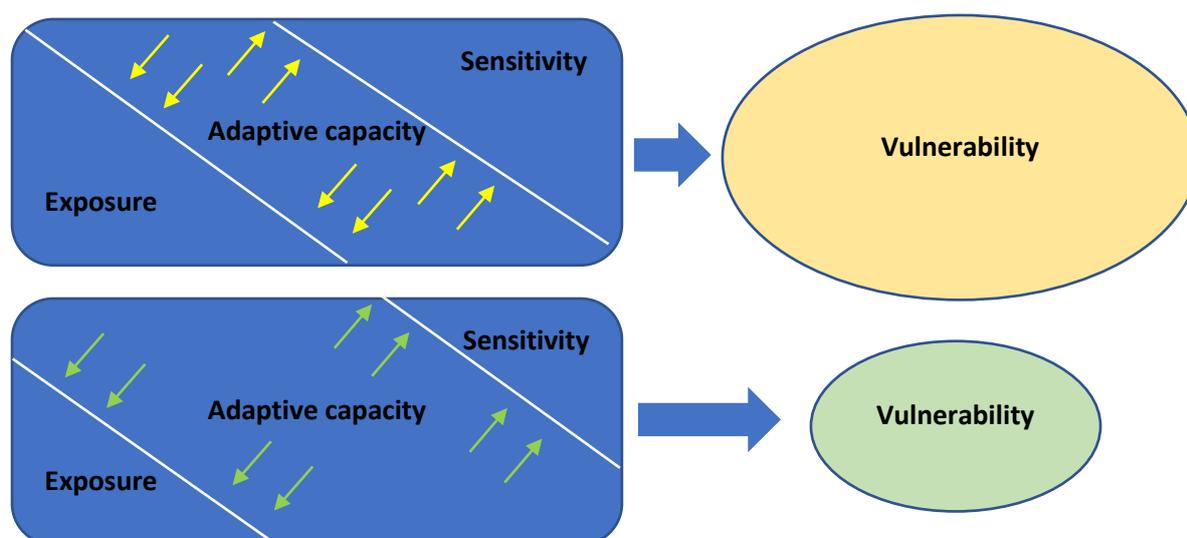


Figure 119.. *The role of adaptive capacity in influencing vulnerability (adapted from Engle, 2011)*

It is of particular importance to assess the vulnerability to stimuli such as climate change in the AFOLU system in North Macedonia through the interaction of exposure and sensitivity, and the adaptive capacities to deal with the associated effects or risks, and to estimate its distribution along the different territorial and community levels in North Macedonia. There is an evident disparity in terms of overall development, resources use and allocation, demographic and social-economic aspect across the eight statistical and planning regions (SRD, 2021). Recent regional level classification (GNM, 2020) has developed a classification of three basic indexes for ranking and comparing the development level of the different regions across the country (Table 1). The indices indicate Skopje as the most developed region from all aspects i.e. development, economic-social and demographic level, followed by the

Southeast, East and Pelagonia region. The Northeast, Polog and Vardar regions are with lowest development, especially pronounced in the socio-economic component. Also, intensive disparity can be noticed in line with the demographic index.

Having in mind this regional disparity, which further diverges at municipality level, the livelihood approach coupled with the climate effects in the AFOLU segment can be used to monitor vulnerability. It can further serve as a basis to program and to evaluate policy frameworks that can focus on broader issues concerning the system, including its ability to respond to stressors and secure livelihoods. The framework is an initial effort to estimate the climate/livelihood vulnerability in the country and besides attempting to set a benchmark for the current situation, it can also point to reducing vulnerability to future climate change.

Table 28. Classification of the regions in North Macedonia according to the development level

	Developing index	Economic-social index	Demographic index
Vardar region	73.5	70.5	75.9
East region	96.1	136.4	65.5
Southwest region	81.4	97.7	69.0
Southeast region	97.1	129.5	72.4
Pelagonia region	91.2	109.1	79.6
Polog region	82.4	50	106.9
Northeast region	62.7	27.3	89.7
Skopje region	151.0	147.7	153.5

Note: higher value indicates higher development levels.

### Assessment approach - data and method

In order to estimate the climate change vulnerability, a common approach is to estimate the complexity of the differential impacts of climate change on different territorial units through composite measures. The Livelihood Vulnerability Index (LVI) and similar adaptations of its concept enable derivation of a composite indicator based on a diverse combination of variables connected to exposure, sensitivity and adaptive capacity to climate change. As such, it requires a detailed dataset to enable LVI calculation. A number of empirical studies use composite indices to study system vulnerabilities to climate change, though the particular research designs are driven by different methodological, data and context settings (Table 2).

Table 29. Selected references to climate vulnerability index research designs

Reference	Country	Method and data approach	Vulnerability indices
Hahn et al. (2009)	Mozambique	Direct household survey (200 households in two districts, collecting data on socio-demographics, livelihoods, social networks, health, food and water security, natural disasters and climate variability).	LVI (Livelihood Vulnerability Index for each district), LVI-IPCC (LVI using the IPCC vulnerability framework, for each district).
Gbetibouo et al. (2010)	South Africa	Vulnerability of South African agriculture to climate change, across 9 regions, 19 environmental and socio-economic indicators to reflect the vulnerability components.	Vulnerability index, derived with PCA to generate weights. First principal component of a variables set taken as the linear index capturing the largest amount of information common to all set variables.
Wirehn et al. (2015)	Sweden	36 method combinations, examining Swedish agricultural vulnerability to climate change on municipal level.	Three summarizing methods used for final vulnerability indices: weighted mean (Ravindranath et al., 2011), arithmetic mean of the three separate latent indices

			(O'Brien et al., 2004), components with eigenvalues over 1 (Nardo et al., 2008).
Žurovec et al. (2017)	Bosnia and Herzegovina	Set of 20 indicators to quantitatively assess vulnerability of rural population to climate change at six municipalities in BiH.	Composite Vulnerability index, based on Equal weights (V EW) and principal component analysis (V PCA).
Gerlitz et al. (2017)	South Asia	Primary household survey data of 16 selected districts of three sub-basins in the HKH region.	Multidimensional Livelihood Vulnerability Index (MLVI), modifying LVI to 12 vulnerability components, using Alkire-Foster approach of multidimensional index construction.
Parker et al. (2019)	Vietnam, Uganda and Nicaragua	FAOSTAT and GIS data, combined with participatory approach, in order to overcome data limitations and spatially prioritize the vulnerability of agriculture and rural livelihoods to climate change.	Crop specific and overall vulnerability scores determined by equally weighted contribution of potential impact (Si+Ei) and Adaptive Capacity (AC).

Taking into account the limitations of the available data sources in the case of North Macedonia, first it was envisioned to calculate LVIs on average regional basis (8 statistical regions). However, in order to ensure more analytical structure of the index, and account for the divergences between more disaggregated territorial units, additional effort was made to set the framework to municipality level, i.e. to calculate respective LVI indices for all 71 municipalities in the country (NTES 2013). Variables were grouped in three major components: exposure, sensitivity and adaptive capacity. Each is comprised of several indicators or sub-components (the adaptive capacity component includes socio-demographic features and social networks; the sensitivity component includes food, health and water aspects; exposure refers to soil, precipitation and temperature). These were developed based on a literature review on each major component, as well as practicality, availability and accessibility for acquiring the required data. Data were collected through desk research of official statistics, primarily through the State Statistical Office latest available publications and MakStat datasets (eg. Field crops, vegetable and fruit production, Economic accounts for agriculture, Regional statistics etc.), as well as regular statistical surveys (eg. Farm structure survey 2013 and 2016). The soil depth, erosion, temperature and precipitation data were derived from the various datasets, as Soil database ([source](#)). Additional sources included data on availability of agricultural, rural and ecological organisations, extension services, memberships in cooperatives, MAFWE personnel distribution etc. The goal was to collect data for all relevant variables on a municipal scale. In cases where such disaggregation was not available, regional statistics were used and all municipalities in the respective region were assigned the same value (similar approach was used in Wirehn et al., 2015).

In order to quantify the multidimensional issues, indicators were developed as proxies and combined into composite indices which in turn integrate different variables. The classification of the variables within the major and sub-components includes an expert assessment of the North Macedonia context based on the literature review interpretations (for example, the classifications presented in Füssel and Klein, 2006; Hahn et al., 2009; Gbetibouo et al., 2010; Wirehn et al., 2015; Žurovec et al., 2017). Some variables in the pre-determined components were more difficult to categorize than others. Agricultural employment is an example; in some studies, it is assumed as a sensitivity indicator, with a premise that larger proportion of people engaged in agriculture would mean more people sensitive to climate stress (Wirehn et al., 2015), while other studies, including this study's rationale, classify it as an adaptive capacity indicator in terms of human capital in the observed local units (similar approach is applied in O'Brien et al., 2004). Another example regards irrigation, which can be considered as a physical resource in terms of access to steady and reliable irrigation facilities (eg. Defiesta

and Rapera, 2014), but in this study it is considered as a sensitivity indicator, implying that municipalities with higher share of irrigated land would be less sensitive to those with lower irrigation access (analogous argument is suggested in Gbetibouo et al., 2010).

In total, 96 variables were derived to calculate the vulnerability index (Table 3). The variables were rescaled (using the procedure proposed by Hahn et al., 2009), accounting for the correlative effect with vulnerability. The relationship with vulnerability was also determined at this stage, i.e. as 'positive' (a positive correlation is assumed if vulnerability increases with an increase in the value of the indicator, and therefore has a positive functional relationship with vulnerability), and vice versa as 'negative' (if vulnerability decreases with an increase in the value of the indicator i.e. negative correlation) (Žurovec et al., 2017). Then, after each variable was standardized, the sub-components were calculated using equal weights approach, and the major components using weighted means, taking into account the number of indicators within each major component.

Table 30. Major components, sub-components and variables comprising the Livelihood Vulnerability Indices developed for North Macedonia

Latent components	Major and sub-components	Variables (relation to vulnerability)	
<b>ADAPTIVE CAPACITY (AC, 52)</b>	<b>Socio-demographic profile (SD, 42)</b>		
	Population (PO, 3)	Population 2016-2019 (+), Population density 2016-2019 (+), Migration (% of population) 2013-2019 (+)	
	Dependency (DR, 1)	Dependency ratio 2016-2019 (-)	
	Social and institutional capital (SI, 9)	Schools primary per 1000 population 2018-2020 (-), Doctors 2019 (-), Number of active business entities 2013/2019 (-), Number of kids in kindergartens 2013/2019 (-), Number of employees in kindergartens 2013/2019 (-), Number of primary schools 2017/2019 (-), Number of teachers primary 2017/2019 (-), Number of secondary schools 2017/2019 (-), Number of teachers secondary 2017/2019 (-)	
	Human capital (HC, 8)	No education (% of population) 2002 (+), No education and incomplete primary (% of population) 2002 (+), Higher education (% of population) 2002 (-), Unemployment rate 2013-2017 (+), Number of pupils primary 2017/2019 (-), Number of pupils secondary 2017/2019 (-), Number of graduated pupils 2016/2019 (-), Number of users in institutions for adult persons 2013/2016 (-)	
	Human capital agriculture (HCA, 3)	Education (% high school in ag. holdings) 2007 (-), No education (% in ag. holdings) 2007 (+), Ag. labour force (in total ag. labour force) 2008 (-)	
	Infrastructure (I, 4)	Roads (km) (2013-19) (-), Roads (km/km <sup>2</sup> ) (2013-19) (-), Number of transport means 2013/2019 (+), Construction work 2013/2019 (-)	
	Financial capital (FC, 5)	GDP per capita parity (region vs total) 2013-2017 (-), Ag sector contribution (in GDP) 2013-2017 (+), UAA per capita 2007/2016-19 (-), Number of active Business entities 2013/2019 (-), Number of active Business entities agriculture 2013/2019 (-)	
	Natural resources (NR, 9)	Ag. holdings density (share in total) 2007 (+), Total ag. land density (share in total available ag. land) 2007 (+), UAA density (share in total UAA) 2007 (+), Farm size (average UAA) 2007 (-), Share own land (in UAA) 2007 (-), Land fragmentation (plots per holding) 2007 (+), Area forest ha 2007 (-), Planted forest area ha 2007 (-), Harvest wooden mass 2007 (+)	
		<b>Social networks (SN, 10)</b>	
	General (G, 1)	Number of environmental and rural associations 2020 (-)	
	Agriculture (AG, 9)	Number of agriculture associations 2020 (-), Number of cooperatives 2020 (-), Number of cooperatives members 2020 (-), Cooperative ha 2020 (-), Cooperative LU 2020 (-), Cooperative income 2020 (-), Number of MAFWE employees 2019 (-), Number of MAFWE forestry	

		police/rangers 2019 (-), Advisory service (ag. households per NEA advisor) 2016/2020 (+)
<b>SENSITIVITY (SE, 38)</b>	Health (H, 3)	Number of died persons 2013/2019 (+), Number of born children 2013/2019 (-), Number of active entities health and social insurance 2013/2019 (-)
	Food (F, 30)	Major crops wheat, maize, potato, tomato, pepper, cabbage, alfalfa, grapes, apples and plums: yield, parity, yield change 2014-2019 (-)
	Water (W, 5)	Irrigation number (% ag. holdings that irrigate) 2007 (-), Irrigation number (% UAA) 2007 (-), Irrigation number (% ag. holdings that irrigate) 2016 (-), Irrigation number (% UAA) 2016 (-), Irrigation number (% ag. holdings that can irrigate) 2017 (-)
<b>EXPOSURE (EX, 7)</b>	Soil (S, 2)	Soil depth 1981/2010 (-), Erosion mean+stdev (+)
	Humidity and Precipitation (HP, 3)	Aridity Humidity %humid (-), Precipitation sum 1981/2010 (-), Net change precipitation between periods 1961/2010 (-)
	Temperature (T, 2)	Variation span from mean T 1981/2010 (-), Net change temperature between periods 1961/2010 (+)

Note: The number of variables for each latent component, major component and subcomponent, together with the code, are put in brackets. The relation of the respective variable to vulnerability is marked as positive (+) or negative (-).

The climate vulnerability was then calculated through three different procedures, given the different approaches in the literature. First, LVI<sub>m</sub> was calculated, as weighted average of the major components (Hahn et al., 2009; Ravindranath et al., 2011). The average vulnerability index (AVI) was derived as arithmetic mean of the three latent components (O'Brien et al., 2004; Sridevi et al., 2014). In both cases, the values were scaled from 0 (least vulnerable) to 1 (most vulnerable). An alternative approach suggested by Hanh et al. (2009) was used to calculate the LVI-IPCC index. The LVI-IPCC diverges from the LVI<sub>m</sub>, since first the IPCC-defined contributing factor (exposure, sensitivity, or adaptive capacity) are calculated using weighted means, and then combined using the following equation:

$$LVI-IPCC_m = (EX_m - AC_m) * SE_m$$

where LVI-IPCC<sub>m</sub> is the LVI for municipality *m* expressed using the IPCC vulnerability framework, EX<sub>m</sub> is the exposure score for municipality *m*, AC<sub>m</sub> is the calculated adaptive capacity score for municipality *m* and SE<sub>m</sub> is the calculated sensitivity score for municipality *d*. The scale for LVI-IPCC ranges from -1 (least vulnerable) to 1 (most vulnerable).

## Results

The major sub-components are presented through several proxy variables in Table 4. In general, the findings confirm high regional and municipality disparity. Demographic factors, such as population density and number of children born indicate highest variation across the municipalities (154.5% and 257.2%, respectively) and deviation between different regions, which significantly impact the local adaptive capacity and increase sensitivity. In general, the human capacity as one of the primary factors for coping with the effects of climate change, is not equally dispersed and has varies greatly across the municipalities, especially in line with indicators on primary education on general population (almost 40%) and more than 50% for people engaged in agriculture. This is directly connected with the local availability of schools (with more than 60% variation), with incidence of municipalities with less than 1 school and some with more than 5 school facilities per 1000 inhabitants. Beside the human capacity, economic factors and infrastructure are also unbalanced and with high variation (GDP per capita 30.1%; Roads infrastructure 90.5%).

Also, significant variation can be noticed in terms of the social capital concentration, with the availability of social networks and presence of the NGO sector as important part of the local adaptive capacity. It can be noticed that in some municipalities no agriculture or ecology and rural development associations exist, while in others more than 100 or even 200 such associations are registered.

Differences between municipalities are also evident in terms of the value added of the agricultural sector. Agriculture does not account for equal importance in all municipalities, with more that 60% variation in the contribution of the agriculture sector in the national GDP. In addition, the potential for irrigation and irrigation practises as important aspects for dealing with climate change are not equally dispersed and vary from almost no irrigation to more than 90% of the utilized agricultural area with irrigation access.

The exposure factors (except soil depth with 20.3%), have small variation, but even these small differences still can have large impact as it can be in the case of maximum net change of temperature of 0.6°C.

Table 31. Representative major and sub-components proxies' descriptive statistics

Component	Sub-component	Mean	Min	Max	StDev	CV
AC_SD_PO	Population density 2016-19	90.4	4.1	1056.3	139.7	154.5%
AC_SD_DR	Dependency ratio 2016-19	0.995	0.969	1.036	0.013	1.3%
AC_SD_SI	Schools primary per 1000 population 2018-20	1.632	0.337	5.201	1.054	64.6%
AC_SD_HC	No education and incomplete primary (% of population) 2002	0.259	0.097	0.539	0.102	39.6%
	Unemployment rate 2013-17	21.3	12.0	38.0	8.2	38.5%
AC_SD_HCA	No education (% in ag.hh) 2007	0.049	0.007	0.123	0.026	53.1%
AC_SD_I	Roads (km/km <sup>2</sup> ) (2013-19)	0.526	0.111	3.018	0.476	90.5%
AC_SD_FC	GDP per capita parity (region vs total) 2013-2017	0.939	0.466	1.431	0.283	30.1%
	Ag sector contribution (in GDP) 2013-2017	0.150	0.021	0.322	0.091	60.4%
AC_SD_NR	Ag. holdings density (share in total ag. households) 2007	0.014	0.002	0.048	0.009	66.5%
AC_SN_G	Number of ecology and rural associations 2020	13	0	251	31	243.7%
AC_SN_AG	Number of agriculture associations 2020	11	0	118	17	159.5%
SE_H	Number of born children 2013/2019	314	18	6673	807	257.2%
SE_F	Wheat (kg/ha) 2014-19	3109	2050	4708	585	18.8%
SE_W	Irrigation number (% UAA) 2007	0.3	0.0	0.9	0.2	64.5%
EX_S	Soil depth 1981/2010	80.1	41.5	118.0	16.3	20.3%
EX_HP	Precipitation sum 1981/2010	577.9	545.4	689.5	35.8	6.2%
EX_T	Net change temperature between periods 1961/2010	0.5	0.4	0.6	0.0	6.5%

Detailed overview of the major and sub-components score is provided in Annex 1. These scores were then used for the calculation of the composite indices.

As it can be seen from the Figure 3 and the maps illustrated in Figure 4, the municipalities with the lowest Adaptive capacity (Rankovtse, Karbintsi, Vasilevo, Bosilevo, Kratovo and Kriva Palanka) are settled primary in the East and Southeast part of North Macedonia, which are at the same time within the regions with the most sensitive and most exposure municipalities (including Staro Nagorichane, Delchevo, Kumanovo, Shtip, Berovo, Probishtip and Pehchevo for sensitivity; and Strumica, Bosilevo for Exposure). It can be noticed that some of the

municipalities from Skopje and Vardar region are also ranked in the top 10 vulnerable areas, evaluated by different vulnerabilities latent components (Zelenikovo for Adaptive and at the same time Exposure factor, but also Studenichani, Veles, Kavadarci, Negotino and Skopje for Exposure and Sensitivity aspects).

The municipalities that can be evaluated as least vulnerable are mainly from the Southwest and Pelagonia region (as Prilep, Bitola, Kichevo, Resen, Struga, Mogila), mostly as a result of more favourable Adaptive capacity and Exposure scores, while the lowest Sensitivity is dominantly indicated for the municipalities from the Southeast region.

The Composite Livelihood Vulnerability Indices calculated based on the latent components (Adaptive capacity, Sensitivity and Exposure) are presented in Figure 5. Although the calculating approach for the three indices is different, still the overall findings provide similar tendency. Those indices show Skopje, Novo Selo, Gevgelija, Bitola and Kochani as the least vulnerable municipalities, while Rankovtse, Staro Nagorichane, Karbintsi, Kumanovo and Plastnitsa are the most vulnerable municipalities in the overall combined climate/livelihood vulnerability assessment.

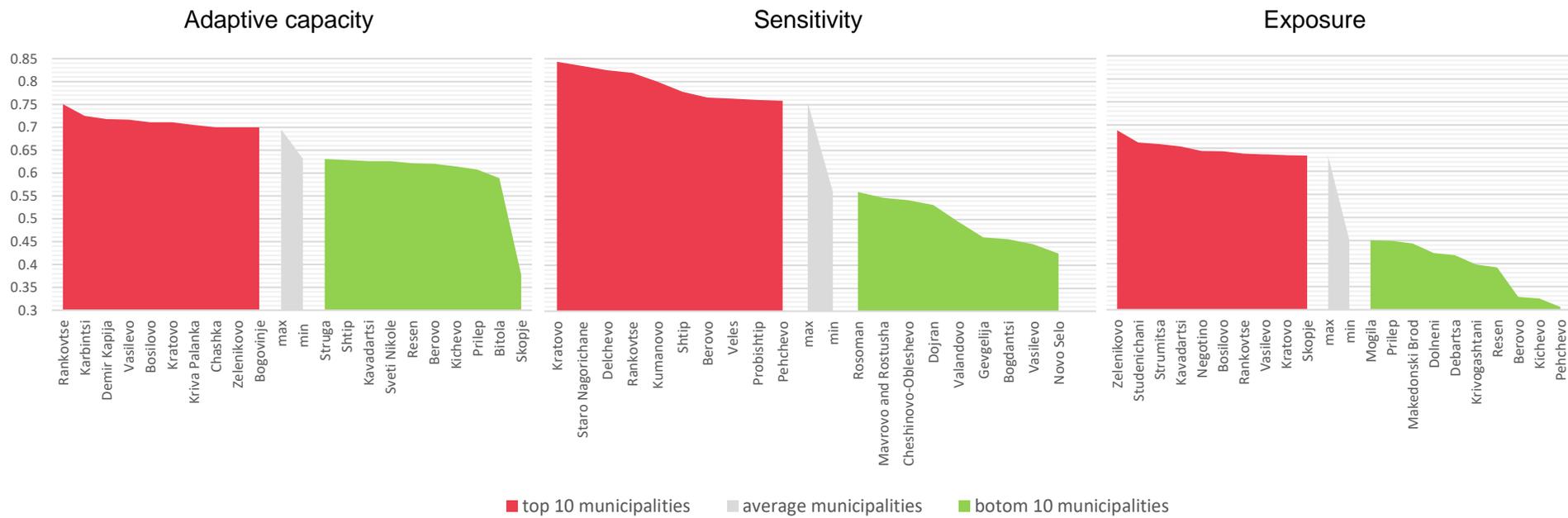


Figure 120. Adaptive capacity, sensitivity and exposure across municipalities (most vulnerable to least vulnerable)

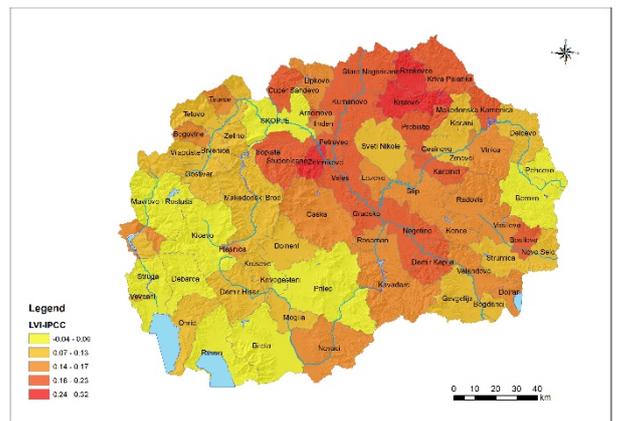
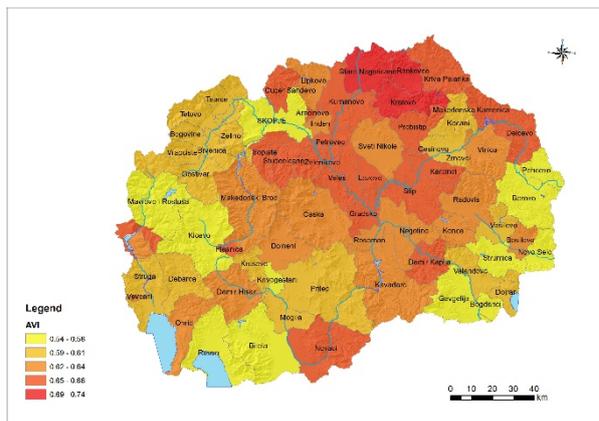
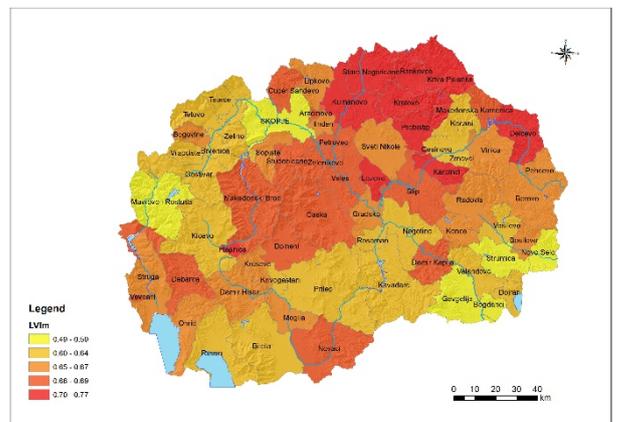
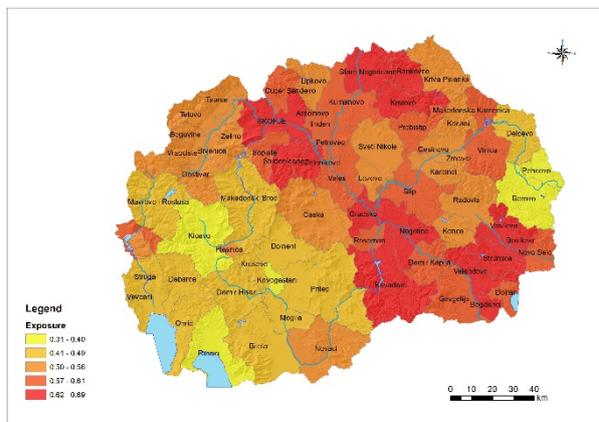
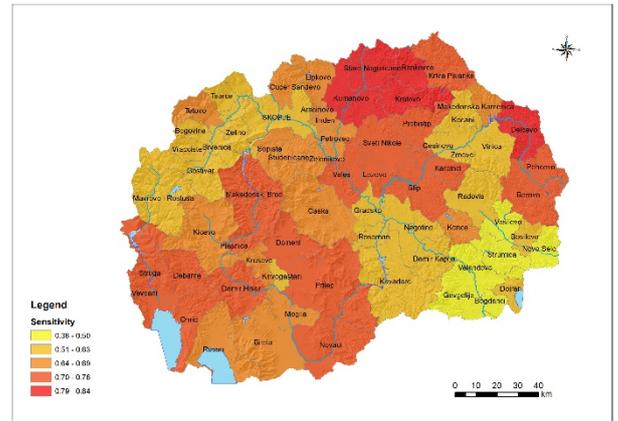
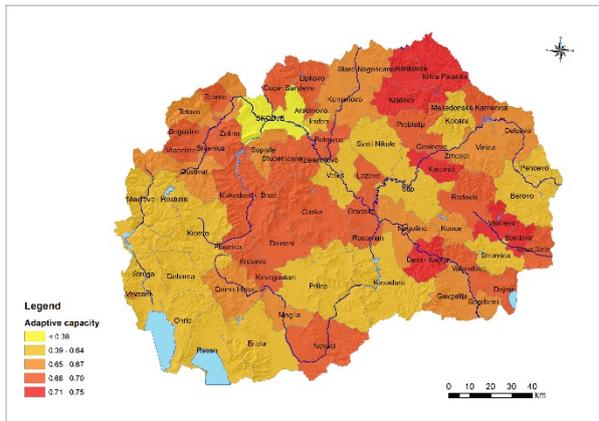


Figure 121. Components of vulnerability to climate (adaptive capacity, sensitivity and exposure) and three approaches to Livelihood vulnerability index (LVI<sub>m</sub>, AVI and LVI<sub>IPCC</sub>)

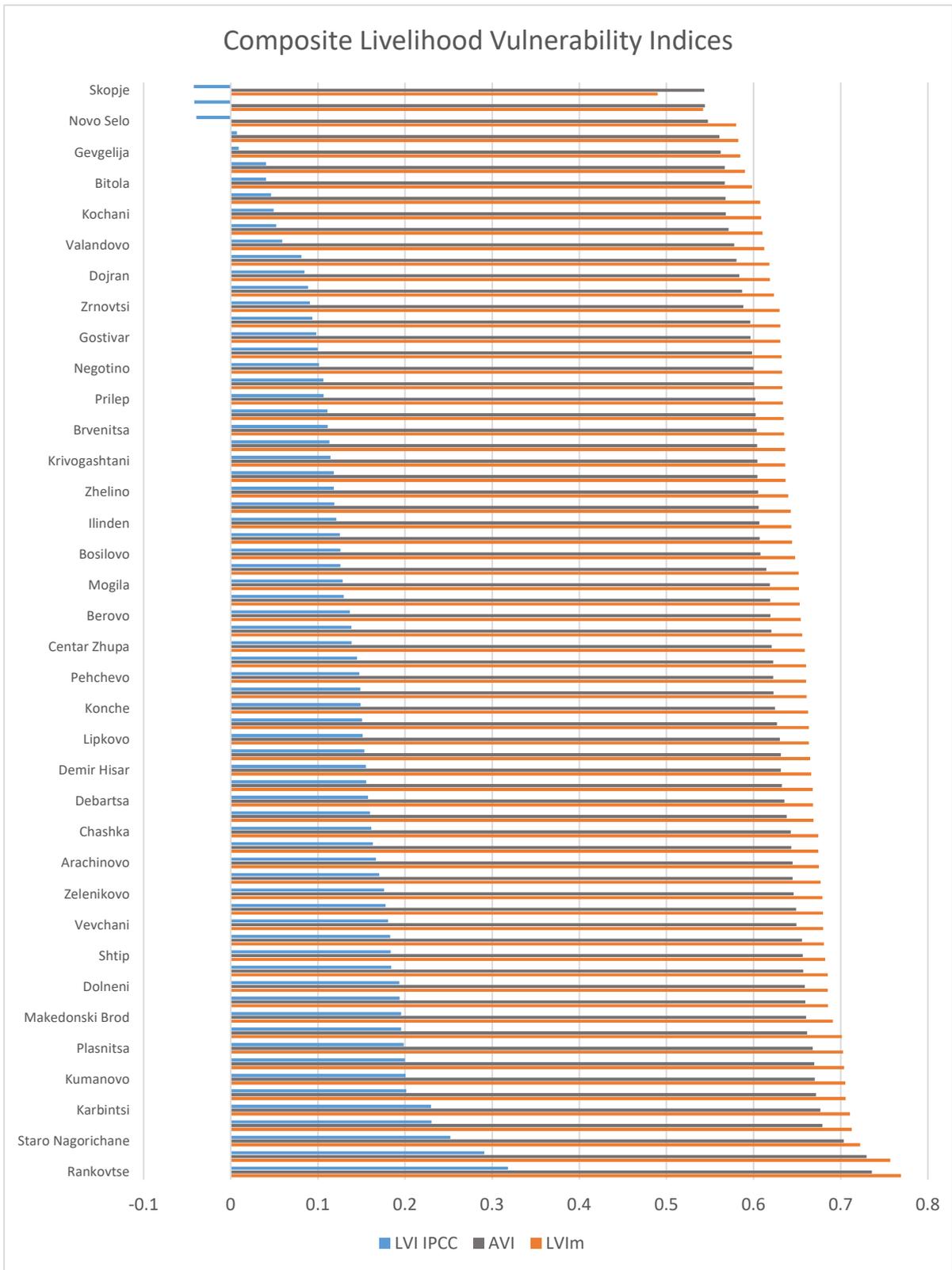


Figure 122. Composite vulnerability indices – LVI IPCC, AVI and LVIIm

In general, the level of municipality vulnerability presented by different indices LVIm, AVI and LVI IPCC is relatively in the same rank. As it can be seen from Table 5, this is especially the case with the municipalities ranked as highly vulnerable. For instance, Rankovtse has scores of Adaptive capacity (0.751), Sensitivity (0.819) and Exposure (0.638), which results into highest values of LVIm, AVI and LVI IPCC. According all these indicators Rankovtse is ranked first i.e. as the vulnerable municipality. The case is similar with Kratovo ranked on the second place and Staro Nagorichane on the third place.

Anyhow, it can be noticed that AVI and especially LVI IPCC indices give higher weight on the level of Exposure, which results with difference and higher/lower ranking compared to LVIm. This can be noticed in case of Arachinovo, which is one of the high exposure municipalities and hence is highly vulnerable and can be ranked seventh according to the LVI IPCC index, while according to the LVIm index it is ranked as less vulnerable (21st position). Similar occurrence is seen in Bosilovo, Valandovo, Gradsko, Demir Kapija, Dojran, Delchevo, Makedonska Kamenitsa, Kavadarci, Strumitsa and especially Zelenikovo, Studenichani and Chucher-Sandevo, which were also on the higher rank according to the AVI index.

On the contrary, there are some municipalities which as result of lower exposure are lower ranked by LVI IPCC and AVI compared with LVIm, such as Berovo, Vevchani, Debartsa, Delchevo, Demir Hisar, Dolneni, Karbintsi, Kichevo, Makedonski Brod, Mogila, Ohrid, Pehchevo, Struga, Centar Zhupa and Shtip.

Table 32. Major components values, livelihood vulnerability indices and ranking, per municipality

Component	Aggregated latent components			Composite vulnerability indices			Ranking (different indices)		
	AC	SE	EX	LVIm	AVI	LVI IPCC	LVIm	AVI	LVI IPCC
Municipality									
Skopje	0.378	0.621	0.634	0.490	0.544	0.007	71	70	68
Arachinovo	0.691	0.665	0.611	0.675	0.656	0.201	21	16	7
Berovo	0.620	0.765	0.328	0.654	0.571	-0.040	37	62	69
Bitola	0.589	0.638	0.474	0.598	0.567	0.040	65	65	65
Bogdantsi	0.665	0.457	0.619	0.582	0.580	0.130	68	60	38
Bogovinje	0.700	0.590	0.532	0.644	0.607	0.137	42	42	37
Bosilovo	0.711	0.560	0.643	0.648	0.638	0.198	41	24	9
Brvenitsa	0.679	0.600	0.510	0.635	0.596	0.113	49	56	48
Valandovo	0.691	0.495	0.632	0.612	0.606	0.160	61	44	24
Vasilevo	0.717	0.446	0.636	0.608	0.600	0.158	64	53	25
Vevchani	0.654	0.752	0.487	0.680	0.631	0.106	17	28	52
Veles	0.641	0.763	0.599	0.685	0.668	0.183	12	9	15
Vinitsa	0.669	0.620	0.569	0.643	0.619	0.148	44	37	33
Vrapchishte	0.693	0.576	0.526	0.635	0.598	0.126	50	54	40
Gevgelija	0.668	0.461	0.604	0.585	0.578	0.125	67	61	42
Gostivar	0.662	0.605	0.546	0.631	0.604	0.126	55	47	41
Gradsko	0.693	0.624	0.617	0.661	0.645	0.194	32	20	13
Debar	0.640	0.730	0.564	0.669	0.645	0.149	24	21	31
Debartsa	0.643	0.752	0.418	0.668	0.605	0.046	25	46	64
Delchevo	0.654	0.825	0.467	0.706	0.649	0.100	6	18	54
Demir Kapija	0.718	0.609	0.603	0.668	0.643	0.195	26	22	11
Demir Hisar	0.648	0.727	0.486	0.666	0.620	0.098	27	36	55
Dojran	0.683	0.532	0.609	0.619	0.608	0.155	59	41	27
Dolneni	0.694	0.727	0.423	0.685	0.615	0.085	13	40	59

Zhelino	0.676	0.610	0.534	0.640	0.607	0.128	45	43	39
Zelenikovo	0.700	0.648	0.689	0.679	0.679	0.252	19	4	3
Zrnovtsi	0.648	0.622	0.543	0.630	0.604	0.118	57	48	46
Ilinden	0.638	0.665	0.571	0.643	0.625	0.139	43	31	35
Jegunovtse	0.669	0.613	0.525	0.636	0.602	0.119	48	50	44
Kavadartsi	0.626	0.577	0.653	0.610	0.619	0.161	62	39	23
Karbintsi	0.725	0.728	0.517	0.711	0.657	0.176	5	15	19
Kichevo	0.614	0.692	0.324	0.624	0.544	-0.042	58	71	71
Konche	0.662	0.685	0.559	0.663	0.635	0.151	31	25	29
Kochani	0.632	0.593	0.526	0.609	0.584	0.094	63	59	56
Kratovo	0.711	0.844	0.634	0.757	0.730	0.291	2	2	2
Kriva Palanka	0.705	0.751	0.555	0.713	0.670	0.195	4	7	10
Krivogashtani	0.681	0.625	0.398	0.636	0.568	0.049	47	63	63
Krushevo	0.676	0.669	0.457	0.656	0.601	0.089	36	52	58
Kumanovo	0.656	0.800	0.574	0.705	0.677	0.184	7	5	14
Lipkovo	0.684	0.661	0.535	0.664	0.627	0.145	29	30	34
Lozovo	0.695	0.749	0.532	0.704	0.659	0.170	8	13	20
Mavrovo and Rostusha	0.637	0.547	0.458	0.590	0.548	0.052	66	69	62
Makedonska Kamenitsa	0.690	0.695	0.600	0.685	0.661	0.201	14	10	6
Makedonski Brod	0.695	0.730	0.443	0.691	0.623	0.101	11	32	53
Mogila	0.671	0.668	0.450	0.652	0.597	0.081	39	55	60
Negotino	0.665	0.585	0.643	0.633	0.631	0.181	53	27	17
Novatsi	0.678	0.713	0.537	0.681	0.643	0.153	16	23	28
Novo Selo	0.694	0.426	0.567	0.580	0.562	0.111	69	67	50
Ohrid	0.631	0.746	0.490	0.665	0.622	0.091	28	34	57
Petrovets	0.682	0.690	0.575	0.677	0.649	0.178	20	17	18
Pehchevo	0.639	0.758	0.306	0.660	0.568	-0.042	33	64	70
Plasnitsa	0.691	0.755	0.525	0.703	0.657	0.163	9	14	22
Prilep	0.608	0.708	0.449	0.634	0.588	0.040	51	57	66
Probishtip	0.676	0.760	0.579	0.701	0.672	0.194	10	6	12
Radovish	0.689	0.618	0.555	0.652	0.621	0.151	40	35	30
Rankovtse	0.751	0.819	0.638	0.769	0.736	0.318	1	1	1
Resen	0.621	0.688	0.392	0.631	0.567	0.009	56	66	67
Rosoman	0.688	0.560	0.610	0.632	0.619	0.167	54	38	21
Sopishte	0.671	0.661	0.605	0.664	0.646	0.183	30	19	16
Sveti Nikole	0.626	0.732	0.540	0.660	0.633	0.121	34	26	43
Staro Nagorichane	0.656	0.834	0.620	0.722	0.703	0.230	3	3	4
Struga	0.631	0.725	0.451	0.653	0.602	0.059	38	51	61
Strumitsa	0.638	0.385	0.659	0.542	0.561	0.115	70	68	47
Studenichani	0.686	0.661	0.662	0.674	0.670	0.230	22	8	5
Teartse	0.693	0.566	0.552	0.633	0.604	0.139	52	49	36
Tetovo	0.649	0.642	0.524	0.636	0.605	0.111	46	45	49
Centar Zhupa	0.636	0.719	0.513	0.659	0.622	0.106	35	33	51
Chashka	0.700	0.668	0.522	0.674	0.630	0.149	23	29	32
Cheshinovo-Obleshevo	0.684	0.542	0.535	0.618	0.587	0.118	60	58	45
Chucher-Sandevo	0.680	0.692	0.609	0.680	0.660	0.200	18	11	8
Shtip	0.628	0.778	0.571	0.682	0.659	0.156	15	12	26
Mean	0.665	0.658	0.542	0.653	0.621	0.133			
Min	0.378	0.385	0.306	0.490	0.544	-0.042			
Max	0.751	0.844	0.689	0.769	0.736	0.318			
StDev	0.046	0.100	0.083	0.044	0.040	0.069			
Variation	7.0%	15.2%	15.3%	6.8%	6.5%	51.8%			

### ***Potential in using multidimensional climate vulnerability indices - conclusions***

The climate vulnerability assessment through the Livelihood Vulnerability Indices proves to be a useful tool for a multidimensional analysis, providing evidence for programming and implementing tailored policy instruments and measures for addressing more targeted local level needs. Policy response options should account for the uneven distribution of impacts across different territorial units and ultimately the affected population in different regions and municipalities, since the multidimensional character of the climate change effects requires a comprehensive understanding of the economic, social and environmental vulnerability specifics.

Composite indices offer a relatively simple and effective way to capture various dimensions of the AFOLU system vulnerability to climate change. Nevertheless, different methodological choices of composing the final indicator can indicate variability between methods and therefore it is advisable to present different approaches to summarizing the results (Wirehn et al., 2015). Even taking that into account, in general, the level of municipality vulnerability presented by different indices LVI<sub>m</sub>, AVI and LVI IPCC is relatively within comparable ranking. In some cases, especially those with high or low exposure index, the difference is more noticeable across the different indices ranking. Potentially this can be overcome with the use of ranking based on an average value derived from all indices, or average of the already derived rankings (See Annex 2). Still, further analysis and in-depth evaluation of the individual impacts of variables used for comprising the Livelihood Vulnerability Indices can be instructive to additionally investigate the divergences between the different indices. The methodological framework can further be expanded in future efforts, as well as the data approach.

The applied methodology and systematic approach for using these multidimensional indices is a pioneer effort in North Macedonia. The methodology and selection of variables used enables regular update of the vulnerability assessment, which in turn can be further upgraded with additional relevant variables for more precise assessment in the future. Last but not least, this approach and methodology can be used as a solid base for additional focused multidimensional assessments in other areas, beside climate change and vulnerability.

## Adaptation of Agricultural sector

Adaptation of agriculture is frequently considered as less important than research in vulnerability due to common approach that farmers will autonomously change their practices and adapt to the conditions prevailing. However, the farms in the country are very small by physical size, averaging to about 1.8ha of utilized agricultural land, and slightly above 2 livestock units per farm. Moreover, about 90 thousand farms are below 2000 Euros in economic size. Waste majority of about 125 thousand farms (about 2/3 of all farms) are below 4000 Euros. Moreover, more than 45% of the people engaged in agricultural sector are with primary education and below. Only 5% of the farm owners do have some type of formal education in agriculture. These farms according their size, economic power and level of education cannot invest in new technologies, in innovations and cannot easily adopt to any new situation. Therefore, the adaptation measures should be careful analyzed, elaborated, transferred to the farmers and supported by the National System for Support of Agriculture.

The increased risk of the last spring frost is pronounced and in recent years several extreme situations as late spring frost on 27 April 2017 that caused severe damages on the crop production in Europe. Also, the coldest April in 2021 impacted crop production with slow crop growth and reduction in the biomass accumulation in initial periods of crop growth that negatively impacted productivity of the crops affected. Moreover, several floods that took place on agricultural land in the country, during the mid-spring negatively impacted winter and spring crops and their productivity. Moreover, the sowing of the summer crops was delayed, growing period was shortened and crops hardly reached full maturity. The systems that should support farmers in predicting and early warning about extreme weather events are not in place in the country. Moreover, the system that will inform farmers about solutions and activities they should undertake to reduce negative impact of extreme weather events do not exist (ex. sowing the hybrids with shorter vegetation in late sowing after the flood, etc.). Therefore, farmers are not supported and without any support related to increasing their knowledge on practices that should be applied their fields are even less resilient to climate change and no adaptation measures are taking place. However, business as usual is not optimal solution when something is changed, disturbed and different than regular situation and usually results with reduction in productivity and lowering the quality.

Adaptation options and measures are something that should be carefully elaborated, tested in national environment, and farmers should be informed on optimal adaptation practice they should use in given situation. Clearly late spring frost, summer drought and new pests required totally different solutions, therefore different adaptation practices should be applied. Therefore, the serious research activities, experimental fields and plots for testing and spreading of the adaptation measures and training programs for agricultural operators should be conducted. Best solution will be establishing the Center for climate change research, technology transfer and training in the frame of the existing institutions with research capacities in climate change in agriculture.

### Actions Summary

Based on the previously analyses presented in the report the list of the actions recommended is presented below.

Table 33. The actions for adaptation of the agricultural and forestry sectors

Action)	Type	Stakeholders	Timeframe
<b>Agriculture</b>			
Strengthening the cooperation among relevant stakeholders at institutional level	Policy	MEPP, MAFWE	Short term
Establishment of the Center for research of the climate change in Agriculture	Policy, Capacity building	MEPP, MAFW, MES, High Educationl and research Institutions	Short Term
Rehabilitation of the existing irrigation and drainage systems for improved resilience to climate change	Capacity Building	MAFWE, JSCWE	Long Term
Construction of the new irrigation infrastructure for improved resilience to climate change	Capacity Building	MAFWE, JSCWE	Long Term
Improving the soil monitoring (particularly for soil organic matter) and develop the institutional setup, legal framework, procedures, protocols and stable financing of the monitoring activities	Capacity building. Policy	MEPP, MAFWE, High Educational and Research Institutions	
Strengthening the agro-meteorological service in the country for providing services for the agricultural sector for increasing the resilience and better adaptation to the changing climate	Capacity Building	MAFWE, High Educational and Research Institutions	Short term
Strengthening the capacities of the Phytosanitary Directorate and Agency for veterinary and food in climate change and risk of new diseases and pests	Capacity building	MAFWE, High Educational and Research institutions	Short term
Evaluation of the mitigation measures with high adaptation potential (biochar and photovoltaic irrigation) as adaptation measures and development of the pilot projects, standards and advisory packages	Capacity building	MAFWE, High Educational and Research	Short term

		institutions, Extension Services	
Evaluation of the cover crops adaptation measure and preparation of the advisory packages for the options selected	Capacity building	MAFWE, High Educational and Research institutions, Extension Services	Short term
Evaluation of the Adaptation measures already tested in the country, and preparation of the advisory packages for the options selected	Capacity building	MAFWE, High Educational and Research institutions, Extension Services	Short term
Introduce the climate change adaptation measures into the National System for Support of Agriculture	Capacity building	MAFWE	Short term
Development of the Agri-environmental measures for supporting the climate change adaptation measures	Capacity building	MAFWE	Short term
Genetically heat-tolerant breeding animals and breeding program toward robust and high productive livestock	Capacity Building	MAFWE, High Educational and Research institutions, Extension Services	Short term
Adoption of special feed and feeding techniques in the period of excessive heat and changes in feeding techniques to increase feed efficiency and digestibility.	Capacity Building	MAFWE, High Educational and Research institutions, Extension Services	Short term
Improvement in housing conditions by adopting proper ventilation, in-house conditioning, and cooling systems installation based on use of renewable energy	Capacity Building	MAFWE, High Educational and Research institutions, Extension Services	Short term
The Introduction of continuous monitoring to follow the farms' productivity level concerning heat waves and high temperatures.	Capacity Building	MAFWE, High Educational and Research institutions	Short term

<b>Forestry</b>			
Develop a program for adapting forestry to global climate change	Policy, Capacity building	HEF, MAFWE, PENF	Short term
Education/training for the climate change of the engineers on PE National forest	Capacity building	HEF, MAFWE, PENF, MOEPP, UHMR	Short term
Education/training for climate change of the engineers in the Sector for design, planning and hunting in the PE National forests (as a precondition for adaptation of the management plans in the forestry in agreement with the climate change)	Capacity building	HEF, MAFWE, PENF, MOEPP, UHMR	Short term
Develop a program for improvement of the forest road network in line with the climate change scenarios, case study PENF "Babuna"-Veles		HEF, MAFWE, PENF, UHMR	Short term
Adaptation of the Management plans in the forestry in agreement with the climate change	Legislation, Capacity building	FFS, MAFWE, PEMF	Long term
Purchasing of drones for monitoring of the forest condition and climate change	Capacity building	HEF, MAFWE, PENF,	Short term
Introduction of technologies for efficient biomass using in the forestry	Legislation, Capacity building	HEF, MAFWE, PENF	Long term
Introduction of the Landscape fire management concept , case study PENF Berovo and Kavadarci	Legislation, Capacity building	HEF, MAFWE, PENF	Midterm term
Develop educational (training) center for sustainable forest utilization	Capacity building	HEF, MAFWE, PENF	Short term
Promotion of the possibilities for production of "green " energy	Promotion, Legislation,	HEF,FASF, MAFWE, PENF, MOEPP	Long term
Implementation of pilot project for renewable energy production from forest and agricultural biomass	Legislation, Capacity building	HEF,FASF, MAFWE, PENF MOEPP	Long term
Forest inventory (last one was done in 1977)	Capacity building	HEF, MAFWE, MOEPP	Short term
Introduction of new environmentally friendly technologies for forest harvesting	Capacity building	HEF, MAFWE, MOEPP	Short term

(electric saw chains, electric harvesters, forwarders, case study NP "Mavrovo" sustainable management zone, and PE National forest – Berovo)			
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## Annexes

### Annex I

Table 1. Analyse of the achievements from the previous action plan

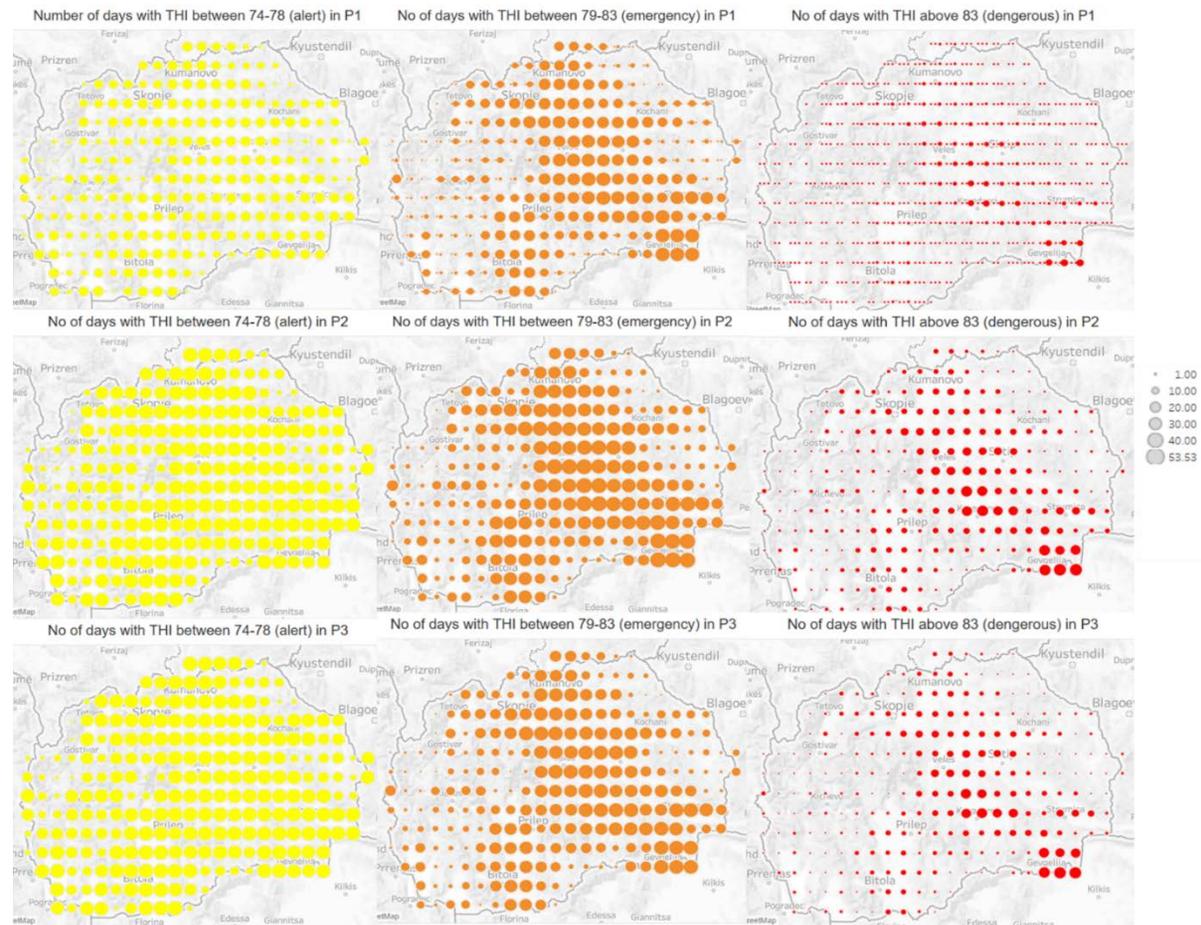
<b>Primary sector: Agriculture - general</b>	
Establishing a national fund for testing of adaptive measures and introduction of drought resistant species	No achievements. However, the USAID supported projects Adaptation to climate change and in the frame of the project number of adaptation measures were tested. The activities stopped after the project end.
Subsidies for implementing adaptation measures for professional farmers	No achievements. However, the new National Strategy on Agriculture and Rural Development 2021-2027 foreseen support for adaptation.
Development a new crop varieties selection and experiment programme to increase crop adaptation to adverse impacts of climate change	No achievements.
Establishing the national center for drought yield forecasting	No achievements
Development of techniques and procedures for cultivation, fertilizers utilization and soil reclamation for the key crops in CC affected areas	No achievements
Development of different tillage practices for the promotion of sustainable agricultural practices.	No achievements
Development irrigation techniques and water supply	No achievements
Implemented the "Policy on Biofuels in Macedonia" which will consider the use of biofuels as an alternative to fossil fuels in agricultural machinery.	No achievements
Establishing of national network for long term monitoring of agro climatic and agro-edaphic parameters as a prerequisite for efficient planning and implementation of the adaptive measures	Partially achieved, the National Hydromet established 3 agro-meteorological monitoring sites in Kocani, Strumica and Gradsko, by support of FAO project
Development of criteria and identification of LUT and AEZ	Partially achieved, AEZ delineated by support of FAO project
Establishment of 15-20 phenological fields and long-term financing	No achievements. However the national hydromet is running the network of phenological stations, but historical data is not readily available

Inclusion of climate change adaptation measures into rural development schemes	No achievements. However, the number of present measures in rural development can be associated to the climate change adaptation. Moreover, the NSARD for 2021-2027 foreseen intensification of the support for
Increased organic farming	The area under organic production increased from 2280 to 3332 ha in the period from 2014 to 2019. For the same period, number of cattle in organic production increased by 136%, sheeps by 112%, goats by 83% and beehives for 47%.
Increasing planting depth	No achievements
<b>Primary Sector Agriculture - Viticulture</b>	
Strengthening and structural changes of the Water User Associations and Corporations.	No achievements, Water Users Associations (Water communities) were abolished.
Support to the Water communities and change the system of irrigation water charge (per m3).	No achievements
Development of criteria for identification and delineation of localities with specific climatic and soil characteristics for certain varieties (terroir)	No achievements
Establishment of facilities for processing of bio residues for biofuels	No achievements. However there is achievement in using the bio-residues for electricity production in Pelagonia and Polog Area.
Establishment of early warning system (network of meteorological stations) for improved pest control and water use efficiency	No achievements
Supporting the research and innovation for development and spreading the new production systems and measures	Fund for Inovation supported several related activities, but no visible changes in the sector.
Improvement of new training systems, especially in table grape varieties (sun burns protection of grapes) and implementing of integrated viticulture production (optimization of pest control and fertilizer use efficiency)	No achievements
Support the establishing of facilities and logistics for production of certified seedlings and varieties more resistant to climatic stress.	No achievements
Establishment of phenological fields in each sub region of Povardarski region and long term financing program	No achievements
Financial support for implementation of modern adaptation measures e.g. UV nets, cover crops, sprinkler irrigation	The protective nets and drip irrigation are part of the support system

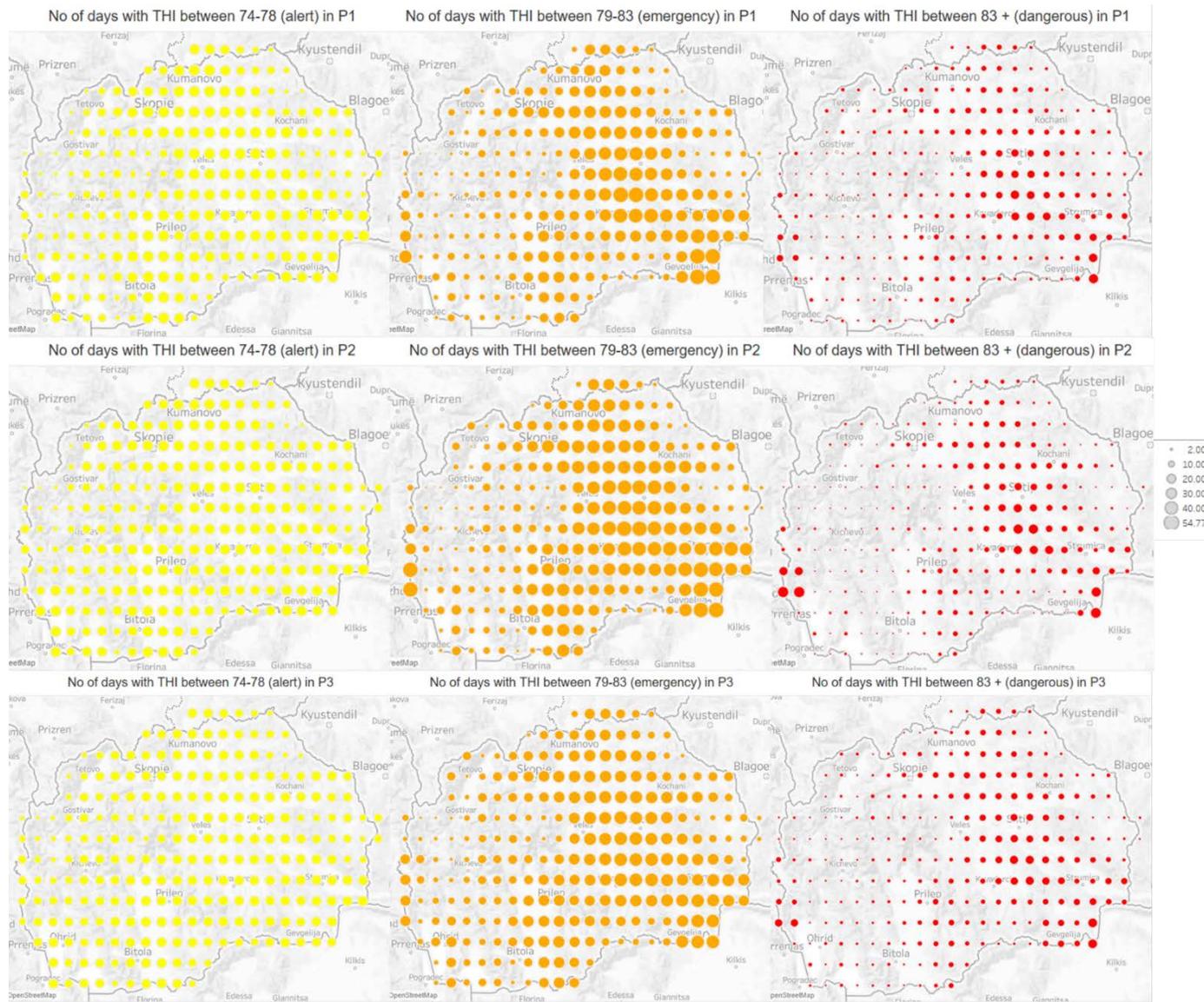
Financial support for implementation of methods and techniques for increasing of water use efficiency, e.g. pressurized irrigation systems, control systems for efficient irrigation scheduling, etc.	Partial achievements, the drip irrigation is supported
Long term investments in reconstruction and extension of dams and irrigation schemes.	Partial achievements, Several activities in Southern Vardar valey and EU support for construction of small irrigation systems
Financial support of dislocation of vineyards on a higher altitude and more appropriate/ resistant varieties to frosts.	No achievements
Financial support for intensification of the process of establishing of new vineyards (only 2% of vineyards are renewed every year), for improvement of the age structure of vineyards	No achievements, but measure for establishing the new vineyards is active for a longer period.
<b>Primary sector: Agriculture - livestock production</b>	
Introduce genetically heat tolerant breeding animals	No achievements
Adoption of special feed and feeding techniques in periods of excessive heat	No achievements

**Annex II Livestock sector**

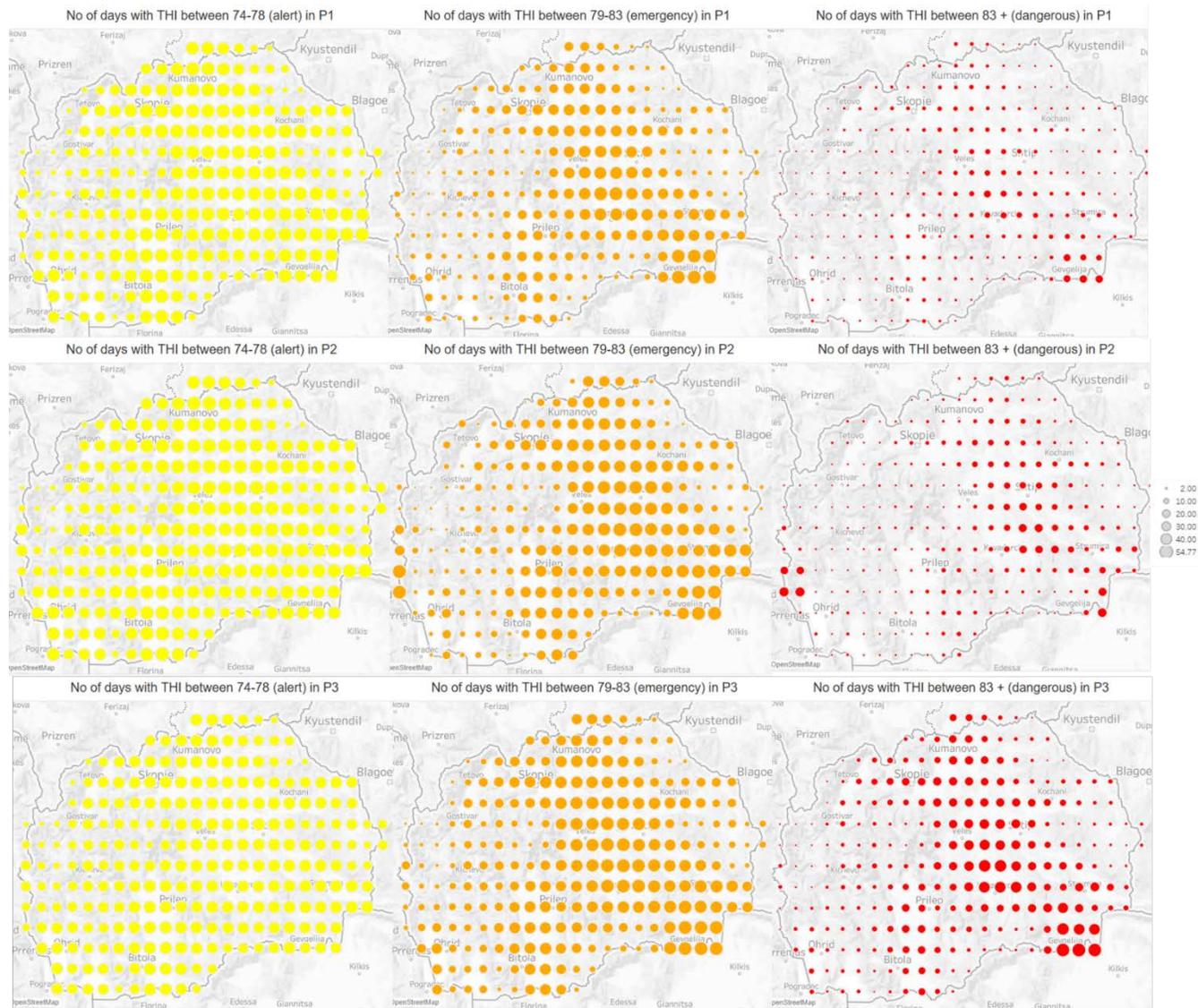
**Appendix 1: Spatial distribution of three different THI loads (74-78; 78-83, 83+) for cattle for three periods (P1:1986 -2015; P2: 2016-2045; P3: 2046-2075) under RCP 2.6, RCP 4.5 and RCP 8.5**



Spatial distribution of different cattle' THI loads in three periods under RCP 2.6 scenario

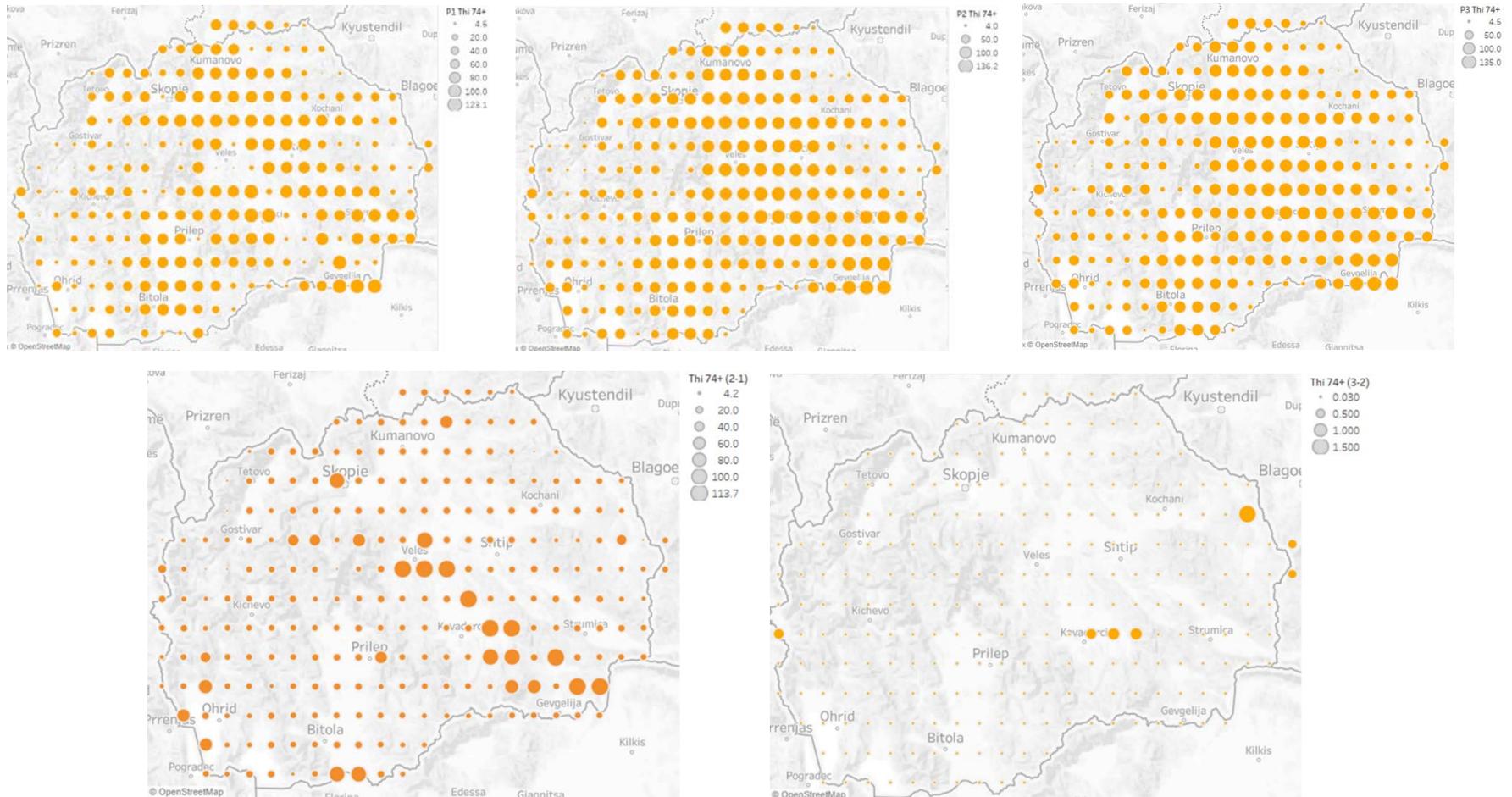


Spatial distribution of different cattle' THI loads in three periods under RCP 4.5 scenario

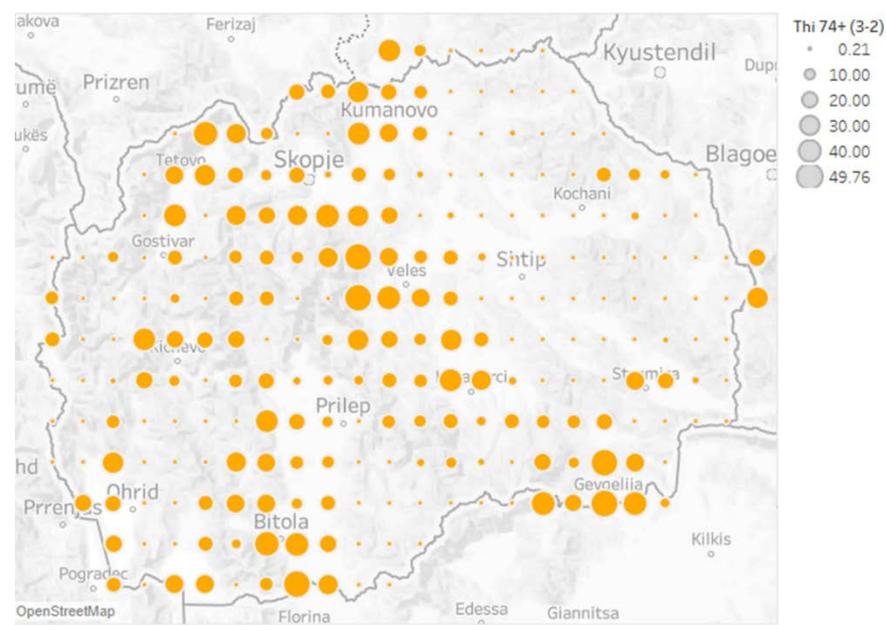
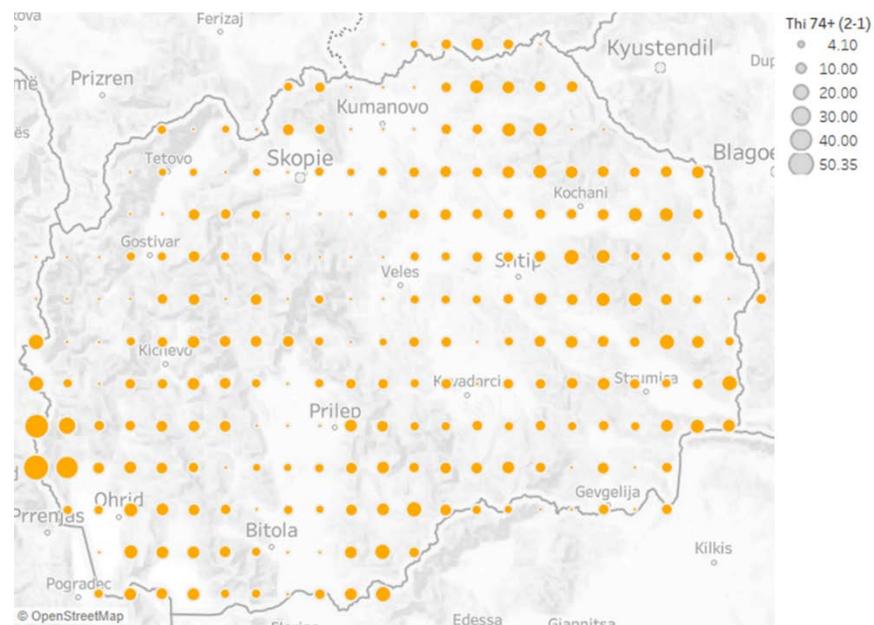
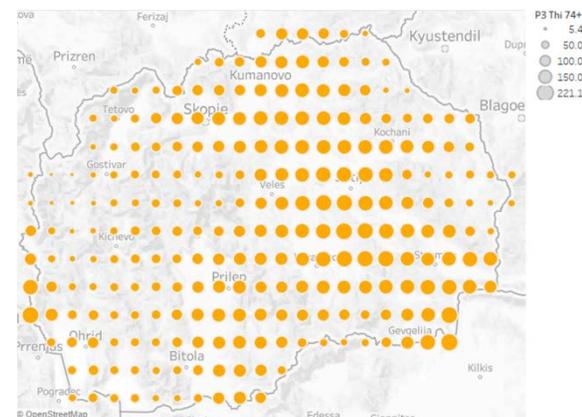
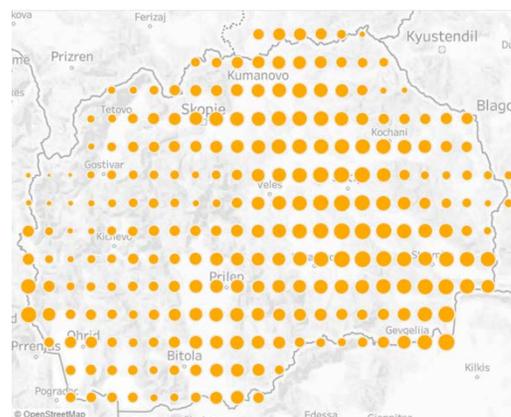
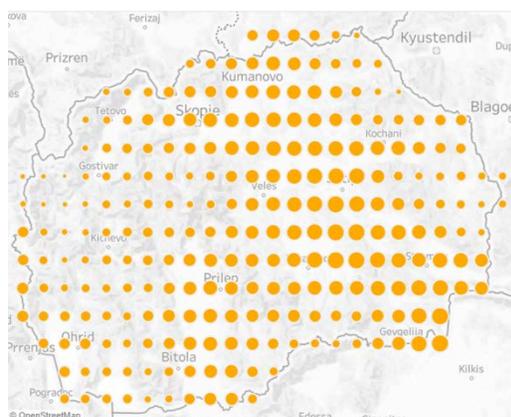


Spatial distribution of different cattle' THI loads in three periods under RCP 8.5 scenario

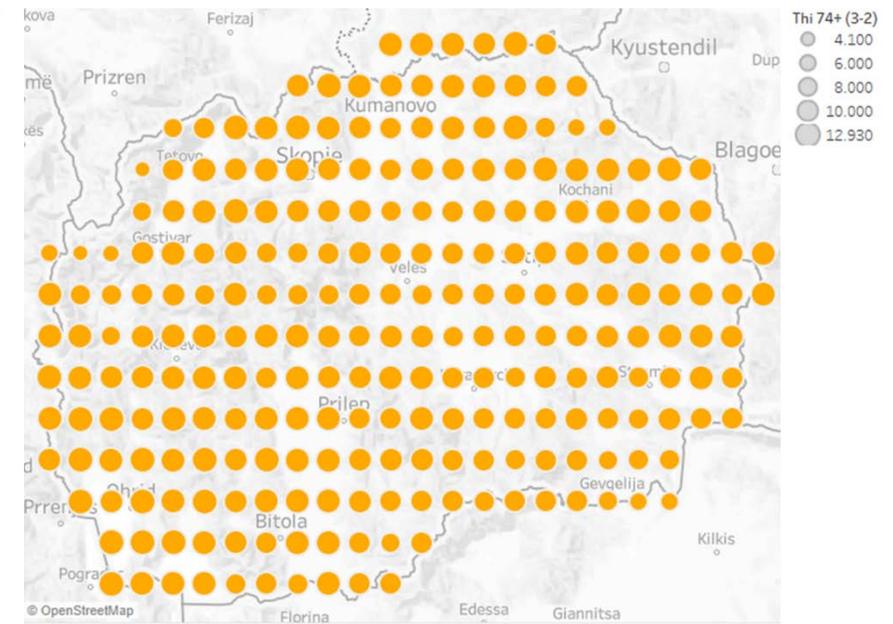
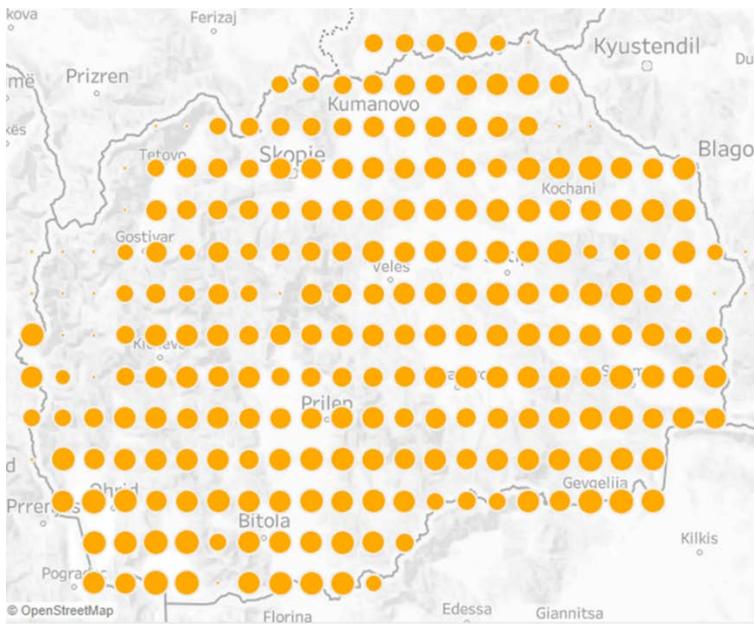
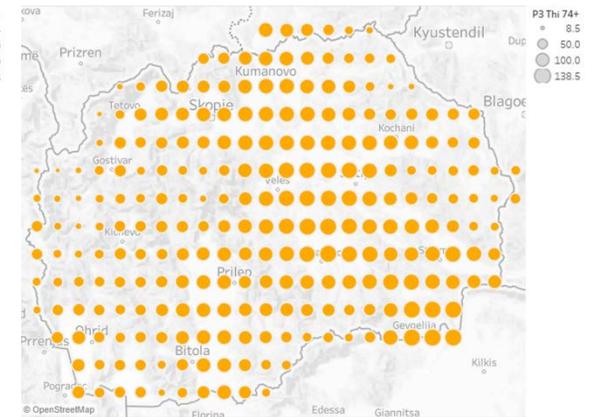
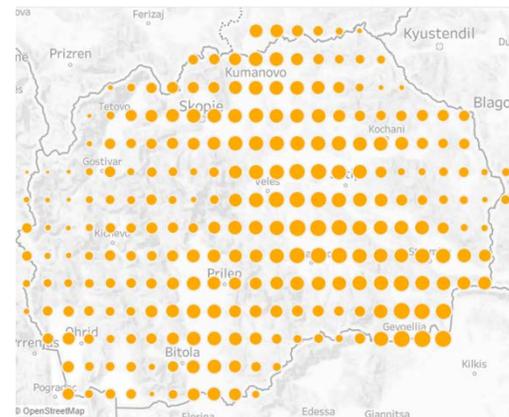
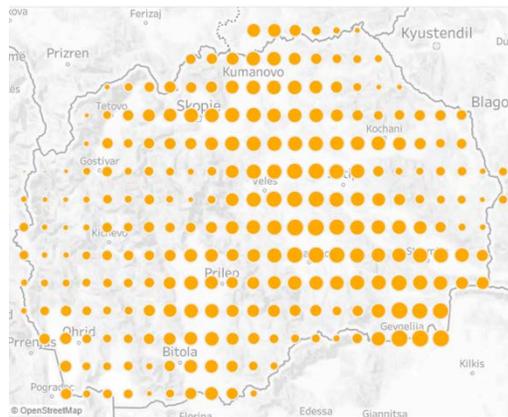
**Appendix 2:** Spatial distribution of the 74+ THI loads for cattle for three periods (P1:1986 -2015; P2: 2016-2045; P3: 2046-2075), and their differences under RCP 2.6, RCP 4.5, and RCP 8.5



Spatial distribution of THI loads above alert phase in cattle under RCP 2.6 scenario

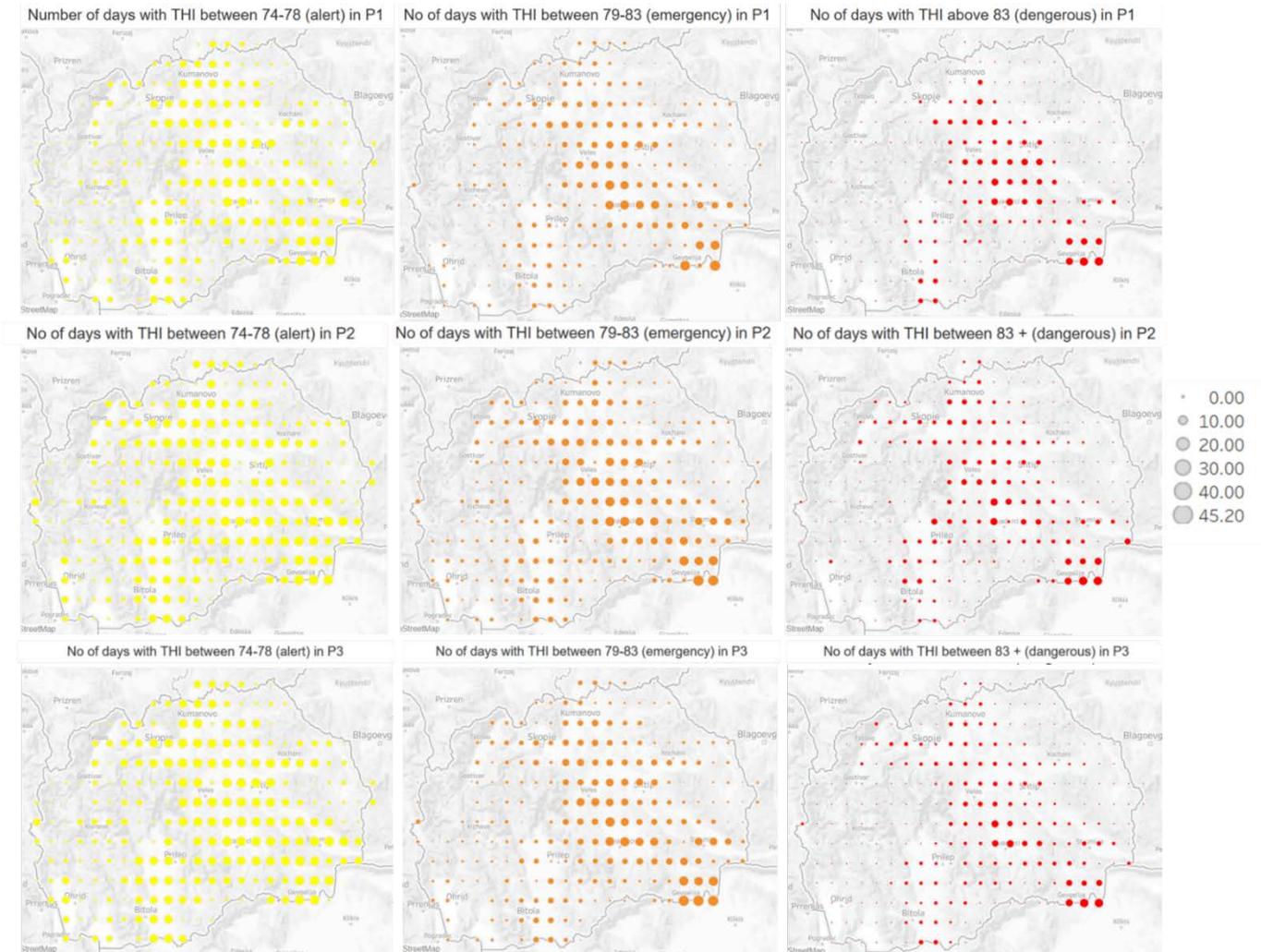


Spatial distribution of THI loads above alert phase in cattle under RCP 4.5 scenario

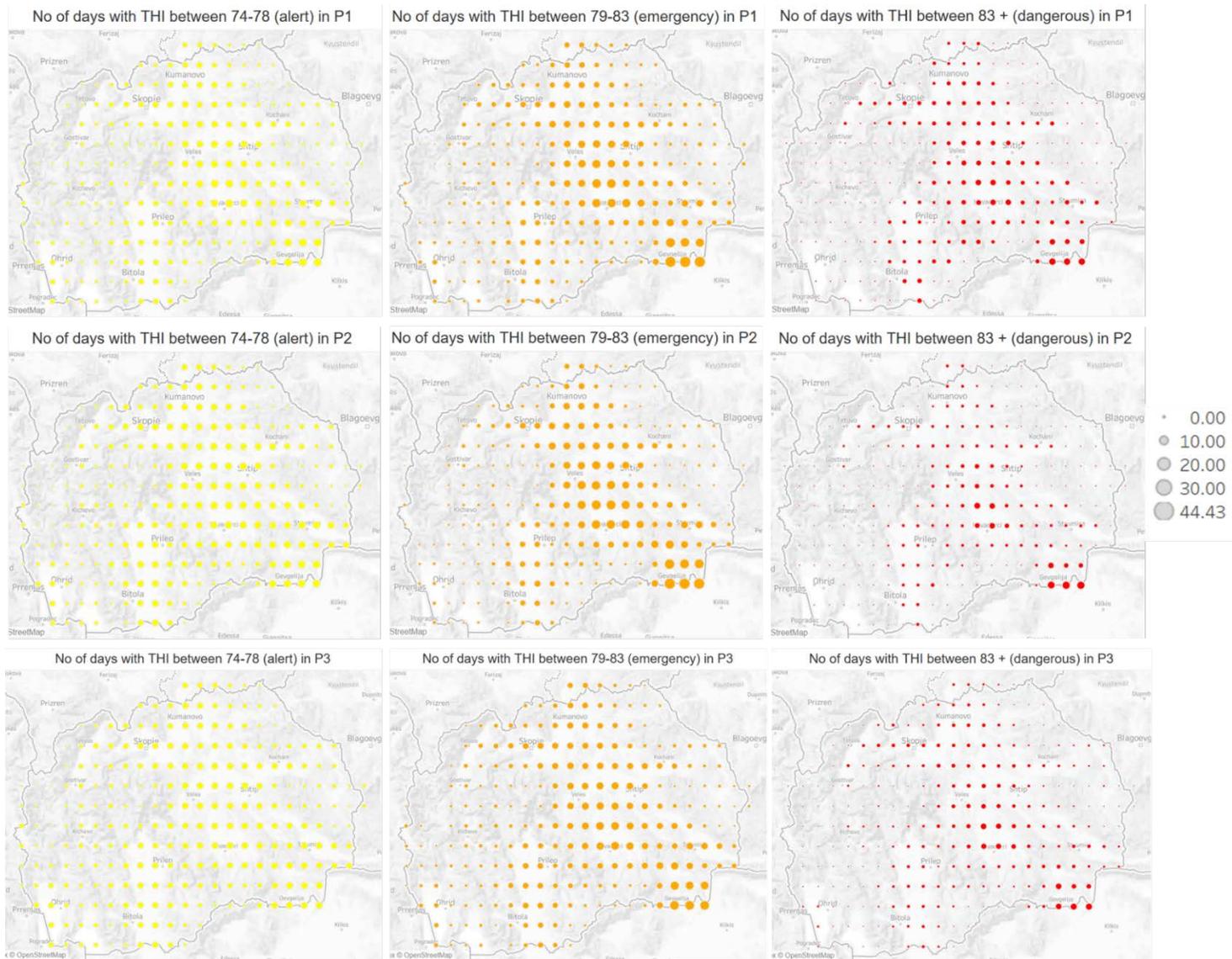


Spatial distribution of THI loads above alert phase in cattle under RCP 8.5 scenario

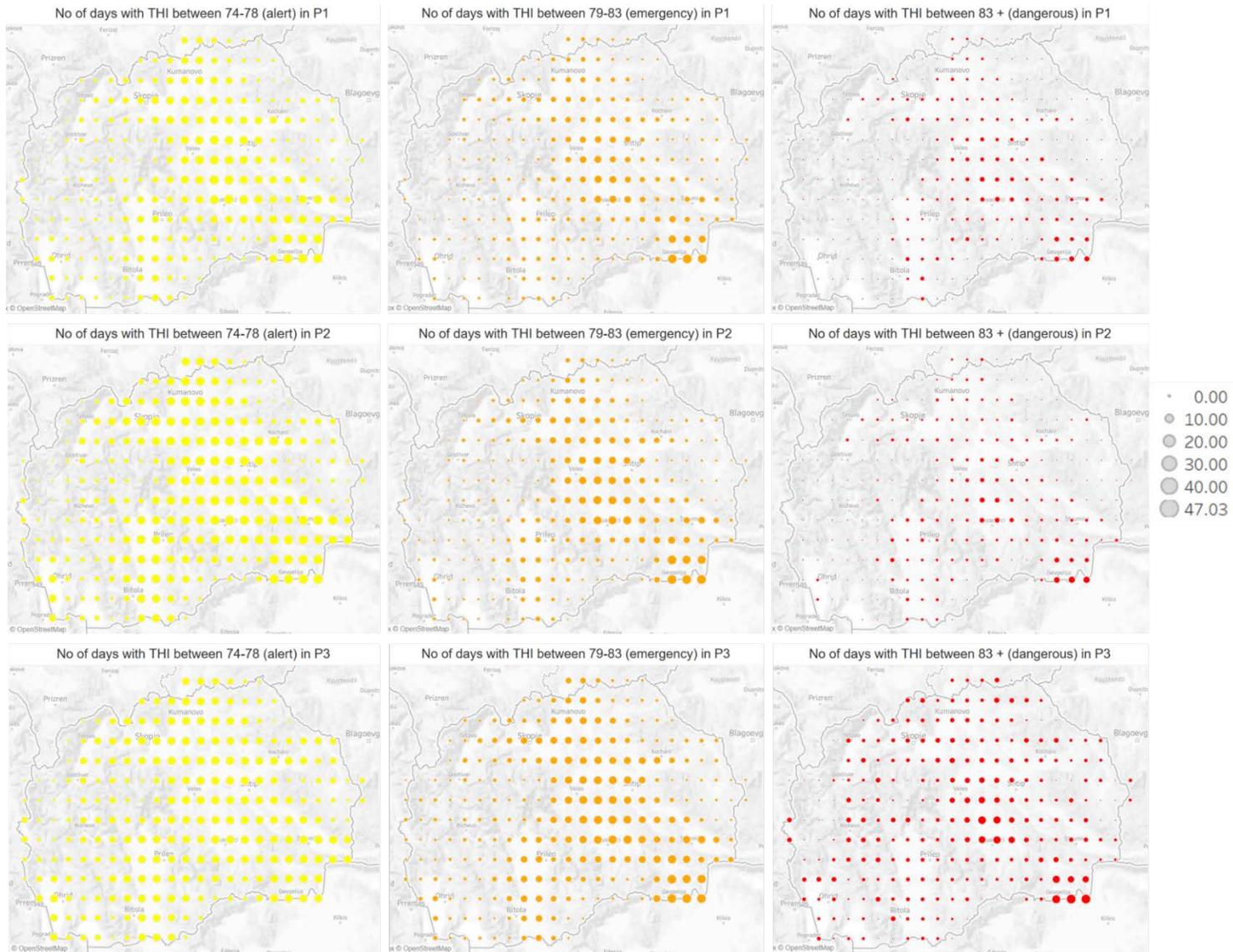
**Appendix 3:** Spatial distribution of three different THI loads (74-78; 78-83, 83+) for pigs for three periods (P1:1986 -2015; P2: 2016-2045; P3: 2046-2075) under RCP 2.6, RCP 4.5, and RCP 8.5



Spatial distribution of different pigs' THI loads in three periods under RCP 2.6 scenario

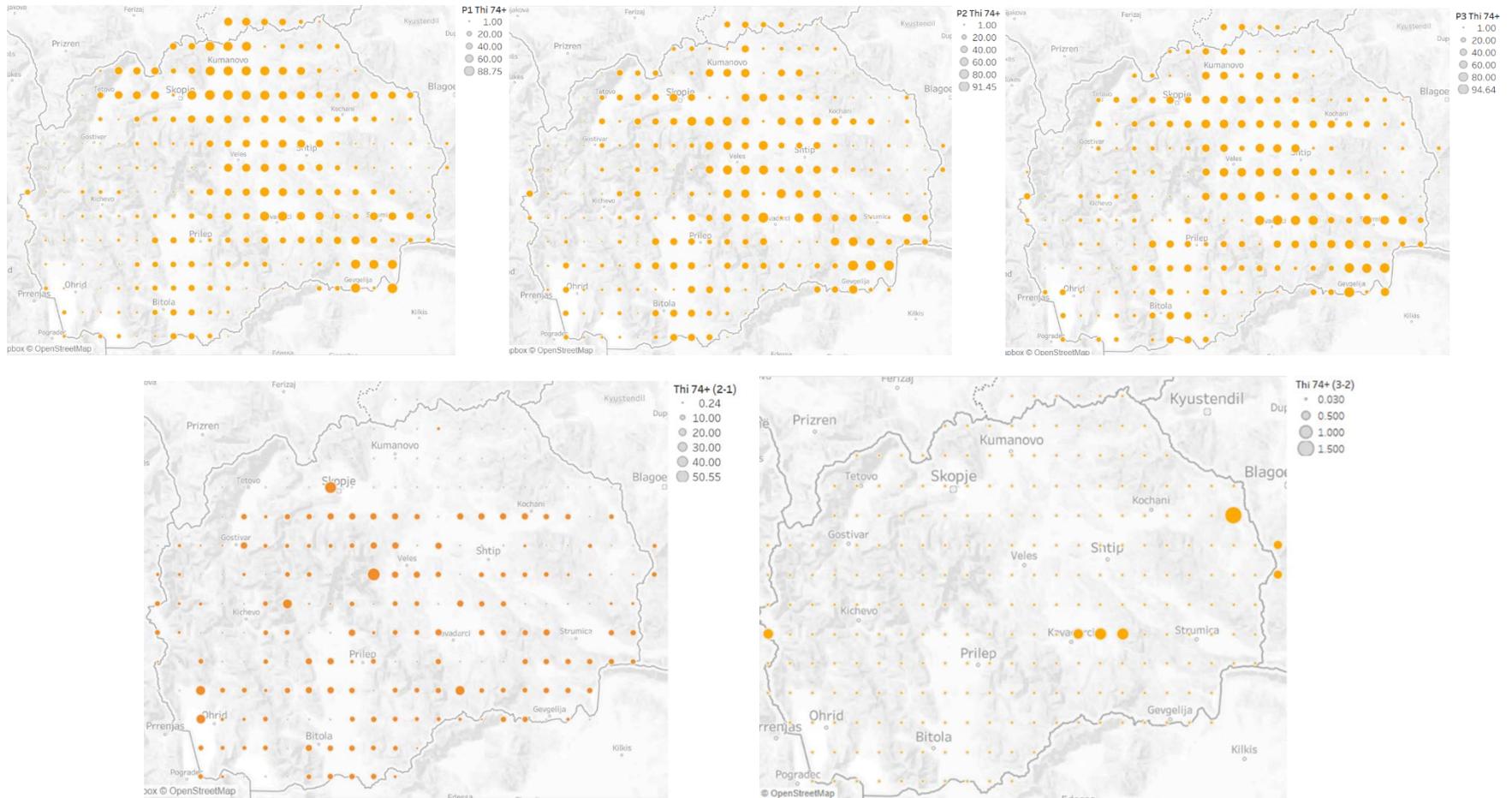


Spatial distribution of different pigs' THI loads in three periods under RCP 4.5 scenario

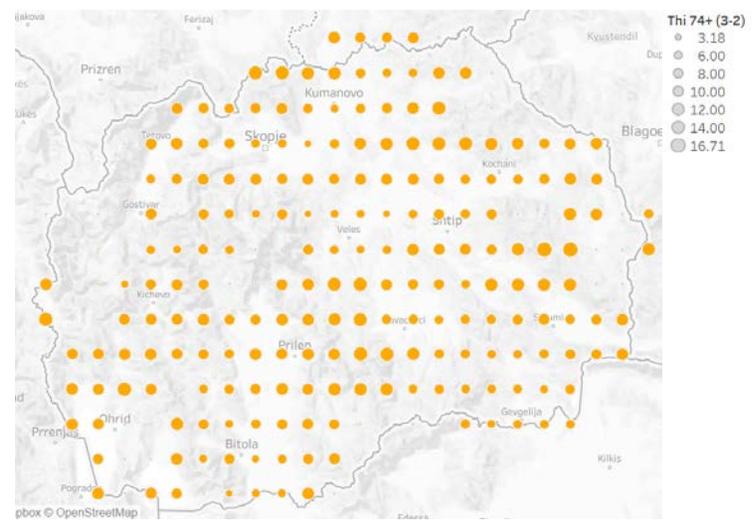
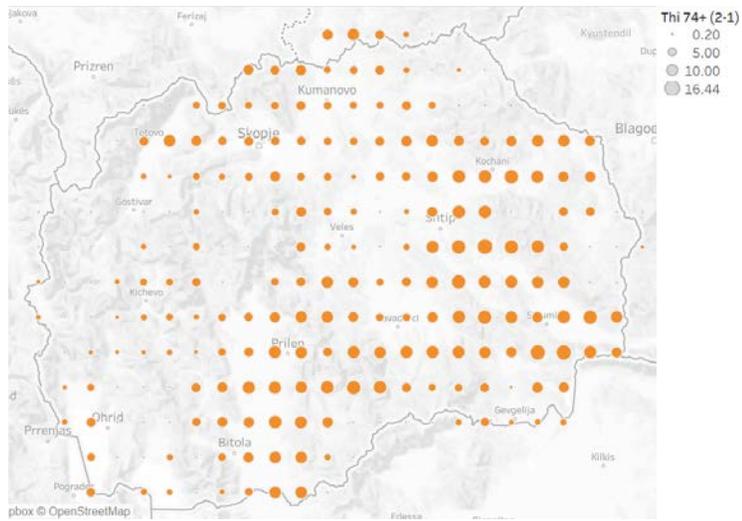
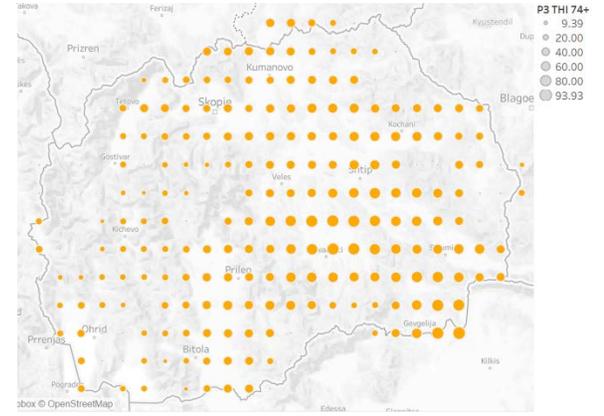
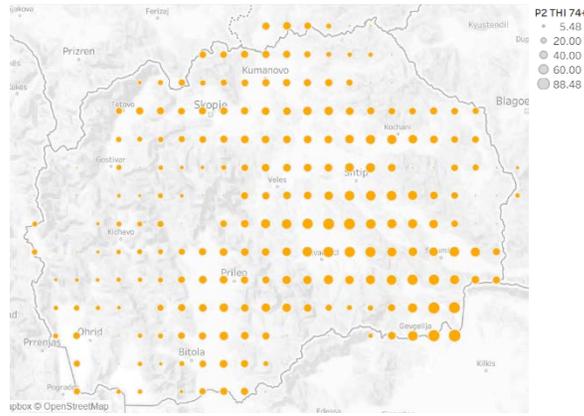
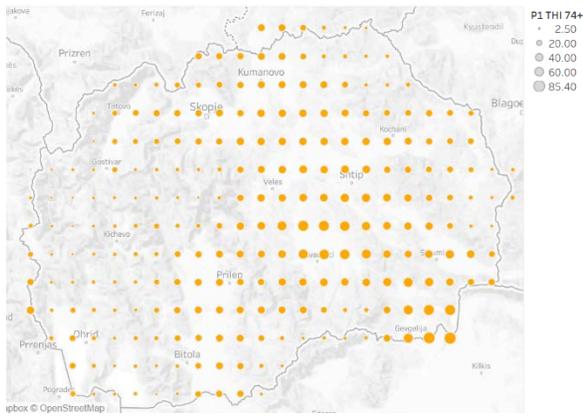


Spatial distribution of different pigs' THI loads in three periods under RCP 8.5 scenario

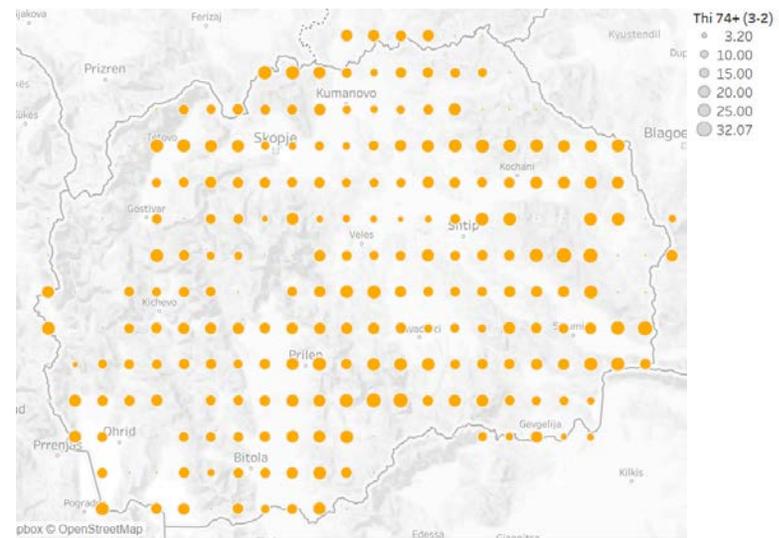
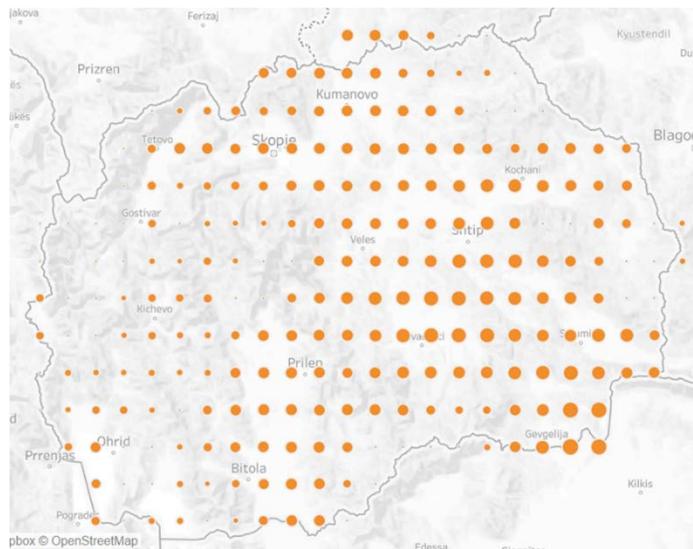
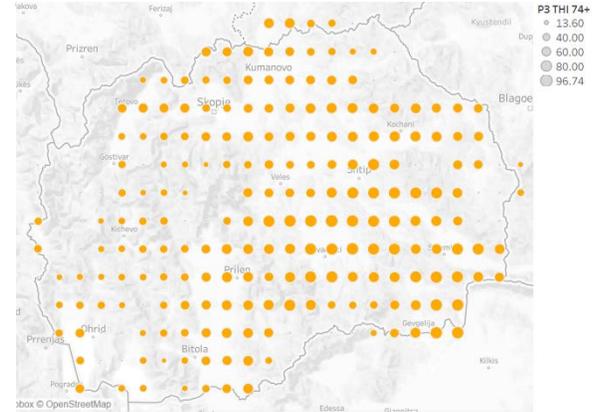
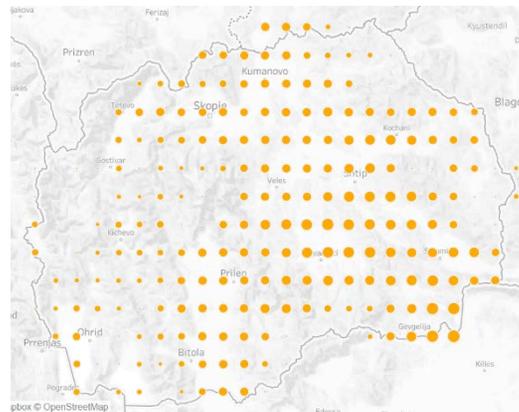
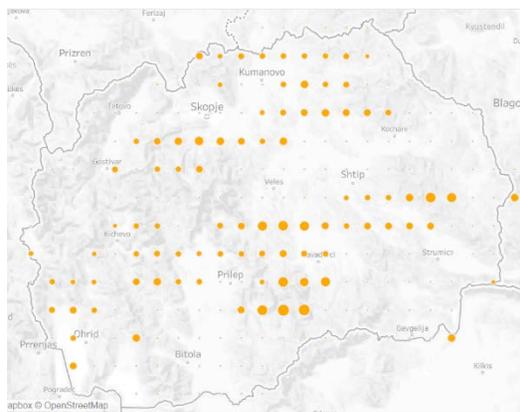
Appendix 4: Spatial distribution of the 74+ THI loads for pigs for three periods (P1:1986 -2015; P2: 2016-2045; P3: 2046-2075), and their differences under RCP 2.6, RCP 4.5, and RCP 8.5



Spatial distribution of THI loads above alert phase in pigs under RCP 2.6 scenario



Spatial distribution of THI loads above alert phase in pigs under RCP 4.5 scenario



Spatial distribution of THI loads above alert phase in pigs under RCP 8.5 scenario

*Annex III Livelihood Vulnerability Index*

**Annex 1. Sub-components standardized values, per municipality**

Components	ADAPTIVE CAPACITY										SENSITIVITY			EXPOSURE		
	Socio-demographic profile								Social networks		H	F	W	S	HP	T
Municipality	PO	DR	SI	HC	HCA	I	FC	NR	G	AG						
Skopje	0.757	0.727	0.000	0.057	0.306	0.408	0.286	0.585	0.000	0.646	0.333	0.653	0.599	0.519	0.656	0.714
Arachinovo	0.183	0.776	0.921	0.753	0.831	0.653	0.587	0.333	1.000	0.895	0.657	0.664	0.686	0.569	0.618	0.641
Berovo	0.168	0.605	0.949	0.593	0.408	0.732	0.692	0.371	0.960	0.748	0.665	0.759	0.885	0.479	0.377	0.104
Bitola	0.178	0.699	0.787	0.466	0.408	0.690	0.632	0.516	0.809	0.722	0.637	0.650	0.546	0.251	0.567	0.558
Bogdantsi	0.150	0.635	0.948	0.621	0.499	0.723	0.832	0.413	0.968	0.890	0.665	0.463	0.253	0.382	0.553	0.953
Bogovinje	0.160	0.671	0.931	0.736	0.752	0.555	0.872	0.451	0.960	0.933	0.656	0.648	0.104	0.174	0.616	0.765
Bosilovo	0.248	0.487	0.967	0.718	0.797	0.659	0.808	0.525	0.980	0.945	0.667	0.585	0.293	0.560	0.679	0.672
Brvenitsa	0.103	0.573	0.954	0.738	0.568	0.663	0.863	0.418	0.992	0.943	0.664	0.650	0.178	0.185	0.591	0.713
Valandovo	0.154	0.739	0.960	0.655	0.603	0.712	0.807	0.442	0.972	0.887	0.664	0.511	0.250	0.417	0.530	1.000
Vasilevo	0.213	0.612	0.967	0.772	0.750	0.669	0.826	0.463	0.984	0.936	0.664	0.448	0.268	0.574	0.554	0.821
Vevchani	0.130	0.638	0.951	0.668	0.465	0.709	0.757	0.384	0.984	0.884	0.665	0.811	0.379	0.380	0.483	0.599
Veles	0.158	0.749	0.857	0.595	0.433	0.692	0.706	0.487	0.900	0.858	0.653	0.778	0.731	0.629	0.580	0.598
Vinitsa	0.189	0.704	0.939	0.662	0.552	0.697	0.720	0.420	0.976	0.851	0.661	0.608	0.676	0.554	0.552	0.611
Vrapchishte	0.268	0.500	0.930	0.726	0.618	0.665	0.871	0.454	0.980	0.942	0.659	0.625	0.145	0.181	0.616	0.736
Gevgelija	0.184	0.821	0.926	0.553	0.442	0.729	0.801	0.437	0.968	0.843	0.656	0.481	0.165	0.358	0.509	0.991
Gostivar	0.302	0.625	0.828	0.669	0.492	0.580	0.848	0.547	0.896	0.853	0.629	0.662	0.160	0.263	0.608	0.734
Gradsko	0.155	0.581	0.987	0.756	0.687	0.730	0.734	0.382	0.996	0.954	0.666	0.619	0.632	0.467	0.639	0.733
Debar	0.167	0.631	0.900	0.679	0.579	0.496	0.744	0.398	0.968	0.865	0.653	0.770	0.483	0.408	0.587	0.686
Debartsa	0.325	0.018	0.987	0.813	0.591	0.695	0.701	0.465	0.980	0.886	0.669	0.798	0.468	0.362	0.460	0.411
Delchevo	0.214	0.707	0.942	0.616	0.495	0.678	0.713	0.383	0.964	0.855	0.662	0.846	0.795	0.485	0.537	0.344
Demir Kapija	0.197	0.862	0.984	0.803	0.569	0.701	0.758	0.389	0.988	0.954	0.666	0.623	0.460	0.352	0.588	0.875
Demir Hisar	0.192	0.362	0.970	0.716	0.539	0.669	0.761	0.470	0.956	0.875	0.667	0.736	0.701	0.384	0.541	0.507
Dojran	0.216	0.584	0.989	0.655	0.628	0.732	0.833	0.360	0.988	0.861	0.666	0.540	0.365	0.462	0.641	0.709
Dolneni	0.157	0.506	0.958	0.791	0.737	0.699	0.726	0.547	0.980	0.856	0.663	0.721	0.819	0.197	0.569	0.429
Zhelino	0.114	0.393	0.944	0.761	0.672	0.633	0.875	0.455	0.992	0.951	0.655	0.654	0.242	0.312	0.580	0.688
Zelenikovo	0.039	1.000	0.985	0.716	0.640	0.692	0.567	0.410	1.000	0.978	0.663	0.637	0.722	0.564	0.711	0.780
Zrnovtsi	0.141	0.367	0.972	0.722	0.701	0.581	0.724	0.401	0.992	0.904	0.667	0.618	0.614	0.355	0.554	0.713
Ilinden	0.127	0.654	0.934	0.708	0.647	0.379	0.568	0.422	0.996	0.976	0.663	0.663	0.683	0.454	0.585	0.667
Jegunovtse	0.082	0.378	0.973	0.753	0.606	0.695	0.863	0.448	0.972	0.946	0.667	0.650	0.298	0.295	0.582	0.669
Kavadartsi	0.183	0.829	0.870	0.592	0.246	0.612	0.724	0.419	0.932	0.879	0.650	0.571	0.570	0.697	0.563	0.745
Karbintsi	0.309	0.792	0.986	0.845	0.680	0.681	0.668	0.410	0.992	0.904	0.667	0.722	0.816	0.293	0.541	0.706
Kichevo	0.126	0.624	0.894	0.767	0.278	0.569	0.733	0.554	0.932	0.684	0.655	0.725	0.475	0.339	0.304	0.341

<b>Konche</b>	0.076	0.249	0.988	0.811	0.816	0.681	0.758	0.414	0.988	0.864	0.666	0.715	0.476	0.393	0.605	0.656
<b>Kochani</b>	0.207	0.731	0.879	0.610	0.468	0.660	0.703	0.488	0.940	0.645	0.654	0.573	0.698	0.278	0.548	0.743
<b>Kratovo</b>	0.201	0.674	0.965	0.826	0.679	0.655	0.769	0.430	0.976	0.955	0.666	0.857	0.876	0.720	0.590	0.615
<b>Kriva Palanka</b>	0.185	0.864	0.939	0.773	0.644	0.661	0.792	0.449	0.976	0.781	0.664	0.759	0.753	0.779	0.477	0.450
<b>Krivogashtani</b>	0.177	0.474	0.984	0.742	0.664	0.740	0.732	0.426	0.988	0.904	0.667	0.624	0.605	0.004	0.590	0.504
<b>Krushevo</b>	0.146	0.514	0.967	0.678	0.685	0.699	0.782	0.418	1.000	0.892	0.664	0.662	0.725	0.254	0.564	0.500
<b>Kumanovo</b>	0.216	0.679	0.786	0.644	0.442	0.694	0.732	0.603	0.900	0.886	0.620	0.808	0.876	0.567	0.578	0.577
<b>Lipkovo</b>	0.180	0.576	0.934	0.777	0.523	0.610	0.790	0.516	0.964	0.996	0.654	0.655	0.717	0.425	0.594	0.557
<b>Lozovo</b>	0.202	0.538	0.992	0.775	0.800	0.642	0.715	0.377	0.988	0.953	0.667	0.773	0.625	0.365	0.549	0.674
<b>Mavrovo and Rostusha</b>	0.141	0.236	0.971	0.756	0.613	0.667	0.883	0.394	0.948	0.781	0.664	0.565	0.328	0.455	0.407	0.538
<b>Makedonska Kamenitsa</b>	0.280	0.515	0.953	0.688	0.829	0.658	0.743	0.397	0.972	0.883	0.666	0.698	0.694	0.630	0.603	0.566
<b>Makedonski Brod</b>	0.225	0.723	0.975	0.741	0.660	0.657	0.739	0.418	1.000	0.838	0.666	0.768	0.488	0.527	0.375	0.462
<b>Mogila</b>	0.157	0.352	0.981	0.796	0.719	0.695	0.652	0.480	0.992	0.913	0.668	0.664	0.703	0.192	0.587	0.503
<b>Negotino</b>	0.225	0.791	0.934	0.616	0.419	0.717	0.742	0.426	0.972	0.836	0.657	0.595	0.458	0.466	0.639	0.828
<b>Novatsi</b>	0.170	0.553	0.991	0.777	0.721	0.640	0.683	0.402	0.956	0.913	0.668	0.709	0.772	0.443	0.572	0.580
<b>Novo Selo</b>	0.231	0.280	0.969	0.720	0.822	0.686	0.816	0.498	0.992	0.948	0.668	0.426	0.242	0.550	0.662	0.442
<b>Ohrid</b>	0.276	0.666	0.862	0.594	0.423	0.665	0.730	0.419	0.873	0.828	0.643	0.793	0.470	0.350	0.505	0.609
<b>Petrovets</b>	0.087	0.748	0.971	0.750	0.661	0.703	0.568	0.393	0.996	0.976	0.662	0.688	0.721	0.452	0.611	0.645
<b>Pehchevo</b>	0.166	0.507	0.974	0.626	0.558	0.677	0.691	0.378	0.964	0.874	0.666	0.753	0.864	0.515	0.324	0.069
<b>Plasnitsa</b>	0.182	0.472	0.949	0.849	0.729	0.716	0.753	0.399	1.000	0.889	0.665	0.784	0.602	0.271	0.601	0.664
<b>Prilep</b>	0.122	0.649	0.834	0.536	0.324	0.652	0.735	0.571	0.928	0.748	0.649	0.732	0.572	0.269	0.559	0.465
<b>Probishtip</b>	0.178	0.834	0.937	0.630	0.571	0.716	0.722	0.447	0.968	0.778	0.665	0.749	0.912	0.481	0.597	0.651
<b>Radovish</b>	0.113	0.779	0.925	0.669	0.584	0.709	0.813	0.487	0.960	0.871	0.655	0.644	0.397	0.291	0.567	0.801
<b>Rankovtse</b>	0.338	0.565	0.983	0.949	0.894	0.656	0.764	0.389	0.992	0.998	0.667	0.846	0.738	0.661	0.604	0.665
<b>Resen</b>	0.198	0.844	0.952	0.625	0.266	0.689	0.774	0.448	0.940	0.488	0.664	0.727	0.408	0.456	0.354	0.384
<b>Rosoman</b>	0.180	0.706	0.985	0.748	0.513	0.722	0.724	0.399	0.980	0.945	0.666	0.580	0.331	0.540	0.663	0.601
<b>Sopishte</b>	0.103	0.727	0.982	0.681	0.586	0.718	0.588	0.384	0.992	0.980	0.662	0.659	0.676	0.801	0.523	0.533
<b>Sveti Nikole</b>	0.187	0.573	0.938	0.663	0.497	0.706	0.529	0.507	0.984	0.694	0.665	0.733	0.775	0.337	0.561	0.710
<b>Staro Nagorichane</b>	0.150	0.120	0.988	0.999	0.662	0.638	0.609	0.440	0.988	0.999	0.669	0.836	0.942	0.688	0.590	0.598
<b>Struga</b>	0.265	0.603	0.863	0.671	0.415	0.608	0.711	0.546	0.817	0.824	0.634	0.768	0.464	0.219	0.523	0.575
<b>Strumitsa</b>	0.237	0.697	0.856	0.585	0.554	0.712	0.795	0.511	0.892	0.551	0.634	0.369	0.317	0.523	0.673	0.774
<b>Studenichani</b>	0.037	0.859	0.944	0.761	0.680	0.686	0.590	0.371	0.980	0.978	0.646	0.668	0.620	0.627	0.653	0.711
<b>Teartse</b>	0.107	0.777	0.928	0.736	0.541	0.610	0.868	0.462	0.976	0.951	0.659	0.622	0.079	0.316	0.610	0.701
<b>Tetovo</b>	0.233	0.834	0.766	0.613	0.565	0.588	0.842	0.468	0.773	0.825	0.603	0.712	0.147	0.145	0.606	0.781
<b>Centar Zhupa</b>	0.094	0.000	0.975	0.764	0.837	0.708	0.746	0.380	0.992	0.888	0.664	0.762	0.442	0.465	0.507	0.569
<b>Chashka</b>	0.171	0.482	0.976	0.844	0.763	0.698	0.745	0.421	0.972	0.954	0.661	0.672	0.639	0.618	0.541	0.398
<b>Cheshinovo-Obleshevo</b>	0.206	0.650	0.979	0.713	0.588	0.710	0.679	0.444	0.992	0.902	0.669	0.514	0.652	0.342	0.541	0.718
<b>Chucher-Sandevo</b>	0.035	0.863	0.966	0.701	0.693	0.661	0.575	0.365	0.988	0.977	0.662	0.706	0.611	0.604	0.580	0.659
<b>Shtip</b>	0.181	0.795	0.834	0.524	0.403	0.658	0.694	0.483	0.964	0.770	0.647	0.776	0.888	0.413	0.551	0.761
<i>Mean</i>	0.185	0.611	0.925	0.699	0.592	0.664	0.731	0.442	0.950	0.870	0.654	0.674	0.546	0.427	0.561	0.626

<i>Min</i>	0.035	0.000	0.000	0.057	0.246	0.379	0.286	0.333	0.000	0.488	0.333	0.369	0.079	0.004	0.304	0.069
<i>Max</i>	0.757	1.000	0.992	0.999	0.894	0.740	0.883	0.603	1.000	0.999	0.669	0.857	0.942	0.801	0.711	1.000
<i>StDev</i>	0.094	0.199	0.124	0.121	0.148	0.066	0.100	0.059	0.123	0.102	0.040	0.104	0.228	0.161	0.079	0.168
<i>Variation</i>	50.5%	32.6%	13.4%	17.3%	25.0%	9.9%	13.7%	13.3%	12.9%	11.7%	6.2%	15.4%	41.8%	37.8%	14.1%	26.8%

**Annex 2. Ranking based on different indices, average of indices rank and indices value**

Component	Ranking (different indices)			Ranking (average of indices rank)	Ranking (average of indices value)
	LVI <sub>m</sub>	AVI	LVI IPCC		
Municipality					
Skopje	71	70	68	71	71
Arachinovo	21	16	7	14	14
Berovo	37	62	69	60	69
Bitola	65	65	65	68	66
Bogdantsi	68	60	38	58	58
Bogovinje	42	42	37	40	37
Bosilovo	41	24	9	22	21
Brvenitsa	49	56	48	55	53
Valandovo	61	44	24	44	42
Vasilevo	64	53	25	48	46
Vevchani	17	28	52	29	31
Veles	12	9	15	10	12
Vinitsa	44	37	33	36	34
Vrapchishte	50	54	40	51	48
Gevgelija	67	61	42	61	59
Gostivar	55	47	41	50	47
Gradsko	32	20	13	19	18
Debar	24	21	31	23	23
Debartsa	25	46	64	45	56
Delchevo	6	18	54	24	24
Demir Kapija	26	22	11	18	16
Demir Hisar	27	36	55	37	40
Dojran	59	41	27	42	41
Dolneni	13	40	59	34	39
Zhelino	45	43	39	42	45
Zelenikovo	19	4	3	5	4
Zrnovtsi	57	48	46	54	51
Ilinden	43	31	35	33	35
Jegunovtse	48	50	44	48	49
Kavadartsi	62	39	23	41	36
Karbintsi	5	15	19	12	10
Kichevo	58	71	71	70	70
Konche	31	25	29	26	26
Kochani	63	59	56	64	60
Kratovo	2	2	2	2	2
Kriva Palanka	4	7	10	4	5
Krivogashtani	47	63	63	62	62
Krushevo	36	52	58	52	52
Kumanovo	7	5	14	5	8
Lipkovo	29	30	34	27	28
Lozovo	8	13	20	13	13
Mavrovo and Rostusha	66	69	62	69	67
Makedonska Kamenitsa	14	10	6	8	9
Makedonski Brod	11	32	53	28	32
Mogila	39	55	60	56	54
Negotino	53	27	17	29	27
Novatsi	16	23	28	21	22
Novo Selo	69	67	50	66	62

<b>Ohrid</b>	28	34	57	38	42
<b>Petrovets</b>	20	17	18	17	17
<b>Pehchevo</b>	33	64	70	59	68
<b>Plasnitsa</b>	9	14	22	15	15
<b>Prilep</b>	51	57	66	63	61
<b>Probishtip</b>	10	6	12	7	7
<b>Radovish</b>	40	35	30	32	29
<b>Rankovtse</b>	1	1	1	1	1
<b>Resen</b>	56	66	67	67	65
<b>Rosoman</b>	54	38	21	35	30
<b>Sopishte</b>	30	19	16	19	20
<b>Sveti Nikole</b>	34	26	43	31	33
<b>Staro Nagorichane</b>	3	3	4	3	3
<b>Struga</b>	38	51	61	53	57
<b>Strumitsa</b>	70	68	47	65	64
<b>Studenichani</b>	22	8	5	9	6
<b>Teartse</b>	52	49	36	46	44
<b>Tetovo</b>	46	45	49	47	50
<b>Centar Zhupa</b>	35	33	51	38	38
<b>Chashka</b>	23	29	32	25	25
<b>Cheshinovo-Obleshevo</b>	60	58	45	57	55
<b>Chucher-Sandevo</b>	18	11	8	11	11
<b>Shtip</b>	15	12	26	16	19