Gefördert durch:

Bundesministerium für Ernährung und Landwirtschaft

aufgrund eines Beschlusses des Deutschen Bundestages

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GFA CONSULTING GROUP
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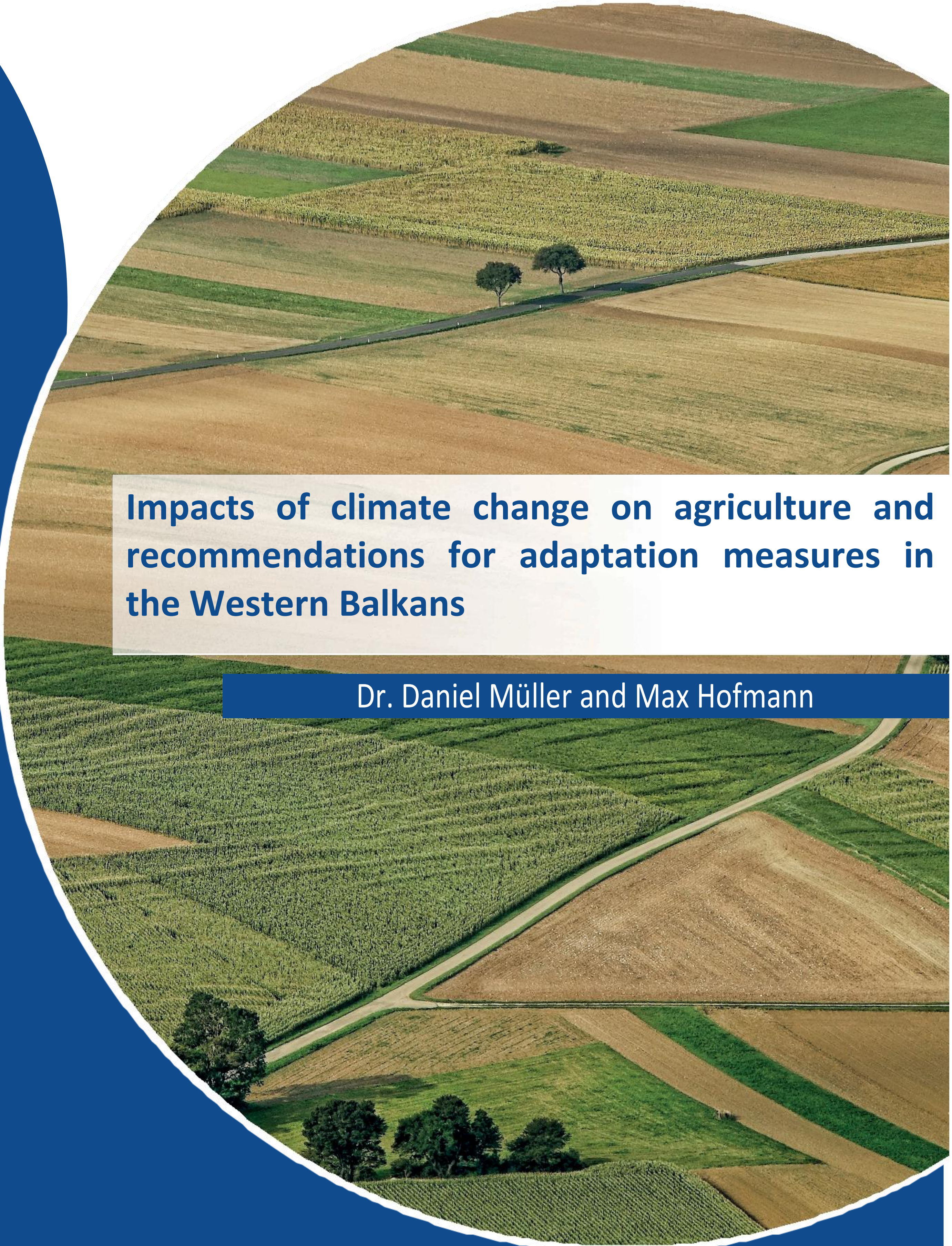

Impacts of climate change on agriculture and recommendations for adaptation measures in the Western Balkans

Dr. Daniel Müller and Max Hofmann

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July 8, 2022

Authors

Dr. Daniel Müller

Max Hofmann

Leibniz Institute of Agricultural Development in Transition Economies (IAMO),

Theodor-Lieser-Str. 2, 06120 Halle (Saale)

Correspondence address:

Dr. Daniel Müller (mueller@iamo.de)
Max Hofmann (hofmann@iamo.de)

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Content

Disclaimer

This report was prepared for the bilateral cooperation programme (BKP) of the German Federal Ministry of Food and Agriculture (BMEL) implemented by the GFA Consulting Group GmbH. The report intends to support the Regional Rural Development Working Group (SWG) in its mission to foster sustainable development and rural livelihoods in Southeast Europe. The report contributes to the portfolio of the Agricultural Policy Dialogue (APD) of the BMEL/GFA that has been established by the German government to support the SWG.

The report features a regional study that covers the six countries of the Western Balkan region. It provides an overview of the likely impacts posed by climate change to agriculture in the region and highlights approaches to respond and adapt to the challenges posed by climate change. Throughout the entire report, we mainly focus on crop production as, to the best of our knowledge, peer-reviewed international studies about the impacts of climate change on livestock production are largely lacking for the region.

We first screen the regional peer-reviewed scientific studies that were published since 2015 to synthesize the current state of knowledge regarding the impacts of climate change on agriculture in the Western Balkans. Since only few studies of sufficient quality are available for the region, we also include evidence from the first two of the three sixth assessment reports of the IPCC in the literature review. We also added high-level but not peer-reviewed reports, such as from the World Bank and the FAO. Besides, we include a few selected studies that examine the impacts of climate change on crop production in other regions of the Mediterranean, which have similar bioclimatic conditions as the Western Balkans. The second part of this report is to summarize existing data regarding historic climate trends (1992-2020) and future scenarios of climate change (2046-2055 and 2086-2095) for the croplands of the Western Balkans. We highlight both the trends in climatic means, such as mean temperature and total precipitation, and the changes in the occurrence in extreme weather events, such as days with extreme heat, tropical night heat, extreme rainfall events, and frost occurrence. All resulting maps and interactive graphs are available at the following website: https://maxhofmann.shinyapps.io/climate_Western_Balkan/.

Introduction

The Sofia Declaration, signed on Nov 19, 2020, by the Leaders of all Western Balkan countries placed climate change, including to develop resilience against the climatic changes, mitigate greenhouse gas emissions, and adaptation to climate change at the forefront of the Green Agenda for the Western Balkans. In this declaration, the region aligned with the goals of the European Green Deal, including to strive towards carbon neutrality by 2050. The Sofia Declaration acknowledges the necessary preparation of climate adaptation strategies and climate resilience plans for the economies of the Western Balkans. This report aims to shed light on the challenges inherent in attaining higher resilience for the agricultural sector regarding climate change and to provide a basis to develop adaptation strategies.

The Western Balkans includes Albania, Bosnia and Herzegovina, Kosovo[*], Montenegro, North Macedonia, and the Republic of Serbia. The region has almost 700 kilometres of coastline along the Mediterranean. Inland from the coast are the Dinaric Alps with the highest peaks reaching up to almost 3,000 meters above sea level in Northern Albania. Towards the Northeast, the Western Balkan region stretches into the Southwestern part of the Balkan Peninsula.

The value added of the agricultural sector (together with forestry and fishing) amounted to 3.4 billion US$ in 2020 in the Republic of Serbia and 2.9 billion US$ in Albania. Agriculture value added is substantially lower in Bosnia and Herzegovina (1.22 billion US$), North Macedonia (1.12 billion US$), and Kosovo* (0.57 billion US$), and Montenegro (0.36 billion US$, World Bank 2022). The share of agriculture, forestry, and fishing in the national gross domestic product (GDP) in 2020 ranged from 19% in Albania, while it remains below 10% in the other West Balkan countries (World Bank 2022). Agriculture covered between 40% and 50% of the land area in North Macedonia, Bosnia and Herzegovina, the Republic of Serbia, and Albania but only 19% of the territory of Montenegro while data for Kosovo* were lacking (World Bank 2022). Average farm sizes in the region are small, ranging from an average of 6 ha per farm in the Republic of Serbia in 2019, 5.9 ha/farm in Montenegro (2016), 3.2 ha/farm in Kosovo*, 1.8 ha/farm in North Macedonia (2016), and also below 2 ha/farm in Albania (FAO 2018, SWG / EC JRC Project 2022). As a result, a large share of the agricultural sector is oriented towards subsistence production and farm incomes remains low. The climate along the regions' coastal areas along the Mediterranean Sea is characterized by humid, mild winters and dry, warm summers (Knez, Štrbac and Podbregar 2022). The Dinaric Alps have a mountainous climate, influenced by the closeness to the Mediterranean Sea that contributes to higher temperature. The climate in the north-eastern part of the Western Balkans, including in the Republic of Serbia, Kosovo*, and northern Montenegro is moderately continental (Knez et al. 2022).

The Mediterranean, including the Balkan region, is among the global hotspots of climate change with above-average warming and highly vulnerable populations (Diffenbaugh and Giorgi 2012). Historic observations suggest that the Mediterranean region already experienced a particularly fast increase in summer temperatures, a decrease in summer precipitation, and an increase in the number of

[*] *This designation is without prejudice to positions on status, and is in line with UNSC 1244 and the ICJ Opinion on the Kosovo declaration of independence*

consecutive dry days (Cramer et al. 2018, Lionello and Scarascia 2018), all contributing to an increase in overall aridity, particularly during the main stages of plant growth.

Warming in the region has accelerated particularly since the 1980s. For example, in the Tirana region, the increase in mean annual temperature between 1980 and 2020 amounted to about two degrees Celsius (Figure 1). As a result, until 2020 nine of the ten years with highest annual temperatures since 1850 occurred in the decade from 2011 to 2020 (www.BerkeleyEarth.org).

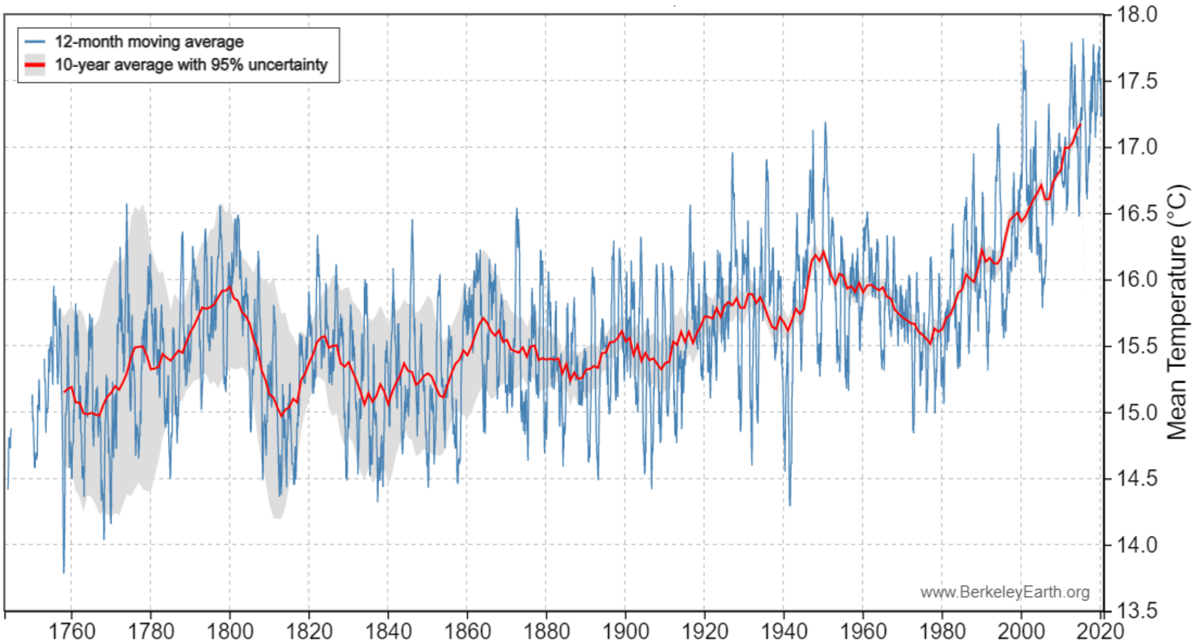

Figure 1: Annual mean temperature recorded from a station located close to Tirana (40.99N, 19.17E), collected from www.BerkeleyEarth.org on Feb. 20, 2022). The patterns are very similar for other major cities in the Western Balkans.

All major simulations of future climate conditions project a temperature increase for the Western Balkans of between 3.5°C (under moderate greenhouse gas emissions) up to 8.8°C for RCP 8.5, the high-emissions scenario, until the end of this century (IPCC 2021). There is very high confidence (which implies, in the terminology of the IPCC, a robust empirical evidence and high agreement across all reviewed studies) that summer temperature will increase more than the terrestrial average at global level; the increase in summer temperatures leads to the increase in the frequency and intensity of heat waves (IPCC 2021).

Evidence of how precipitation will develop in the future under climate change is less clear-cut. Overall, precipitation is likely to continue to decrease in summer, while winter precipitation will likely tend to increase. Importantly, the intensity of precipitation events may alter with climate change and the frequency of extreme rainfall events is likely to increase, although the evidence is not very robust.

Part 1: Literature review about the impacts of future climate change on agriculture

Overall, the general warming trend will continue across the Mediterranean region with temperature increases of between 1°C and 5°C relative to the 1986 to 2005 period. Warming will be strongest in summer (Zittis et al. 2019). Besides, most climate projections suggest an increase in the length of the growing season in the region due to increasing temperatures. Higher heat accumulation will lead to earlier physiological activity of plants and tend to have a positive impact on crop yields if heat does not cross a maximum temperature threshold and if sufficient water is available. However, higher temperatures will also elevate evapotranspiration of plants and thus raise the demand for water. Although water demand of plants will likely increase with climate change, there is a tendency that total precipitation might decrease by between 10% and 40% in the Mediterranean; however, the estimates for the precipitation changes are less significant and robust than those for the temperature changes (Zittis et al. 2019). Other projections confirm a similar range of future decline of precipitation for the Balkan region (Barcikowska, Kapnick and Feser 2018, Tramblay et al. 2020).

Weather anomalies and weather extremes will pose growing risks for crop and livestock production in most of the Mediterranean. Droughts will become more intense and more severe in all scenarios of future climate change (Tramblay et al. 2020). We are, however, not aware of a fine-scale and region-specific assessment of future drought conditions in the Western Balkans. Extreme weather events, such as heat waves, frost, or heavy rainfall during critical phenological stages of the plants will be a growing challenge for farmers in the Balkan region. Weather extremes bring unexpected losses by contributing to crop diseases, causing yield reductions, and by elevating yield variability (Cramer et al. 2018). Profits from farming in the region, particularly when farms are specialized in crop production, have been shown to react sensitive to droughts (Todorović, Ivanović and Bogdanov 2021).

Higher average and maximum temperatures, particularly during summer, will elevate thermal pressure, and hence lead to higher evapotranspiration of plants. This in turn contributes to higher water demand of the crops and hence the need for additional irrigation (Charalampopoulos 2021). Demand for irrigation water will particularly increase during the summer period when plant evapotranspiration will be highest.

The direct effect of climate change on livestock is also important. Higher than optimal temperatures have been shown to adversely affect animal productivity and, in the case of extreme events, such as heat, can lead to elevated mortality rates related to heat stress. However, there is currently limited empirical knowledge on how heat stress affects animal productivity, though empirical evidence from other regions suggest that milk yield will decrease under heat conditions (Liu et al. 2019). Besides, more frequent outbreaks of infections with helminth worm parasites have been observed across Europe (IPCC 2022), and will likely also pose growing risks to livestock production in the Balkans.

Impacts on crop production

Earlier assessments suggested that mean annual precipitation will likely decrease by up to 40% in the Western Balkans until 2100, compared to a reference period 1917 to 2000. At the same time, the intensity and frequency of extreme precipitation is likely to increase, leading to higher likelihood for flooding and landslides (Djurdjevic et al. 2019).

With climate change, crop production will likely expand towards the north and to higher altitudes in the Western Balkans, because of changes in growing season timing and length (Charalampopoulos 2021). Cold extremes are also projected to increase with climate change. In the Western Balkans, all crops, including fruits and vegetables, may suffer from late or early frost events (Charalampopoulos 2021). Impacts of pressure from excessive heat events will likely damage crop yields, particularly in Albania where average temperature are highest during summer (Charalampopoulos 2021). It remains unknown up to now how other extreme events, such as hail, severe storms, or heavy snowfall, will alter with climate change (IPCC 2021).

Warming will also affect olive production, one of the oldest permanently grown crops in the Mediterranean region (Fraga et al. 2020) by increasing irrigation requirements, the risk of heat stress around flowering, and the accumulation of chilling temperatures that are all necessary to ensure a proper flowering (Cramer et al. 2018). Unfortunately, empirical evidence of the impacts of climate change on olive production are lacking. It is however likely that most Mediterranean regions will suffer yield losses and higher yield variability, albeit the pattern in growing areas in the Western Balkan region, mainly in Albania, are less clearcut (Fraga et al. 2020).

Fire occurrence and intensity

The Mediterranean has always been the area in Europe with the highest incidence of wildfires (Knorr et al. 2016). Wildfire occurrence will likely increase with climate change across the entire Mediterranean due to the rise in fire-prone conditions, particularly during summer (Dupuy et al. 2020, Knorr et al. 2016). Summer heat, coupled with longer periods without substantial rainfall, will lead to drier vegetation conditions and elevate the risks for wildfires. However, it remains unclear how non-anthropogenic ignition sources will alter with climate change, e.g., if there will be an increase in lightning.

While higher maximum temperature in summer and lower soil moisture suggest that climate change will contribute to elevated fire occurrence, land use is likely similarly important. Particularly, farmland abandonment and the reduction of forest area and quality increases fuel load, and thus contribute to more and larger wildfires. For Greece, for example, it has been shown that wildfires are likely to become progressively more likely with climate change, depending on the climate scenario. In RCP 8.5, the high-end scenario with ongoing high emissions (the trajectory that humanity is currently on), Greece will experience on average 40 days more per year with high fire risk (Rovithakis et al. 2022).

Part 2: Empirical analysis

Data

1. Crop yields

We have taken stock of publicly available agricultural statistics for the Western Balkans to empirically examine the effects of climate means, such as average temperature and the sum of precipitation, and weather extremes, such as heat waves and frost, on the yields of the major crops planted in the region. Unfortunately, reliable fine-scale time series for yield data are difficult to access for the region. The most consistent database that covers the entire Western Balkans for a period of at least 20 years is, to our knowledge, the FAOSTAT database (https://www.fao.org/faostat/en/). However, FAOSTAT is only available at the national level, does not contain data on Kosovo*, and the data are combined for the Republic of Serbia and Montenegro for the period before the independence of Montenegro in 2006. We hence combine the yield data for Serbia (since 2006) with the yield data for Serbia and Montenegro (from 1992 to 2005) in the subsequent analysis and assume that Kosovo* is included in these time series. Our subsequent analyses include yields for winter wheat and maize for Albania, Bosnia and Herzegovina, North Macedonia, and Serbia (including the territory of Kosovo* and Montenegro) since 1992 and until 2020, the last year that was available in FAOSTAT at the time of writing (Figure 2).

The data suggest a steady rise of crop yields over the study period, with the strongest increases of maize yields in Albania and the Republic of Serbia (Figure 2). Wheat yields increased more modestly in the other countries. Yield variability is high, particularly for maize, and in Bosnia and Herzegovina and the Republic of Serbia, which suggest a substantial effect of weather variations on the yields.

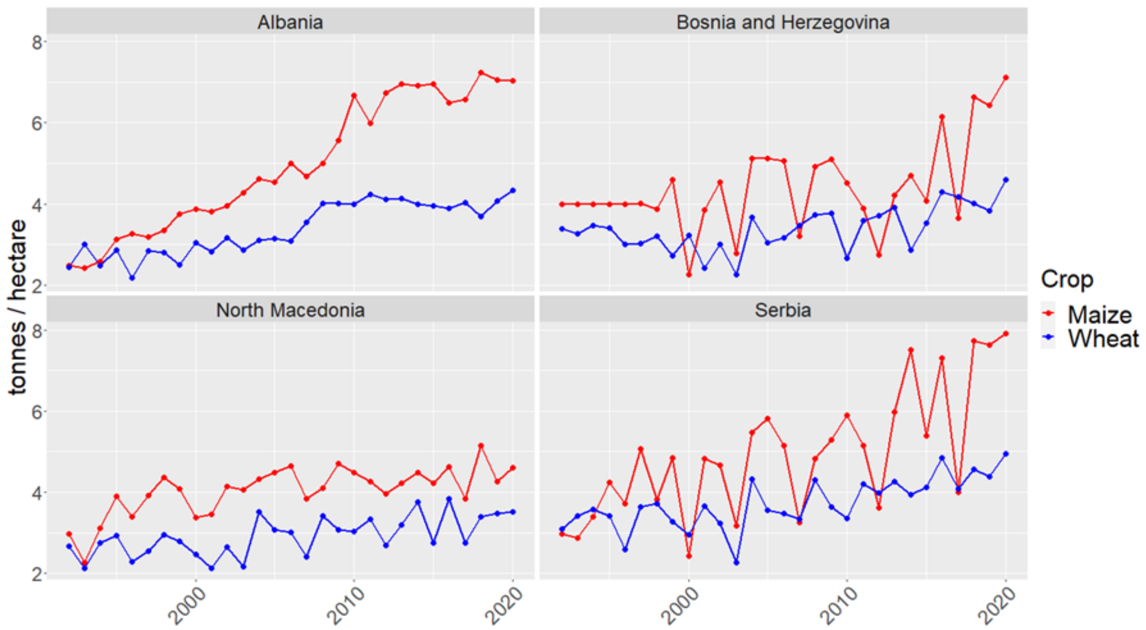

Figure 2: Annual yields of maize and winter wheat in the four Western Balkan countries from 1992 to 2020 (FAO 2022). Note: Yields from the Republic of Serbia have been used after the secession of Montenegro in 2006.

2. Cropland mask

We focus the summary of the historical and future climate and weather variables as well as the yield analysis on areas that are used for crop production. To do so, we used a recent high-resolution cropland mask (Venter and Sydenham 2021). The cropland data relies on a machine learning algorithm that extracted cropland from Sentinel-1 and Sentinel-2 satellite data from 2018 for all of Europe. The resulting land-cover map has a 10-m spatial resolution. The model used ground-truth points from the LUCAS (Land Use/Cover Area Frame Survey) data, which are not available for the countries of the Western Balkans. However, Venter et al. (2021) postulated that the model fit is acceptable for the region because the LUCAS data cover a broad range of environmental conditions, including conditions that prevail in the Western Balkans. We resampled the land-use map of Venter et al. (2021) to a resolution of 1 km^2 and masked the areas that were cropland in 2018 according to the map (Figure 3). We summarized the country-level historical climate and weather data for this cropland mask. We therefore excluded most mountainous areas, areas covered with macchia and forest, as well as urban areas. Unfortunately, we are not aware of maps that detail where on the croplands from the Venter et al. data maize and wheat are grown. We used the cropland mask for the analyses of the yield trends (shown later in Figure 16 to Figure 19). We did not apply the cropland mask for the analysis of historical trends because past cropland coverage may have substantially expanded in some locations and was abandoned in others. We also did not use the cropland mask for the future climate projections because the development of cropland extent is uncertain.

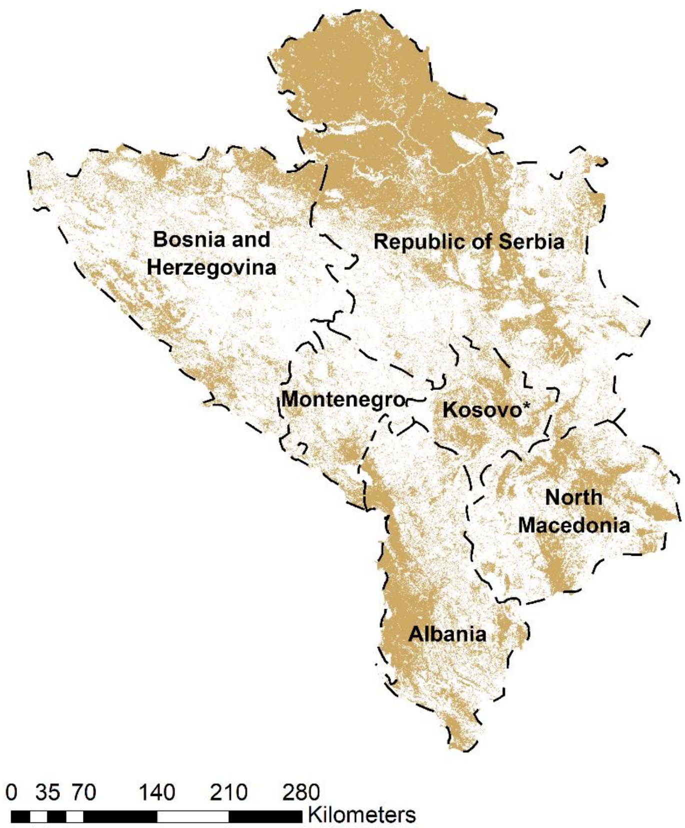

Figure 3: Cropland distribution in the Western Balkan in 2018 from Venter et al. (2021).

3. Crop calendars

We were unable to collect systematic phenological information for many crops for the Western Balkans. We therefore focus on winter wheat and maize, which are the most important grain crops in the Western Balkans and for which we obtained crop-specific calendars from the Foreign Agricultural Service (FAS) of the United States Department of Agriculture (USDA). The phenological data contain country-level averages of planting and harvesting periods for Albania, Bosnia and Herzegovina, North Macedonia, and Serbia (https://ipad.fas.usda.gov/rssiws/al/crop_calendar/europe.aspx). We summarized climate and weather data for the period from planting to harvesting for winter wheat (October to July) and maize (April to October). In this way, we excluded weather impacts during the periods that are less relevant for crop growth.

4. Climatic data

We sourced historical rainfall data from the Climate Hazards group Infrared Precipitation with Stations dataset (CHIRPS, https://data.chc.ucsb.edu/products/CHIRPS-2.0/global_daily/netcdf/p05/). CHIRPS comprises daily gridded estimates based on satellite and weather station data with a spatial resolution of 0.05° (~5 km). We used historical temperature records from the reanalysis dataset ERA5-Land (https://cds.climate. copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land), provided by the climate data store of the Copernicus program and available at a spatial resolution of 0.1° (~11 km) and a temporal resolution of one hour. We used all available data from 1992 to 2020, which corresponds to the period for which yield data are available. Among the gridded climate datasets that are freely available, CHIRPS and ERA5-Land have the highest available spatial and temporal resolution. Moreover, both datasets are continuously updated in near-real time, which permits for updates of our results once new data becomes available.

We analysed climate projections of temperature and precipitation for two future scenarios (RCP 4.5 and RCP 8.5) and for two future periods ("2050", which corresponds to the 10-year average from 2046 to 2055; and "2090", which corresponds to the 10-year average from 2086 to 2095). We obtained these data from the ISIMIP repository (https://data.isimip.org/) and restricted our analysis to the four climate forcing models for which data are available for both future scenarios: GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, and MIROC-5. The datasets are in a gridded format and have a resolution of 0.5 degrees, which in the Western Balkan is equivalent to a cell size of approximately 55 km height x 35 km width. To calculate relative and absolute future climatic changes, we compared the future predictions to the historical baseline model of 1991 to 2005.

We calculated four standard climatic mean variables (minimum, average and maximum temperature, and precipitation) and four extreme weather variables (day heat, night heat, heavy precipitation, and frost) for each yearly growing period of each selected crop. For minimum, average, and maximum temperature, we averaged the daily values of each growing period; for precipitation, we calculated the sum of the daily values within each growing period. To assess day heat, we counted, for each growing period, the number of days when maximum temperature exceeded 35°C. For night heat, we counted the number of days when minimum temperature was above 20°C. Heavy precipitation is equivalent to the number of days when precipitation exceeds 20 mm, and frost events are days when average temperature is below 0°C.

For the historical climate data, we calculated spatial means of all eight variables for each district to obtain maps of historical trends. We also calculated the eight variables on the country level to relate them to the reported yield statistics under consideration of the cropland mask. For the climatic mean variables, we also calculated spatial means; for the extreme weather variables, we counted for each country the number of cropland cells that experienced extreme events. To understand which climatic variables have determined yields in the past, we calculated the Pearson correlation coefficient between annual yields and all eight climatic variables for each crop and each country for which yield statistics were available. Note that more elaborate statistical approaches are not applicable because these would require yield statistics at subnational level and for longer time periods.

Results

Historical climate

1. Long-term climate means

Changes in **average temperature** during the growing season of **maize** reveal an increase of about 1°C to 2°C from 1992 to 2020 across the Western Balkans (Figure 4). Hotspots of higher temperature increase are visible in south-eastern Montenegro, the territory of Kosovo* and the western part of North Macedonia. Temperature increase has historically been less pronounced in the eastern parts of the Western Balkan region.

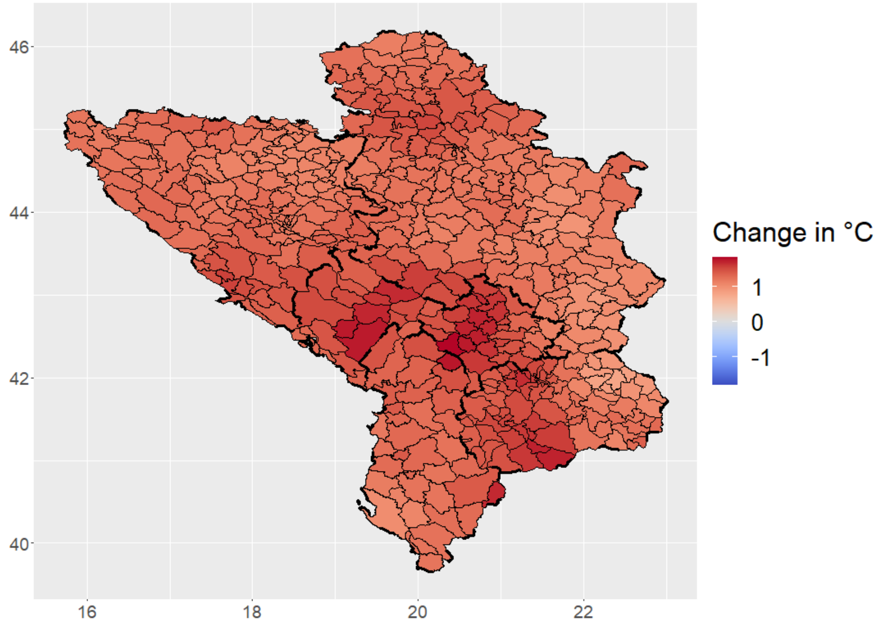

Figure 4: Changes in average temperature from 1992 to 2020 during the growth period of maize (April to October). All historical temperature records stem from the reanalysis dataset ERA5-Land (https://cds.climate. copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land).

Changes in **total precipitation** are more heterogenous across space during the growing period of **maize** (Figure 5). Decreases in precipitation were particularly pronounced in the peaks of the Dinaric Alps on the border between Albania, Kosovo*, and Montenegro and reached up to 300 mm from 1992 to 2020. Along the coast of Bosnia and Herzegovina and in the north-eastern parts of the Western Balkan, precipitation has increased, while in much of southern Albania, eastern parts of Bosnia and Herzegovina, and western Serbia changes have been negative but small.

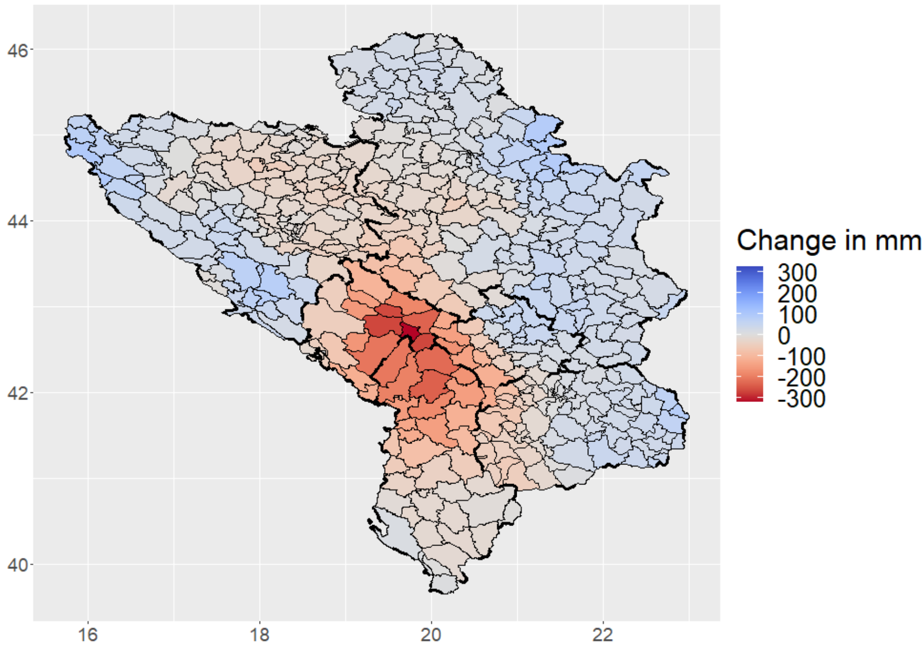

Figure 5: Changes in total precipitation from 1992 to 2020 during the growth period of maize (April to October). All historical rainfall data stem from the Climate Hazards group Infrared Precipitation with Stations dataset (CHIRPS, https://data.chc.ucsb.edu/products/CHIRPS-2.0/global_daily/netcdf/p05/).

The growing period of **winter wheat** lasts from the sowing in October through the winter dormancy until the harvest in July (Figure 6). Changes in **average temperature** for this period have been slightly less pronounced than those for the growing period of maize, which extends over the hotter summer months. Hotspots of temperature increases for winter wheat are eastern Albania, the western part of North Macedonia, and the southern Dinaric Alps.

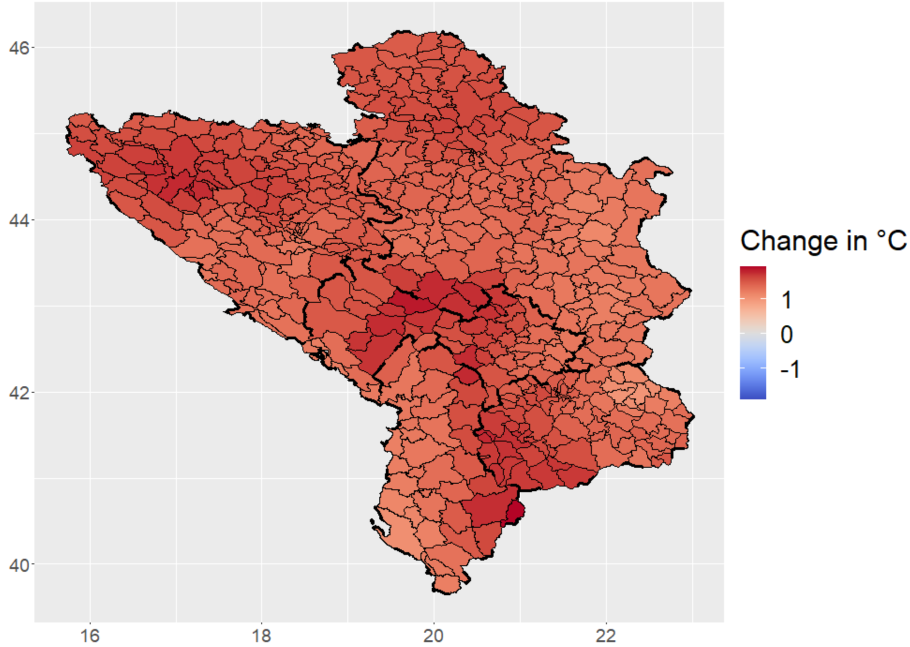

Figure 6: Changes in average temperature from 1992 to 2020 during the growth period of winter wheat (October to July).

Changes in **total precipitation** show similar spatial patterns for the growing period of **winter wheat** as for maize (Figure 7). Again, the largest decreases occurred in the northern Albanian Alps and in north-eastern Montenegro. Precipitation in most other regions has slightly increased during this period.

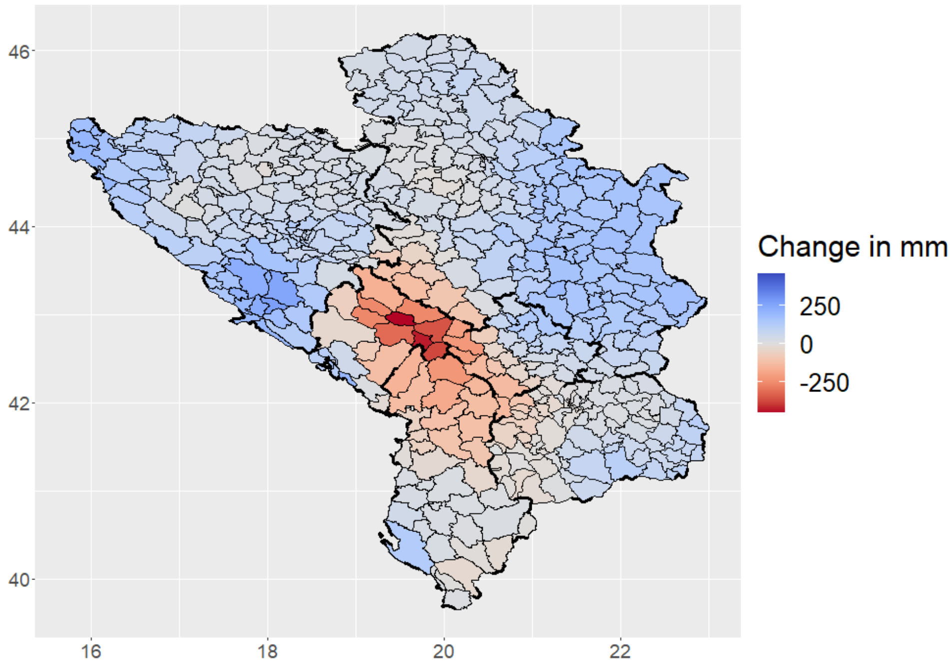

Figure 7: Changes in total precipitation from 1992 to 2020 duirng the growth period of winter wheat (October to July).

2. Extreme weather events

Days with excessive heat above 35°C have increased across the region from 1992 to 2020 (Figure 8). Particularly some coastal areas in Albania and in Bosnia and Herzegovina, northern Serbia, and central Macedonia experienced about five more heat days between 1992 and 2020 during the growing period of **maize**.

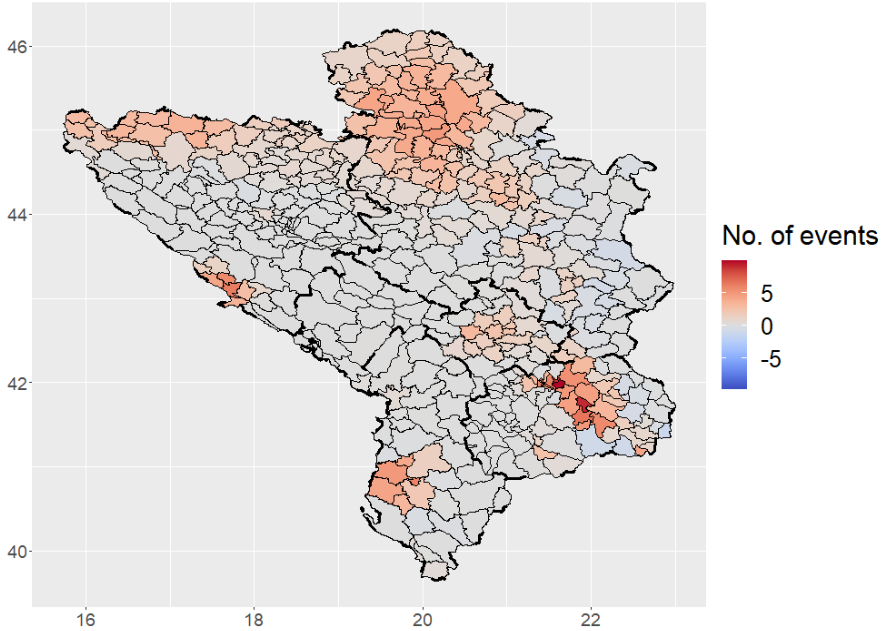

Figure 8: Changes in the number of day heat events (days with temperature above 35°C) from 1992 to 2020 during the growing period of maize (April to October).

Night heat events (nights with minimum temperatures above 20°C) increased especially strongly during the period when **maize** is grown (Figure 9): Albania's and Montenegro's coast recorded up to 30 more heat nights. Hot nights also increased in much of North Macedonia and in northern Serbia.

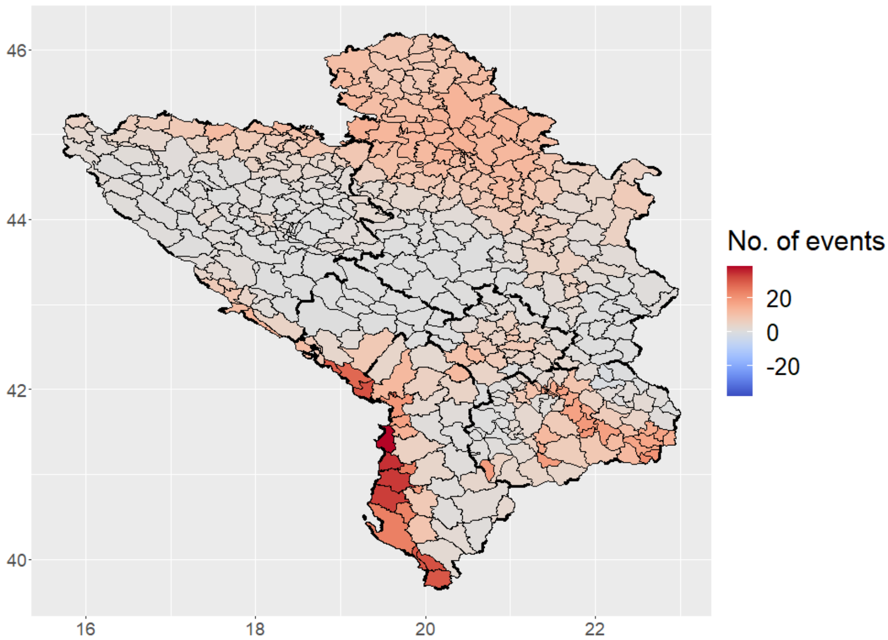

Figure 9: Changes in the number of night heat events (nights with minimum temperature above 20°C) from 1992 to 2020 during the growing period of maize (April to October).

Changes in the number of **heavy precipitation** events (number of days with more than 20 mm of precipitation) showed spatially heterogenous patterns for the growing period of **maize** (Figure 10). While in the east, north, and west of the Western Balkans, heavy precipitation events became more frequent, they decreased in much of the southern parts of the Dinaric Alps, and especially in mountains of northern Albania.

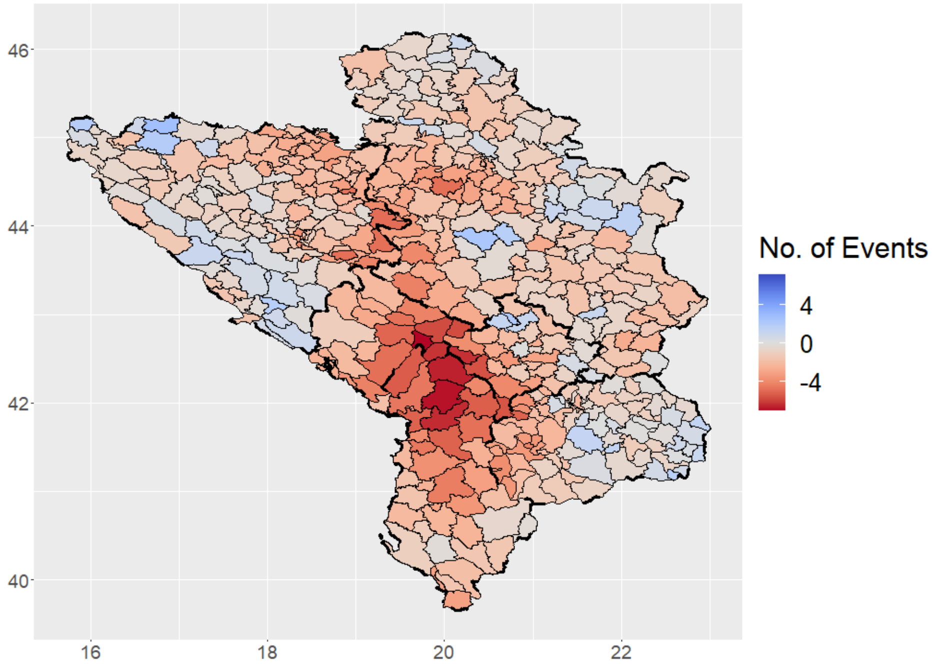

Figure 10: Changes in the number of days with more than 20 mm of precipitation from 1992 to 2020 during the growing period of maize (April to October).

Expectedly with warming average temperatures, the number of **frost events** have decreased in most areas during the growing period of **maize** (Figure 11). This is particularly the case in hilly and mountainous areas and especially in the Dinaric Alps, while they remained constant in most other regions.

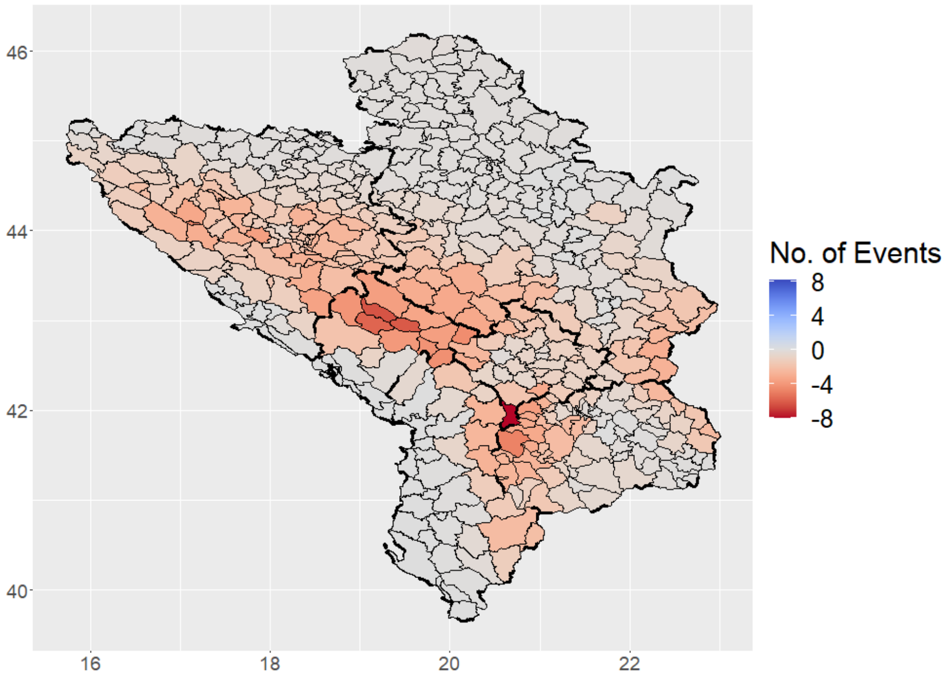

Figure 11: Changes in the number of days with frost events (average night temperature below 0°C) from 1992 to 2020 during the growing period of maize (April to October).

Days with excessive heat have only slightly changed from 1992 to 2020 across most of the region during the growing period of **winter wheat** (Figure 12). Exceptions are in parts of eastern Serbia where days heat events increased, as well as in some coastal areas in Albania and in Bosnia and Herzegovina. Northern Serbia and the central parts of North Macedonia experienced about five more heat events between 1992 and 2020 over the growing period of **winter wheat**.

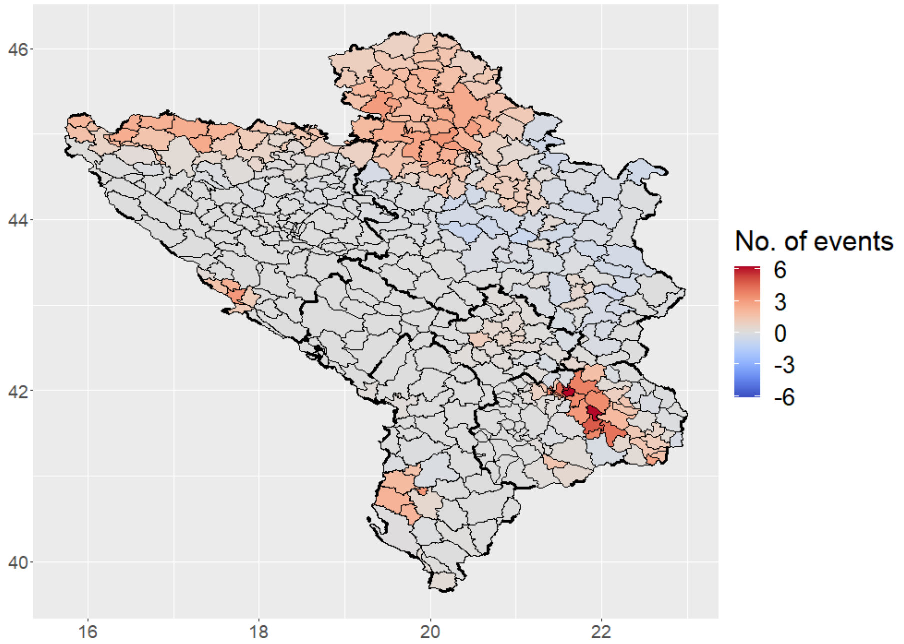

Figure 12: Changes in the number of day heat events (days with temperature above 35°C) from 1992 to 2020 during the growing period of winter wheat (October to July).

Night heat events increased during the period when **winter wheat** is grown (Figure 13). The spatial changes are very similar to night heat events during the growing period of maize (Figure 9) and occur along the Albanian and Montenegro's coast, as well as in the central parts of North Macedonia and in northern Serbia.

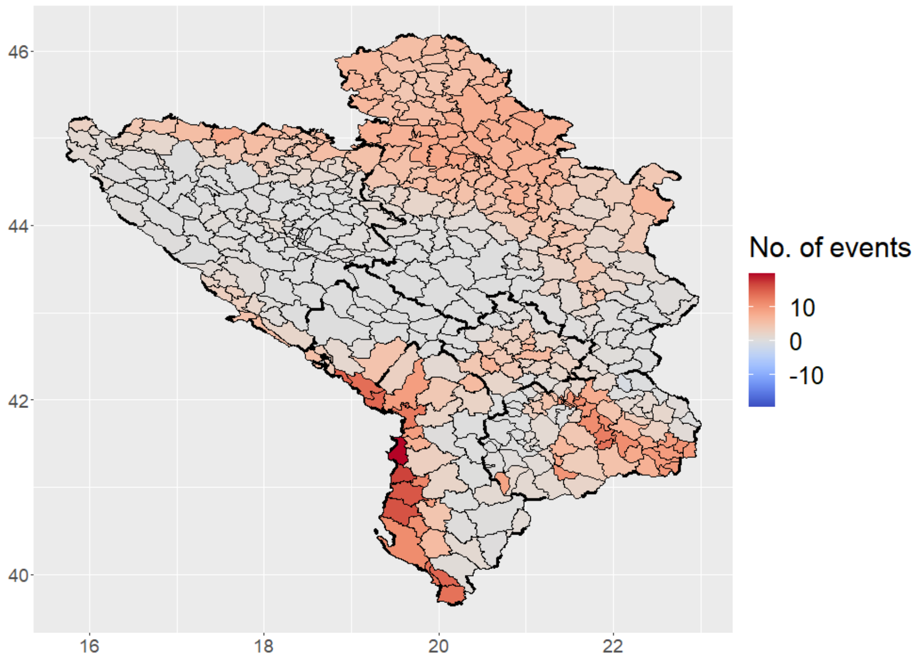

Figure 13: Changes in the number of night heat events (nights with minimum temperature above 20°C) from 1992 to 2020 during the growing period of winter wheat (October to July).

The number of events of **heavy precipitation** during the growing period of **winter wheat** increased mainly along the coastal areas, and particularly on the coast of Bosnia and Herzegovina but also in eastern Serbia (Figure 14). In mountainous areas, heavy precipitation became less frequent, particularly in the southern Dinaric Alps.

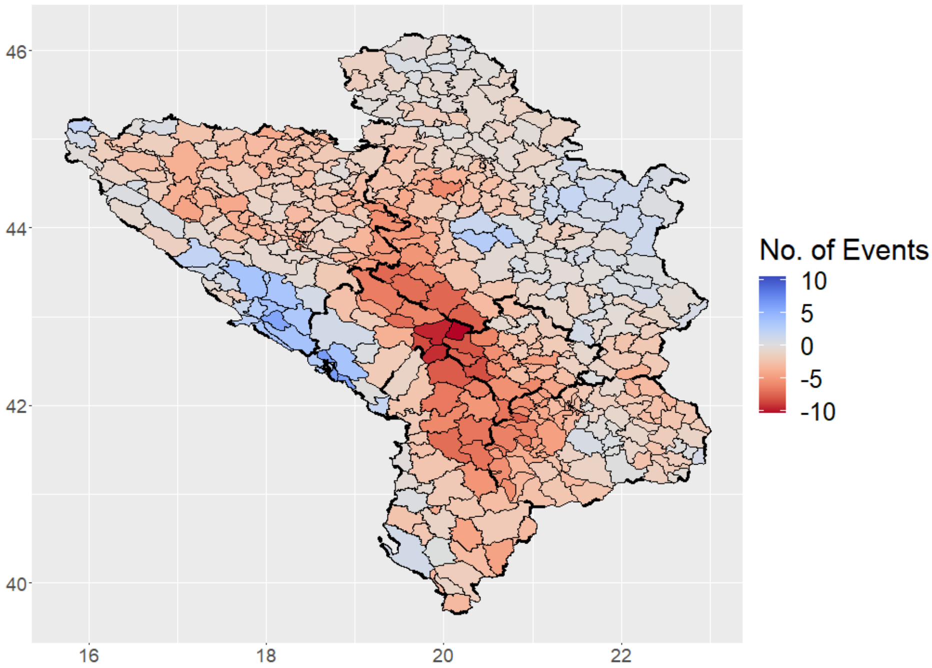

Figure 14: Changes in the number of days with more than 20 mm of precipitation from 1992 to 2020 during the growing period of winter wheat (October to July).

The number of **frost events** also decreased during the growing period of **winter wheat** (Figure 15), i.e., from October to July. Because this period includes the winter dormancy, the decrease in frost events is much larger than for the growing period of maize, with a reduction of up to 40 frost days from 1992 to 2020.

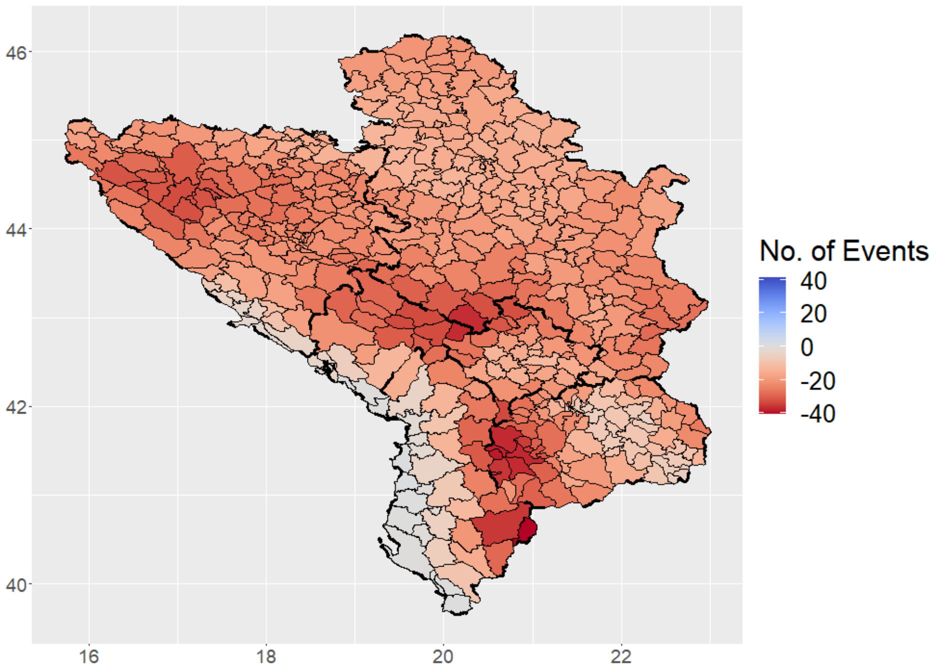

Figure 15: Changes in the number of days with frost events (average night temperature below 0°C) from 1992 to 2020 during the growing period of winter wheat (October to July).

Historical effects of climate means and extreme weather events on crop yields

We calculated the Pearson correlation coefficient between national yield statistics and climatic mean and weather extreme variables, which were aggregated over the growing period of the respective crop. **Wheat** yield is positively correlated with minimum, average, and maximum temperature in all four countries for which yield statistics were available (Figure 16). This relationship was most pronounced in Albania. Precipitation is positively correlated with wheat yield in North Macedonia and night heat positively influences wheat yields in Albania. More frequent frost had a negative effect on wheat yields in all four countries, with the strongest statistical association in Serbia. All other variables had negligible effects. However, we caution the reader that these analyses can only provide a rough indication of the relationships between yields and weather in the absence of subnational yield data.

Figure 16: Correlation of wheat yield with climatic mean and extreme weather variables from October to July for all years from 1992 to 2020. Blue indicates positive and red indicates negative correlations. The larger the dot, the higher is the correlation. TAVG = average temperature, TMAX = maximum temperature, PRCP = precipitation, NH = night heat, FR = frost, DH = day feat, HP = heavy precipitation.

Minimum temperature was positively related to the yields of winter wheat in Albania (Figure 16). The relationship is depicted in detail in Figure 17, where the positive relationship is visualized with a spline regression, which plots yields against the minimum temperature.

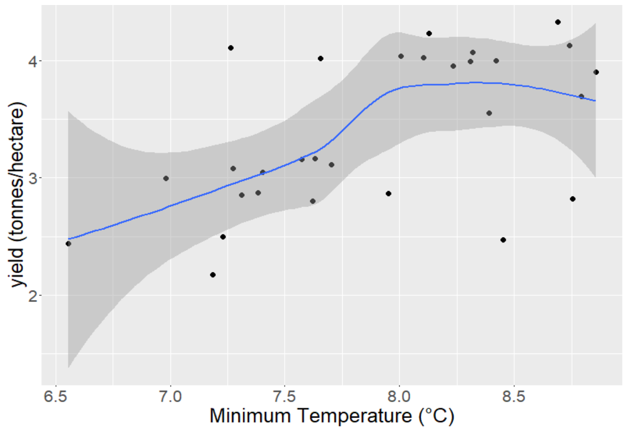

Figure 17: Relationship between winter wheat yield and minimum temperature in Albania. Each dot represents one year from 1992 to 2020. The grey shaded area is the 95% confidence interval, and the blue line captures the fit of a spline regression.

The Pearson correlation coefficients between **maize** yields and climatic mean and weather extreme variables again reveal the strongest relationships between yields and the climate and weather variables in Albania (Figure 18). Higher values of all temperature variables were associated with higher yields while extreme events had less influence, except that more days with night heat tended to raise yields (Figure 18). Heat extremes during daytime have a strong negative bearing on maize yield in Bosnia and Herzegovina and, to lesser extent, in the Republic of Serbia. More precipitation was associated with higher maize yields in all countries, except Albania.

Figure 18: Correlation of maize yield with climatic mean and extreme weather variables from October to July for all years from 1992 to 2020. Blue indicates positive and red indicates negative correlations. The larger the dot, the higher is the correlation. TMAX = maximum temperature, PRCP = precipitation, NH = night heat, FR = frost, DH = day feat, HP = heavy precipitation.

For maize, we visualize the functional relationships between heat days with yields in more detail (Figure 19). The strong negative impacts of more heat days became visible after a threshold of approximately 5,000 heat events after which maize yields progressively declined.

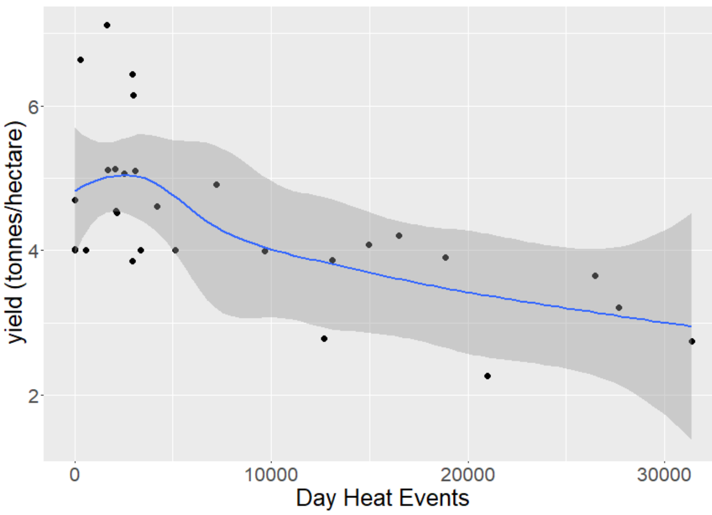

Figure 19: Relationship between maize yield and day heat in Bosnia and Herzegovina (see Figure 17 for explanations).

Future scenarios of climate change

1. Long-term climate means

Average **temperature** during the growing period of maize will likely remain highest in the lowland and coastal areas of the Western Balkan. Temperature increase will be substantially higher under RCP 8.5 than under RCP 4.5, and higher in 2090 than in 2050 (Figure 20).

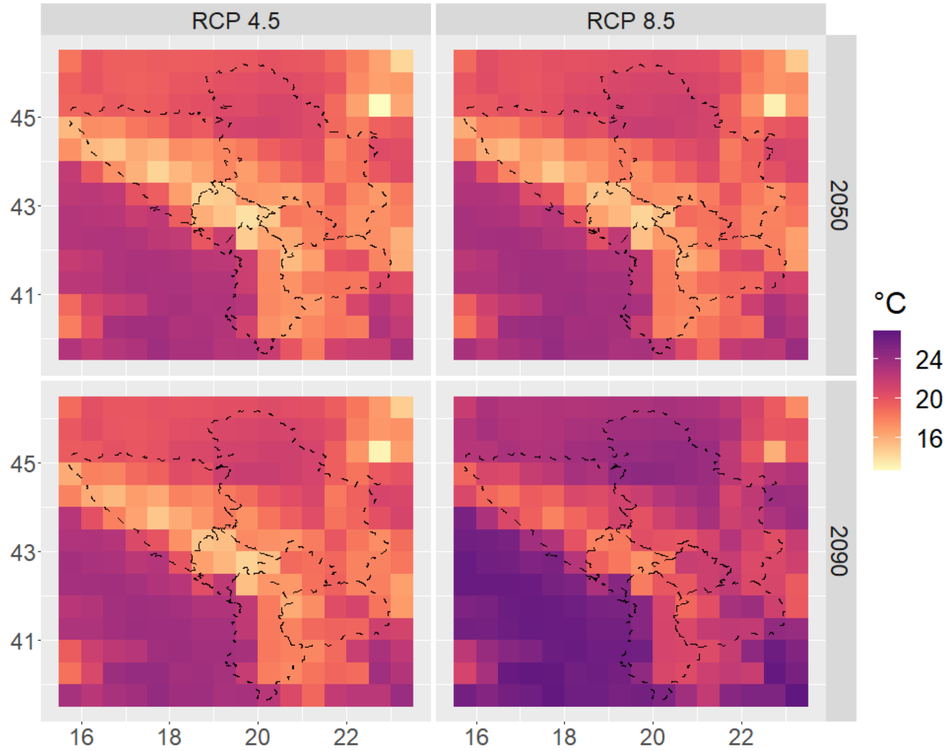

Figure 20: Future average temperature during maize growth (April to October) under two RCP scenarios and for two future time periods. The climate projections of temperature and precipitation consider two future scenarios (RCP 4.5 and RCP 8.5) and two future periods ("2050" captures the 10-year average from 2046 to 2055; and "2090" corresponds to the 10-year average from 2086 to 2095). Data are from the ISIMIP repository (https://data.isimip.org/).

The absolute changes in average future temperature follows regional topographic gradients and increases from south to north and from east to west (Figure 21).

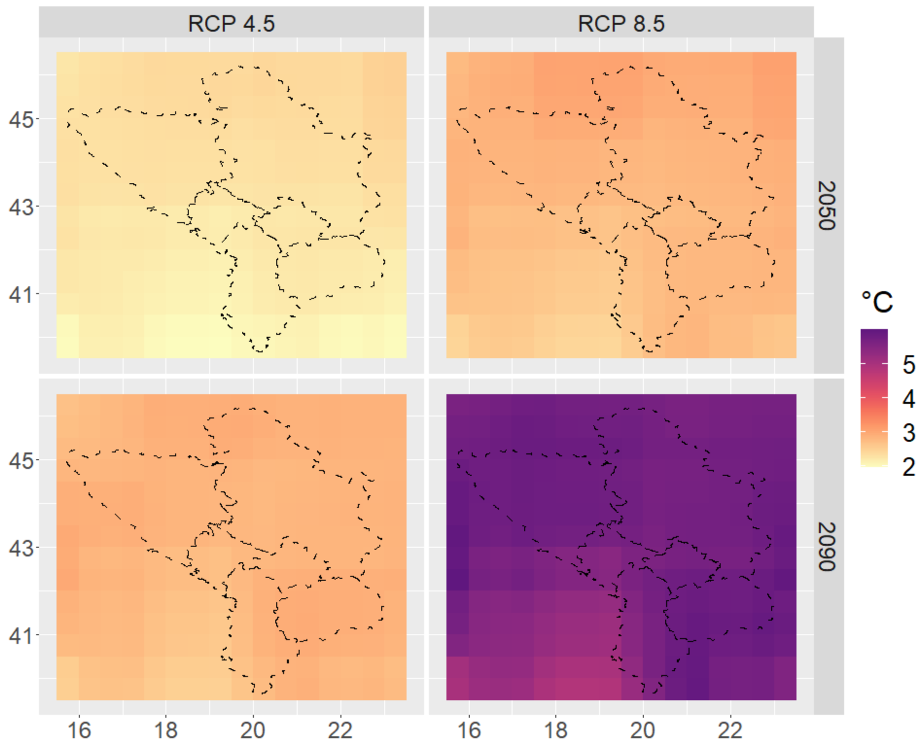

Figure 21: Future change in average temperature during the growth period of maize (April to October) under two RCP scenarios and for two future time periods, compared to the reference period from 1991 to 2005.

Precipitation during the growing period of maize (April to October) is expected to be highest in the Dinaric Alps, and lowest in North Macedonia (Figure 22). Obviously, these patterns largely follow the current climatic patterns. However, the amount of precipitation will decrease with future climate warming. Precipitation will overall be lower in RCP 8.5 compared to RCP 4.5 and it will be lower in 2090 compared to 2050 (Figure 22).

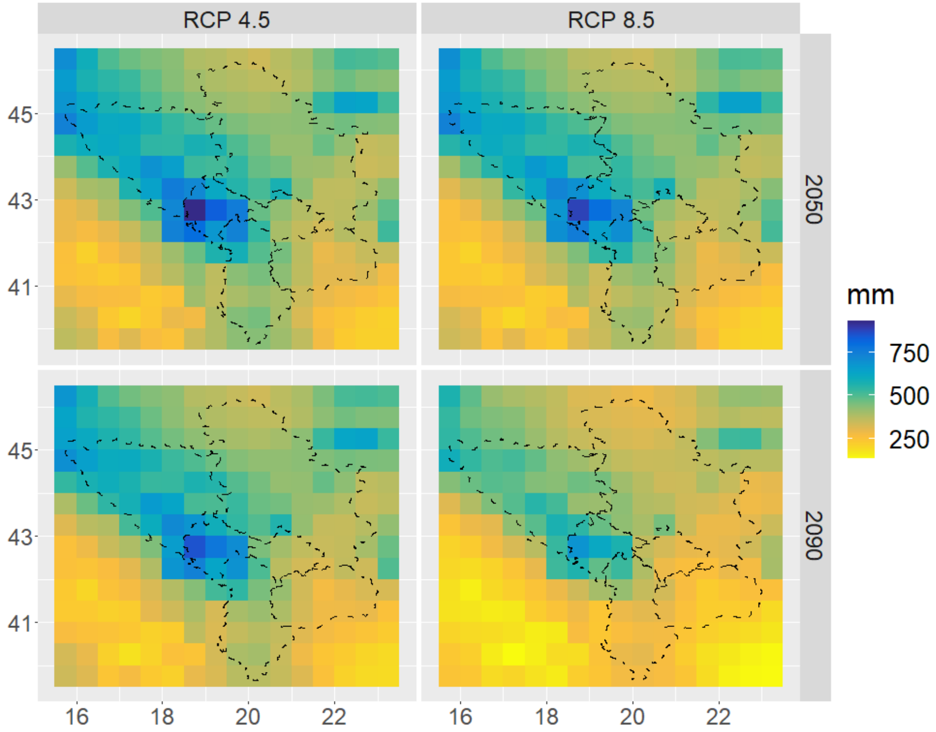

Figure 22: Future precipitation during the growth period of maize (April to October) under two RCP scenarios and for two future time periods.

The decrease of precipitation will likely be highest in the Dinaric Alps, particularly in Montenegro, where precipitation is projected to decrease by up to 300 mm under RCP 8.5 until by 2090, compared to the reference period from 1991 to 2005 (Figure 23).

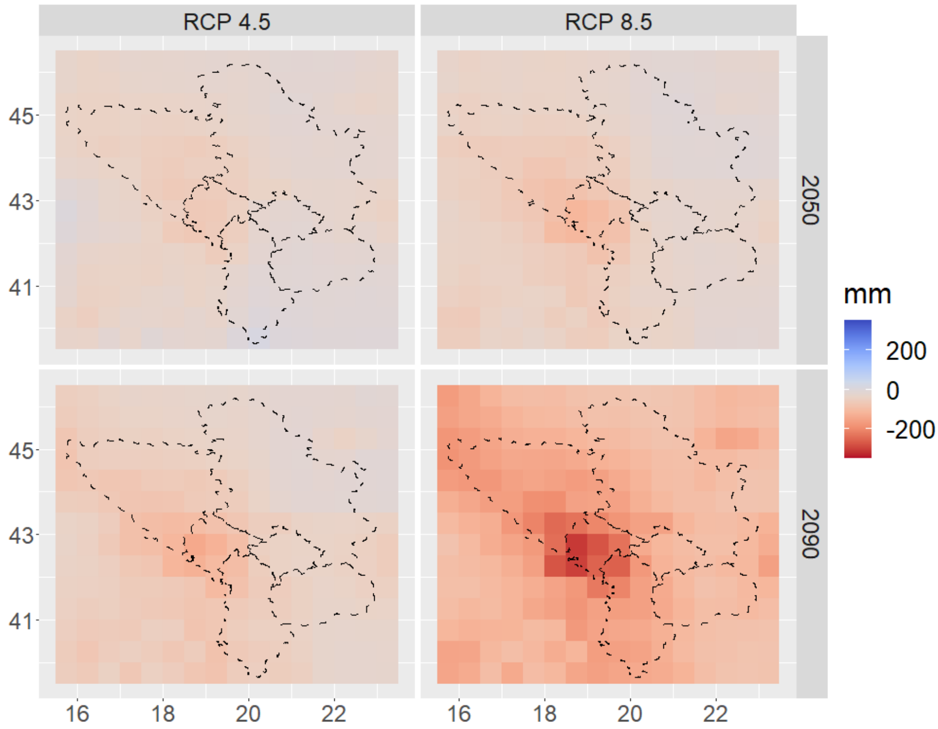

Figure 23: Future change in precipitation during maize growth (April to October) under two RCP scenarios and for two future time periods, compared to the reference period from 1991 to 2005.

2. Extreme weather events

All six countries of the Western Balkans will experience an increase in the number of **day heat** events (daily maximum temperature above 35°C) in the future according to the climate models. Extreme heat events will occur more often in 2090 compared to 2050, and they will occur more often under RCP 8.5 (Figure 25) compared to RCP 4.5 (Figure 24). Heat events will also likely become more severe, i.e., they will affect larger parts of the region at once, as illustrated by lines that stretch further outwards form the centre. Moreover, the analysis shows that heat events will tend to become frequent in spring and autumn. We caution the reader not to use these figures for country-by-country comparisons because of the different sizes of the countries.

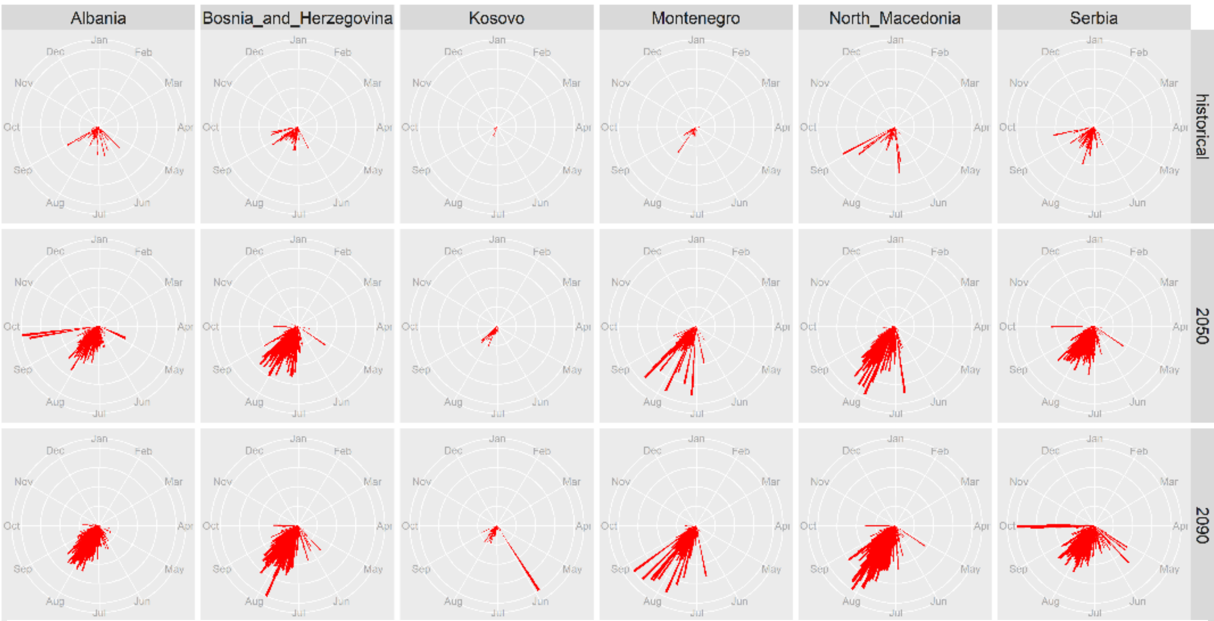

Figure 24: Day heat events under RCP 4.5. Longer lines imply that a higher share of a country's surface is affected.

Figure 25: Day heat events under RCP 8.5. Longer lines imply that a higher share of a country's surface is affected.

Night heat events, i.e. when minimum temperatures during the night stay above 20 °C, will also become more frequent and more severe with future climate warming in all countries. The probability of night heat is higher in 2090 than in 2050, and it is higher under RCP 8.5 (Figure 27) than under RCP 4.5 (Figure 26). In contrast to day heat, the night heat events will largely only occur during July and August, and not during spring or autumn.

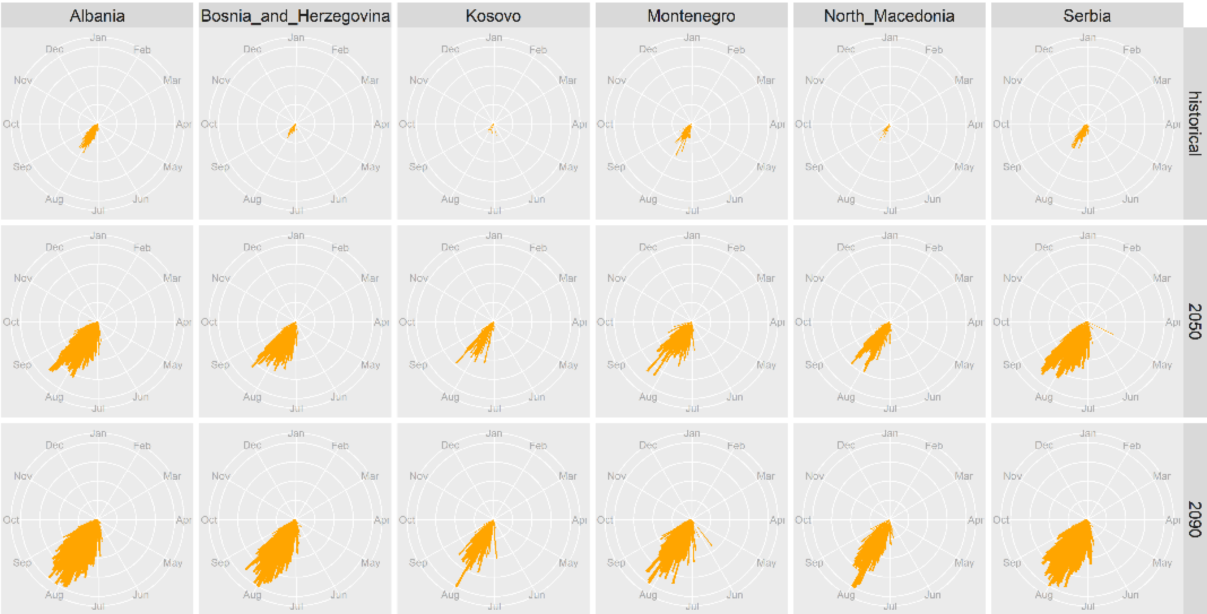

Figure 27: Night heat events under RCP 4.5. Longer lines imply that a higher share of a country's surface is affected.

Figure 26: Night heat events under RCP 8.5. Longer lines imply that a higher share of a country's surface is affected.

Heavy precipitation events are characterized by daily amounts of precipitation above 20 mm. Such events can happen all year round and seem not become more frequent or more severe with future climate warming (heavy precipitation events show similar patterns in RCP 4.5 in Figure 28 and in RCP 8.5 in Figure 29). However, there is a slight increase in the amount of more severe events during the months from April to September in 2050 and 2090, particularly in countries that have more mountainous terrain and where most heavy precipitation events occur during the historical baseline period.

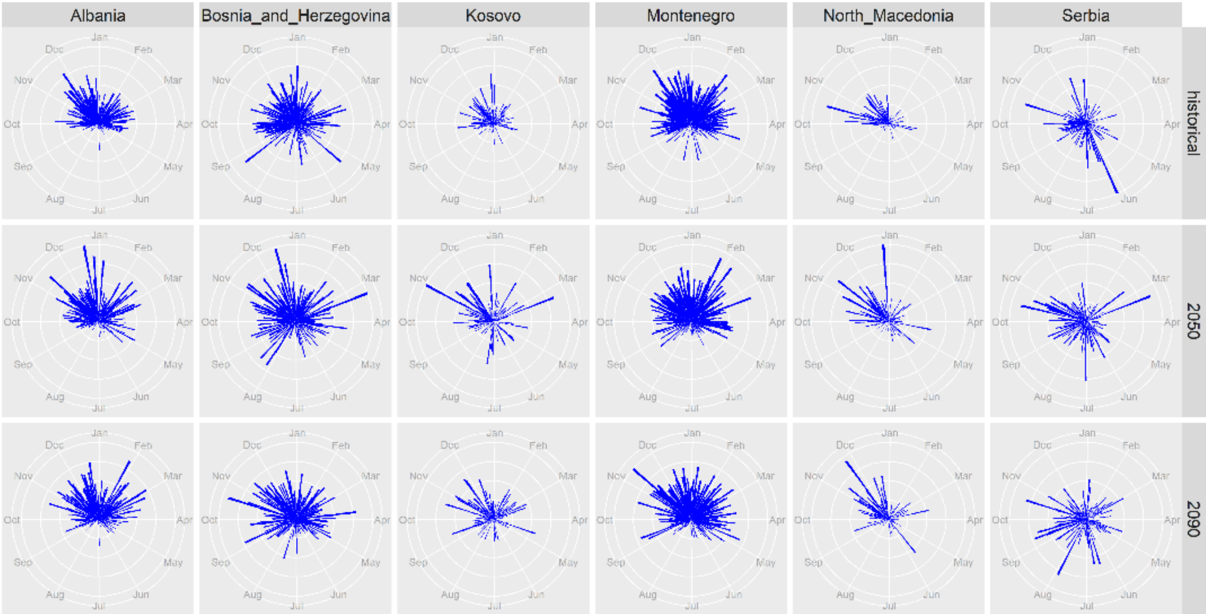

Figure 28: Heavy precipitation events under RCP 4.5. Longer lines mean that a higher share of a country's surface is affected.

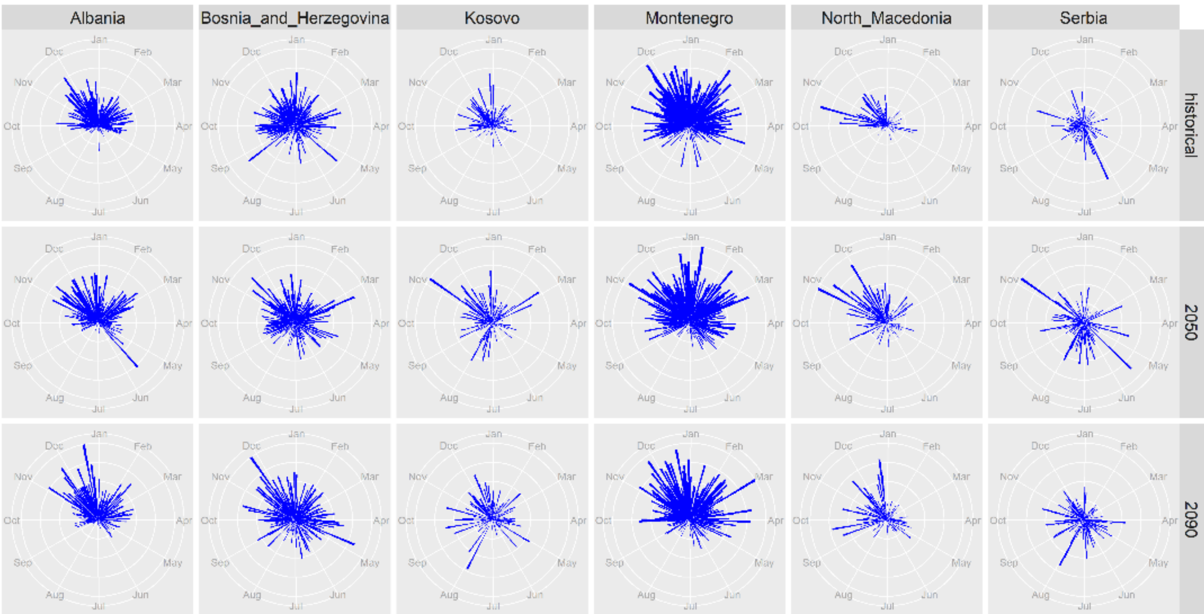

Figure 29: Heavy precipitation events under RCP 8.5. Longer lines mean that a higher share of a country's surface is affected.

As expected, increasing future warming will lead to a significant decrease in the severity and frequency of **frost events**, which are characterized by daily average temperatures below 0°C (Figure 30 for RCP 4.5; Figure 31 for RCP 8.5). Frost events will become more restricted to the months December to February, and they will become less likely during November and March.

Figure 30: Frost events under RCP 4.5. Longer lines mean that a higher share of a country's surface is affected.

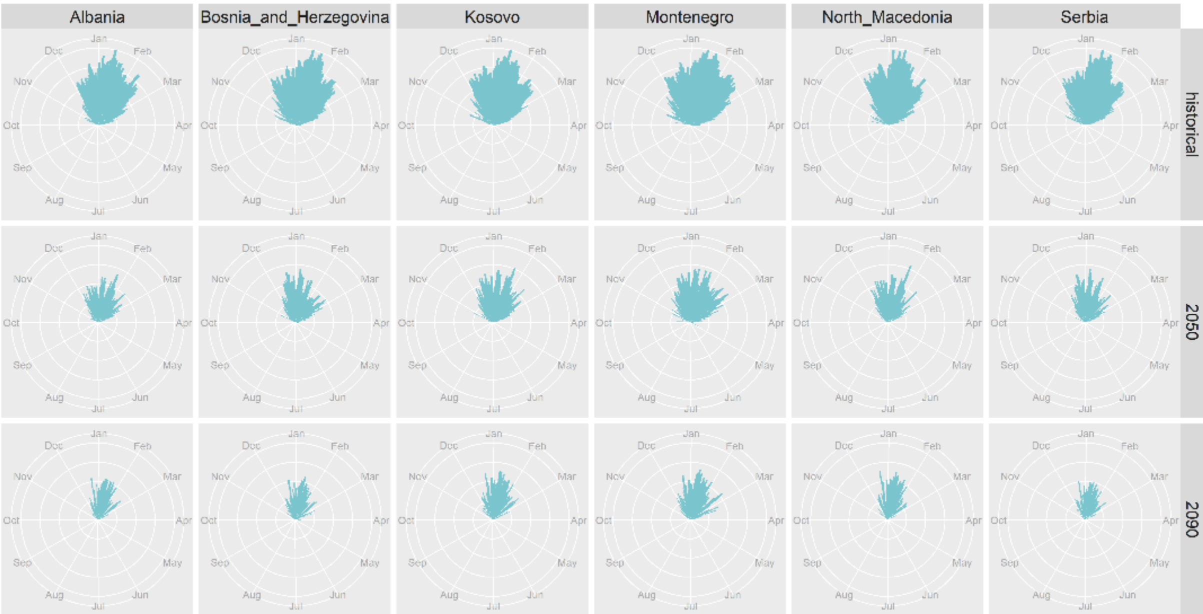

Figure 31: Frost events under RCP 8.5. Longer lines mean that a higher share of a country's surface is affected.

Data availability

All maps can be accessed in an interactive online application under the following link: https://maxhofmann.shinyapps.io/climate_Western_Balkan/.

Part 3: Recommendations for project activities

Improve availability of agricultural statistics and meteorological observations

Effective and efficient monitoring and assessment of the impacts of climate change on agricultural production will be increasingly pertinent in the Western Balkans. However, at present, the Western Balkan countries suffer from a lack of access to and the low quality of statistical data. Insufficient data quality and availability are a major hindrance for solid assessments of the impacts of climate change on crop production in the region.

It is pertinent for the region to improve the collection of consistent high-quality agricultural statistics with rigorous data collection frameworks and at high quality standards (for example, by implementing standardized systems of farm accountancy data networks (FADN) in those countries where these are not yet implemented). Agricultural census data and accurate geospatial data are of utmost importance for monitoring environmental and agricultural changes. Provision of such data with free access will enable implementing agencies, ministerial staff at different levels, and academia in monitoring, assessments, and research. Embracing open data concepts would also provide for better participation of civil society organization and the interested public.

In particular, accurate and precise environmental data is crucial for many applications that focus on analysing agricultural and rural development in the face of climate change. High-quality spatial data are also prerequisite to monitor the convergence towards the goals of the Green Agenda, including to facilitate better assessment of efficient and effective pathways of adaptation to the challenges of climate change. This can include the establishment of more meteorological and soil measurement stations in the region, including small-scale stations on farms, managed by farmers themselves. Satellite remote sensing is another crucial pillar, which seems to receive too little attention in the region in both academia and education. At present, the best maps of land-cover types for Europe exist for EU member states because of the availability of training and validation data for the EU. The accuracy of these maps for the Western Balkans is therefore elusive. A thorough monitoring scheme for ground-truthing observations would be essential for the validation of satellite-derived land cover and land use maps and to produce maps that represent the environmental and land use conditions that prevail in the region.

One step towards this end are land-parcel information systems (LPIS), which are to date largely missing in the region. North Macedonia has an LPIS and in Serbia an LPIS seems in the making with support from the World Bank (https://projects.worldbank.org/en/projects-operations/project-detail/P167634). Having access to LPIS data permits to analyse land use and changes therein over larger areas, and supports land-use planning, such as for the implementation of the Green Agenda. LPIS further facilitates solid scientific assessment of agricultural development and of how agriculture is impacted by climate change and can hence improve the spatial targeting of adaptation measures.

Future projects should invest into capacity building in statistical data collection, storage, and analysis, ensure high data quality standards, and the free provision of data. These measures are likely pivotal to adequately monitor progress towards achieving the goals that were stipulated in the Sofia Declaration.

Diversification of farming systems for climate adaptation and mitigation

In the future, temperatures will continue to rise and extreme weather events, such as heat waves and droughts, will become more frequent and severe. With ongoing climate change, the challenge for agriculture is two-fold: On one hand, crop production must become more resilient to environmental changes to avoid production losses; on the other hand, greenhouse gas emissions from agriculture should be reduced to contribute to emissions reductions. We identify three crucial pillars for climate change adaptation and mitigation.

1. Adapt choice of varieties and cropping cycles

Climate Change can stimulate spatial shifts in crop distributions and even the displacement of some crop types to higher elevations (Cho and McCarl 2017). Extreme weather events will further threaten agricultural production and make production shortfalls more likely. To avoid yield losses and the abandonment of arable land, heat- and drought-adapted breeds should increasingly be developed to substitute varieties that are prone to suffer most from the changing climatic and weather conditions (Hampton et al. 2016). In the future, crops with a low transpiration coefficient, such as sorghum and pigweed (Abouziena, El-Saeid and Amin 2015), may replace crops that require more water to produce the same amount of biomass and protein. To reduce the risks from extreme weather events, farmers can adapt the cropping cycles to make such events less likely to coincide with the growing season. For example, earlier seeding of summer grains reduces the risk of heat waves occurring before harvest (Olesen et al. 2011).

2. Efficient resource use

Inefficient or unnecessary use of agricultural inputs raises production costs and increases greenhouse gas emissions. Modern precision irrigation techniques, for example drip irrigation, and precision agriculture approaches, such as spatially fine-tuning the application of fertilizer and pesticides, can greatly contribute to more efficient use of intermediate production inputs, and at the same time reduce emissions and provide other environmental co-benefits, such as for biodiversity, health, and water quality (Surendran, Jayakumar and Marimuthu 2016, Finger et al. 2019). However, the uptake of drip irrigation and precision agriculture requires not only awareness and capacity building, but also necessitates up-front investments, which could be facilitated by policies that provide subsidized credit programs or that impose taxes on environmentally damaging production systems (Finger et al. 2019).

3. Soil-conserving cropping practices

One popular measure towards making cropping systems more resilient is conservation agriculture. This farming system aims at reducing soil disturbance to an absolute minimum through measures of reduced or not tilling the topsoil, maintaining a constant soil cover (e.g., by mulching), and through diversifying crop rotations. As a result, the humus content in the soil increases, which improves soil fertility, sequesters CO_2, and elevates the water retention capacity of the soil, which renders crop production more resilient toward droughts and heat waves. Moreover, conservation agriculture reduces the risk of soil erosion and pests, and benefits biodiversity (Somasundaram et al. 2020, Hobbs, Sayre and Gupta 2008).

4. Agroforestry

Agroforestry systems can provide ample benefits in the Western Balkan region. Integrating trees into farming systems can help store additional carbon in vegetation and soil, enhance soil fertility and prevent soil degradation, reduce inputs requirements for crop farming, provide shade for people and livestock, and decrease the need for synthetic input applications (IPCC 2022, Hernández-Morcillo et al. 2018). Practices, such as hedgerows and other landscape elements, provide additional habitat and can ensure connectivity between habitats, which benefits biodiversity and supports ecosystem functioning. Agroforestry practices that integrate tree species that are well adapted to the local circumstances can hence contribute to reducing the climate stress compared to conventional agricultural systems and assist in adapting to the new climatic norms.

Providing institutional frameworks that incentivise nature-based solutions

Agricultural policies should actively promote and support the uptake of sustainable cropping practices to ensure that climate-resilient and nature-friendly agricultural systems represent a financially viable alternative for farmers. Reforestation, afforestation, and other nature-based solutions are examples that can help to cushion the local effects of climate change, such as through providing a better microclimate and shade and help to adapt to climate change but can also contribute to emissions reductions targets of the western Balkan countries through sequestering carbon in vegetation and soils.

Such a transition necessitates policy support for institutional development, awareness raising, capacity building, knowledge exchange, and agronomic extension. Markets and policies should support the establishment of value chains and initiatives that channel financial support to compensate for the additional costs of providing ecosystem services through nature-friendly farming. For example, subsidies could incentivize the upscaling of agronomic measures that improve the efficiency of input usage, enhance soil quality, and reduce greenhouse gas emissions. Moreover, financial institutions should provide tailored credit and insurance products to enable farmers to make the necessary investments into nature-based solutions that facilitate the adoption of sustainable and climate-resilient farming practices and help to cushion production shortfalls caused by extreme weather events.

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