UKRAINE

BUILDING CLIMATE RESILIENCE IN AGRICULTURE AND FORESTRY

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ABBREVIATIONS AND ACRONYMS

ATR	Annual temperature range
CSA	Climate-smart agriculture
EU	European Union
EURO-CORDEX	European branch of Coordinated Regional Downscaling Experiment
FPIC	Free prior and informed consent
GDP	Gross domestic product
GIS	Geographic information system
ha	Hectare
IFPRI	International Food Policy Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	Intergovernmental Panel on Climate Change
LTA	Long-term average
NCRC	National climate resource center
RCM	Regional climate model
RCP	Representative concentration pathway
TPM	Third-party monitoring
UHMI	Ukrainian Hydrometeorological Institute
URIFFM	Ukrainian Research Institute of Forestry and Forest Melioration
WOFOST	World Food Studies Crop Simulation Model

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EXECUTIVE SUMMARY

Ukraine has made impressive progress on key reforms and restored macro-financial stability, but weak growth and poverty remain a concern. The Maidan Revolution of 2013–14, the events in Crimea in 2014, and the ongoing armed conflict in the eastern region since 2014 have all played an important role in undermining economic growth. A weak recovery since 2015 reflects both lower potential growth and the severity of the 2014-15 economic crisis. While poverty has declined relative to its peak during the crisis, it remains higher than during the pre-crisis period: In 2019, 23% of the population lived below the national poverty line, versus 8% in 2013 (World Bank 2021d).

Despite these economic challenges, Ukraine recognizes climate change as the most consequential factor this century, affecting the economy and future generations. The country updated its Nationally Determined Contribution (NDC) in 2021 and recently affirmed its commitment to the European Green Deal. However, in the absence of dedicated analyses, the nature of climate impacts on Ukraine's economy are not yet fully understood.

The present study is the first detailed assessment of the potential impacts of climate change on Ukraine, with a focus on agriculture, a key driver of the economy and jobs. It was designed as a bottom-up study, based on detailed climate projections for over 7,400 grid points covering the country — which together with biophysical modeling, were used to estimate the impact on key crops and forest timber species. This analysis provides an insight into the spatial dimension of climate change — how these changes would be experienced in different oblasts in the country. The results point in the direction of actions to avoid negative impacts, and reveal potential to tap into new opportunities. The study focused mainly on two scenarios, RCP 4.5 and RCP 8.5, which are compatible with a global 2.4°C and 4.3°C warming limit by 2100, respectively (IPCC 2021).

This report is supported by four background technical reports on climate projections, impact on agriculture, impact on forests and distributional analysis. In addition, climate datasets of over two terabytes generated for this assessment are housed at the Ukrainian Hydrometeorological Institute, Kyiv. The results of this study are expected to inform Ukraine's national adaptation strategy, which is now being finalized. This study also paves the way for the development of sub-national and sectoral adaptation strategies with the spatially disaggregated information that has been generated for all oblasts. It will also inform the World Bank's programs in Ukraine — the Climate Change and Development Report in particular.

Key Findings: Climate

Ukraine's climate has changed significantly over the last 60 years, with accelerating warming since the 1980s resulting in the rates of 0.4-0.6°C per decade that exceed the mean value in Europe and are higher than the global rate by a few times. This causes changes in the precipitation regime: While total annual precipitation has not changed significantly in recent decades, greater precipitation was observed in the autumn and less precipitation in other seasons, with the most decreases occuring in summer. Rising air temperatures causing increased evaporative demand with uneven precipitation have resulted in lower accumulations of moisture in the soil, leading to an increase in the frequency and intensity of droughts in the last decade.

The strongest annual temperature increases of over 4°C are projected for RCP 8.5 at the end of the century with the largest effect on the east and northeast of Ukraine (Kharkivska, Luhanska, Sumska oblasts) and the smallest in the west (Ivano-Frankivska, Lvivska, Volynska oblasts). In the scenario with lower GHG concentrations (RCP 4.5), estimated warming is projected to be approximately twice as small. Cities could experience intense temperature increases by the end of the century (over +5.0°C in summer in Luhansk and in winter in Kyiv), aggravated by the urban heat island effect. These impacts will need to be further analyzed for their effect on the heating and cooling needs of the population, especially the health considerations of vulnerable groups, and for their effect on urban infrastructure.

Annual temperature cycles are expected to be altered during the century due to higher projected monthly temperature increases in summer months in warmer regions, and in winter months in colder regions. These temperature increases will likely result in continuing reductions in the annual temperature ranges already observed and the decreasing continentality of the climate. These changes will have significant implications for ecosystem dynamics and vegetation growth. Rising temperatures in summer could result in heatwaves and increases in aridity in Ukraine’s south and east.

Over the course of the year, minimum temperatures at night are expected to rise most sharply in the cold season, while daily maximum temperatures will increase the most in the summer season. It will result in a decrease in the number of days and nights with negative temperatures while the number of tropical nights with temperatures over 20°C and summer days with mean daily temperatures over 15°C will increase. More than 100 tropical nights and up to 135 summer days per year are projected for the southern steppe by the end of the century under RCP 8.5.

In all scenarios, annual precipitation in Ukraine is projected to increase, with larger increases towards the end of the century, especially under RCP 8.5. Precipitation is projected to increase significantly in the winter months for almost the entire country. Larger precipitation increases are expected in northern oblasts (especially in the northwest, e.g., Rivnenska, Volynska). The summer months are projected to have a relative decline getting larger over time under RCP 4.5 and RCP 8.5.

By the end of the century, changes under RCP 8.5 show not only twice higher warming but broader ranges of precipitation variability across oblasts, suggesting strong spatial differences. The southern and central areas are characterized by the lowest increase in precipitation, with a significant decrease in warmer months exacerbating with temperature rise. Overall, the southern and central oblasts are projected to become drier, and northern and western oblasts wetter with rising uncertainty of the delineation between these two opposite tendencies under RCP 8.5.

The frequency and intensity of extreme weather and climate events, including heat-waves, thunderstorms, heavy precipitation, pluvial and river flooding, droughts, hail-storms, squalls, tornadoes, heavy snowfalls, freezing rains, accumulation of wet snow, icing, etc., are expected to rise with higher warming. Extreme events especially, those known as “low-likelihood, high-impact events,” (IPCC 2021) could have additional and significant consequences on all sectors and ecosystems, resulting in a significant number of lost jobs and livelihoods. Most losses would be concentrated in sectors of middle and lower-income workers – manufacturing, utilities, retail, and tourism. The Inter-governmental Panel on Climate Change Sixth Assessment Report (IPCC AR6) assigns low confidence levels to the occurrence of these events, which does not exclude the possibility of their occurrence, but instead, is a reflection of the limits of predictability of these events. The potential impacts of such events on Ukraine need to be analyzed through a separate study.

Key Findings: Agriculture and Forests

With no adaptation interventions, the range of possible yield outcomes is large as is the risk of outcomes below expectations in any given year. Yields of selected crops (winter wheat, barley, maize, soybean, and sunflower) were modeled with a probability distribution for low and high projection: i.e., the 5th percentile of the distribution and the 95th percentile, respectively. Under RCP 8.5 yields of all crops, except wheat and soybean, face significant decline in 2030 and in 2050. In percentage terms, the decline is greater for barley followed by maize. However, the projected decline in maize yield is more important, since it is a critical export commodity.

While climatic conditions become favorable for higher productivity of winter wheat in the near future period and up to the mid-century under both RCP 4.5 and 8.5, the unpredictability of precipitation patterns make oblast-level adaption planning very essential to prepare the agriculture sector for this climatic shift. Based on the projected changes in precipitation (autumn, winter), increased CO_2 concentration, and decrease in the number of frost nights, yields are projected to increase 20-40% by 2050 as compared to the 2010 baseline period in the north and northwestern parts of the country first. This result is also in line with projections for the EU states in the recent PESETA IV study (Feyen 2020). Conditions for increased productivity of winter wheat also become favorable by mid-century for more areas of the country under RCP 8.5, based on the increase in autumn and winter precipitations projected under this scenario. However, the unpredictability of precipitation patterns especially for the latter part of the century under RCP 8.5 makes it essential to pay greater attention to projected changes at the local level. The detailed projections from this study could be used to develop regional or local adaptation plans.

The productivity of maize, sunflower and barley could also see an increase by mid-century, provided that climate-smart water management interventions are deployed for their production. Climate-smart strategies for water management could increase overall yields by 20-40%, and up to 80% for maize and 40-80% for sunflower.

With optimal water availability, benefits for maize, soybean and sunflower crops could reach US$112 million per year over the 10-year period from 2026- 2035 under the mean projection.[1] Simulations of low and high yield projections show that the annual benefits of maintaining optimal water balance could amount to US$264-504 million or 2-4% of Ukraine's GDP for agriculture in 2019. The highest benefit of better water management in relative terms is expected for soybean output that could increase by 26-40%. The highest impact is estimated at US$92.7 million for maize.

To benefit from higher agricultural value, it is essential to carry out an assessment of the feasibility of different water management options. While an assessment of water resources was not part of this study, carrying out such assessments as part of oblast adaptation planning would be imperative to understanding the costs and suitability of different options for water management and water availability. Water management strategies adopted to offset climate impacts could vary by crop and by oblast, and could include planting of drought-resistant varieties, use of cover crops, conservation agriculture, and drip-irrigation, among others. In addition, for winter crops, sowing dates may need to be shifted to later times (October-November), when increases in temperature and precipitation are predicted. For spring crops, sowing dates would need to be earlier, with harvests before the dry weather conditions at the end of July and August, especially in the south of Ukraine.

Based on the temperature and humidity conditions projected under both RCPs, a significant reduction is expected in the area suitable for the growth of spruce, beech, pine and oak. Less than 3% of the country's forest areas would have optimal conditions for Norway spruce, Scots pine and beech under RCP 8.5 projections and just 8% of the territory will have optimal conditions for English oak. By mid-century, under both RCP 4.5 and RCP 8.5, only the Carpathians will remain a suitable zone for Norway spruce. In the Carpathians, the forest boundary is expected to move to a higher altitude.

The projected changes are likely to exacerbate disturbances and stressors such as wildfires and insects. During prolonged droughts, a significant proportion of forest biomass becomes combustible, increasing the fuel load of the forest. In addition, pest infestations which have been documented with warming conditions can result in the deterioration of forest health and increased tree mortality. These will, in turn, enlarge the fuel load available for combustion in wildfire events. Pine forests in the southern and northern steppe and forest-steppe areas will also be at high risk due to the drier conditions expected there under both RCPs.

Impact of Climate Change on Agriculture and Inequality by Oblast

Climate change will have a greater impact on some oblasts than others based on its impact on agricultural production, and the resultant impact on poverty indicators. The top five oblasts with the highest impact in absolute terms by 2030 are Cherkaska, Khersonska, Kirovohradska, Poltavska, and Vinnytska. Kirovohradska oblast has the highest agricultural GDP in Ukraine and the value of its agricultural production will also be considera-

[1] The low projection considered for this analysis reflects the lowest production potential of the selected crops under climate change. These values describe the worst-case scenario, in which the potential reduction in the agricultural production values will be the most significant.

bly impacted by the changing climatic conditions in this century. By mid-century Kyivska and Zhytomyrska oblasts will undergo significant changes in climatic conditions. With a consistent rise in dry and hot conditions, Kyivska and Chernivetska oblasts will be exposed to extremely high temperatures, as indicated by the increasing number of tropical nights that may result in increase of extreme weather events.

The most significant loss in household incomes and the highest increase in poverty and inequality due to lower agricultural production values is projected to be in Kharkivska, Kirovohradska, Lvivska, Luhanska, and Zhytomyrska. Although the agricultural sector accounts for a relatively minor share in the GDP of most of these oblasts, the projected changes in agricultural production values will have significant implications for inequality measures. These oblasts would be most susceptible to the rise in food prices and reduction of income from agricultural production caused by the warming climate. Among the five oblasts, Lvivska and Zhytomyrska oblasts will be most exposed to the reduction of projected precipitation in spring and summer in relative terms, with potentially significant losses of agricultural production value in the near future period.

Opportunities and Priorities for Climate Action

Ukraine must take action to address the potential risks and opportunities that climate change will present for agriculture and forestry, and in turn livelihoods and poverty levels, across the country. Based on the analysis presented in this report, as well as international experience, actions are recommended along three broad streams:

- **Strengthen Institutions, Policy and Planning**
- **Increase Scientific Capacity and Research**
- **Promote Transition to Climate-Smart Agriculture and Forestry**

Strengthen Institutions, Policy, and Planning

Establish a national level institutional mechanism to coordinate climate change policy and actions across all line ministries. Enabling fiscal risk assessment of climate actions, policy and planning and climate budget tagging will be necessary to prepare critical sectors such as energy, infrastructure, health, and agriculture to address climate impacts.

Establish a mechanism to integrate climate change action within the Ministry of Agrarian Policy and Food (MAPF). Strengthening climate expertise and functions will equip MAPF with the necessary knowledge and technical capabilities to support effective and coherent climate policies and programs for farmers. It will also be important for MAPF to regularly carry out agriculture sector climate vulnerability assessments and develop action plans (every five years).

Include climate change risk assessment in oblast development planning. Carrying out more comprehensive impact assessment reviews at the oblast level will be important to identifying specific climate risk considerations for development planning and tailoring action to the sectors that face highest risk in the oblast.

Increase Scientific Capacity and Research

Enhance institutional capacity for collecting, maintaining, analyzing, and disseminating climate data through a National Climate Resource Center. Strengthen the *Ukraine Hydrometeorological Institute (UHMI)* and the *Ukrainian Hydrometeorological Center (UHMC)* as a *National Climate Resource Center (NCRC).* Both institutions fall under the jurisdiction of the State Emergency Service of Ukraine, and combining them under the umbrella of an NCRC can ensure systematic research on hydrometeorology, agrometeorology, and climate science, including up-to-date climate projections, assessment of risks and impacts at the sectoral, national, and regional levels. This will help strengthen the capacity and resources of the UHMI and UHMC to analyze and manage big data for climate planning. This study filled an important data gap by generating over two terabytes of highly granular data on a range of climate indicators for Ukraine using the latest available global and regional climate models. It will be necessary to continue analyzing and updating this data for sub-national adaptation planning, which will require significant hardware and software capacity as well as trained personnel within these institutions. It will also help Ukraine participate in and take advantage of the EURO-CORDEX[2] experiment and develop highly disaggregated climate projections that could be used to estimate climate risks in different sectors of the national economy and on the sub-national level.

Promote Transition to Climate-Smart Agriculture and Forestry

Promote climate-smart agriculture including, better soil and water management (e.g., through contour ploughing, contour bunding, conservation tillage, surface mulching, and revegetation and reforestation of areas around farmlands), agroforestry (planting combinations of trees and crops), drought-resistant varieties of key crops and cover crops, and expand landscape diversity and connectivity to increase the ability of ecosystems to adapt to changing climate conditions and stresses. Maintain or restore riparian areas, wetlands, peatlands and floodplains to help regulate water balance and reduce soil erosion; give incentives to farmers through agro-tourism and eco-tourism programs to manage non-arable lands to maintain biodiversity and natural habitats. These approaches have been shown to protect agriculture from environmental and climate stresses.

Promote Farmer Information Systems and Precision Agriculture Technologies. Provide farmers with reliable and accessible knowledge about climate-smart agriculture and enhance their capacity for adaptation. An information system for farmers through mobile, online and in-person extension services will be key to raising awareness and initiating action on the ground. Promoting the use of precision agriculture (including Variable Rate Technology, or VRT, remote sensing and drones) would help move Ukraine towards more climate-friendly technologies by reducing wastage of water and other inputs. To develop and maintain such systems, Ukraine can leverage its significant capacity and large pool of talent in information technologies.

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2 EURO-CORDEX is the European branch of the international CORDEX initiative, a program sponsored by the World Climate Research Program (WRCP) to organize an internationally coordinated framework to produce improved regional climate change projections for all land regions world-wide. See https://euro-cordex.net/.

Improve targeting of subsidy programs and develop insurance products for climate risks. Agricultural loans and subsidies could be redesigned and better targeted to incentivize the adoption of climate-smart technologies by farmers. Another approach would be to increase farmers' resilience to climate change via the coverage of residual risks not addressed by adaptation actions. Products such as parametric crop insurance would help in areas where adverse weather events such as droughts and long-lasting heatwaves are expected and there is limited capacity for adaptation. As a part of the wider adaptation strategy, index insurance protects farmers' investments from weather volatility and climate uncertainty.

As the forest sector requires sustainable management with long-range climate risk planning, it is especially important to include climate risk management in the forthcoming Forest Strategy 2030 and the country's associated plans for reforestation/afforestation. A regularly updated national forest inventory will be key, in addition to field trials, to monitor growth and plan the planting of timber. Increasing capacity in geospatial technologies is essential for the management of forest fires. It is crucial to plan for this sector as it impacts the hydrological balance and soil conditions for agriculture.

CHAPTER 1:
INTRODUCTION

Despite its economic challenges and the COVID-19 pandemic, Ukraine is making efforts towards a green transition. There has been impressive progress on key reforms and the restoration of macro-financial stability, but weak growth and poverty remain concerns. However, Ukraine has recently affirmed its commitment to the European Green Deal and updated its Nationally Determined Contribution (NDC) in 2021.

Recognizing climate change as the defining factor of global development in this century, Ukraine has begun focusing on climate risks and planning for adaptation. Ukraine's climate policies have traditionally focused on mitigation, given its status as one of most carbon-intensive economies in Europe, but there is increasing urgency to understand the impact climate change could have on key sectors such as agriculture and forestry.

Figure 1: Map of Eco-regions of Ukraine

Source: Buksha et al. 2020

Agriculture is a key driver of the economy, contributing about 10% to the national GDP and employing 17% of the labor force. The sector accounted for about 44% of total exports in 2018 (World Bank 2021d). Agriculture also contributes significantly to the subsistence, food security, and livelihoods of the rural population, with about four million farmers farming 15 million hectares. However, Ukraine's agriculture exports are of low value (€436 per hectare compared to Poland €2030, Germany €630/hectare (UN 2021; FAO 2021b). Farmers face high input costs, particularly for fertilizers, and lack access to financing due to fragmented and poorly designed subsidies (World Bank 2021d). Despite very high potential, agriculture could face risks due to climate change.

The ongoing decentralization reforms and the establishment of an agricultural land market offer an important opportunity to address climate change. Territorial communities are expected to take charge of local development budgets and the management of (some) natural resources, including environmentally critical lands in Ukraine. This, combined with the opening of agricultural land markets, is expected to give communities and farmers greater control over land and resources, leading to sustainable land management. Empowering local level decision-making is recognized internationally as a good practice for better development outcomes. However, it is critical to ensure that the newly empowered decision-makers have the resources and information to make the right decisions, including on impending climate change risks.

The Government has started taking steps toward adaptation but there is a need to enhance the knowledge base. The President of Ukraine's Decree of March 23, 2021 (№ 111/2021) indicates that ecological security is being linked to national security and emphasizes the need to address climate change and adaptation. The Government has drafted two documents emphasizing the importance of increasing the resilience of forest ecosystems to climate change: National Strategy on Environmental Security and Adaptation to Climate Change through 2030 and State Strategy of Forest Management of Ukraine until 2035. However, there remains insufficient information to underpin policies and action plans.

This study lays the foundation for developing detailed adaptation planning at the national and sub-national levels. It presents a comprehensive assessment of the impacts of climate change, with a deep dive into the agriculture sector and a limited analysis of climate impacts on forests. The approach and data generated can be used for deep dives in other sectors and for developing oblast-level adaptation plans.

1.1 The Analytical Framework

The study was conducted in four stages, starting with climate projections and biophysical and economic impact assessments, followed by distributional analysis and identification of hotspot oblasts which are most likely to be affected by poverty and inequality. (Box 1, and Annex I for more details). The first stage involved projections of key climate variables for three future periods: the near future (2021-2040), mid-century (2041-2060), and end of the century (2081-2100) under RCP 2.6 (compatible with a 2°C global warming limit by 2100), RCP 4.5, (compatible with a 2.4°C global warming limit), and RCP 8.5 (compatible with a 4.3°C global warming limit). Seven key climate variables were simulated: min, max, and mean air temperature; precipitation; surface wind speed; and relative humidity. Additional climate indexes were also calculated for sectoral analysis.

The second stage assesses the biophysical impacts of climate change on forestry and the agricultural sector. Specifically, the forestry assessment studies changes in the ecological amplitude (zones of tolerance) for eight main forest-forming species in three future periods under RCP 4.5 and RCP 8.5. These species include Norway spruce, European beech, common hornbeam, Scots pine, English oak, black alder, silver birch, and black locust. The assessment under RCP 2.6 was not conducted due to limited climate data for this scenario. The agricultural analysis simulates changes in yields and production for five prominent crops in the near future (2026-2035) and mid-century (2046-2055) under RCP 4.5 and RCP 8.5. These are barley, maize, soybean, sunflower, and winter wheat, which together accounted for 61% of production volume in 2018 (Ukraine Statistics 2021).

Figure 2: Methodology

Climate protection	Biophysical Impact	Economic impacts	**Distributional impact**
For: Near Future (2021-2040). Mid-Century (2041-2060), End of century (2081-2100) **Scenario: RCP 2.6, RCP 4.5, RCP 8.5** **Resolution: ~ 10 x 10 km**	**On: Agriculture and Forestry** **For: Near Future, Mid-Century** **Scenario: RCP 4.5, RCP 8.5**	**On: Agriculture** **For: Near Future, Mid-Century** **Scenario: SSP2 & RCP 8.5**	**Impact analysis of the effects on agriculture by income group, impact on poverty and Gini coefficient** **For: Near Future**
Euro CORDEX (GCMs & RCMs)	Agriculture: WOFOST Model (change in yield) for five major crops	Agriculture; IMPACT Model (change in production & value) for five major crops	Local data on household and expenditures
Core climate indicators: min, max and mean temperature, precipitation, surface wind speed, relative humidity	Forestry: assessment of eight key forest species for ecological amplitude using local forest typology models		Impact of increases in consumer/producer prices and agricultural income change on poverty and Gini coefficient
Climate indicators for sectoral analysis, and vulnerability indicators			

During stage three, economic impacts of climate change on agriculture were estimated by assessing changes in production values for the same three future periods under RCP 8.5 (future crop prices are not available under RCP 4.5). During stage four, utilizing the agricultural assessment results, the distributional analysis assessed the impacts of climate change on households' real incomes through its impacts on food prices and agricultural income. Based on existing socio-economic data and all analysis results, "hotspot" oblasts were then identified and highlighted for prioritizing adaptation actions. Similar analysis for the impact of climate change on forests was not conducted due to the lack of socio-economic data at subnational levels and the onset of the COVID-19 pandemic.

The analysis was conducted at a highly granular level, but most of the results are reported at the oblast level to present spatially meaningful results. Most of the analysis was conducted at the individual grid level, covering more than 7,400 grid cells over the entire territory of Ukraine. Then the results were aggregated at the oblast level to facilitate appropriate and tailored decision-making and planning at the local administrative level. Reporting results at the oblast levels also allow inter-regional comparisons and prioritization of locations that need adaptation solutions.

1.2 Caveats and Limitations of the Methodology

The climate projections presented in this report have uncertainty ranges and should not be interpreted as forecasts. The uncertainties in constructing and running climate models are inherent and manifold. Climate models cannot fully capture the complexities of climate systems. When constructing climate models, simplifications, assumptions, and choices of parametrizations are made, resulting in model and projection errors. Although certain methods have been applied to reduce these systematic and inherent errors, climate projection results are reported in ranges with upper and lower limits of confidence intervals. Since the projected climate variables are used as inputs for agricultural assessments, the results for agricultural projections are also presented in a probabilistic distribution.

The study did not consider extreme events due to the complexity in data analysis on this specific aspect of climate change and higher uncertainty of their projections. The analysis focused on the long-term impacts of climate change on specific sectors. The frequency and intensity of extreme weather and climate events, including heatwaves, thunderstorms, heavy precipitation, hailstorms, squalls, tornadoes, heavy snowfalls, freezing rains, accumulation of wet snow, icing, etc., could have significant impact on the yields and value of agricultural production but are not modeled in this study. Estimation of mean changes is justified for this study due to a higher uncertainty of extreme projections, especially for granular approaches such as the CORDEX experiment (Seneviratne 2012). However, extreme events, especially those known as "low-likelihood, high-impact events," (IPCC 2021) could have additional and significant consequences on all sectors and ecosystems, resulting in a significant number of lost jobs and livelihoods. Most losses would be concentrated in sectors of middle and lower-income workers – manufacturing, utilities, retail, and tourism. The AR6 report assigns low confidence levels to the occurrence of these events, which does not exclude their possibility, but instead reflects the limits of these events' predictability. Potential impacts of such events on Ukraine need to be analyzed through a separate study.

Box 1: Description of Methodologies

A detailed description of the methodology and models used is given in Annex I.

Climate projections. Datasets from the European branch of the International Coordinated Regional Downscaling Experiment (EURO-CORDEX) initiative at a resolution of 0.11 degrees (~12.5 km) are obtained to produce daily climate projections over approximately 7,400 grid points for the entire territory of Ukraine for more than 100 years. Over 300 datasets for seven climate variables under three RCPs are obtained for the projections from various combinations of multiple Regional (RCM) and Global (GCM) climate models. Historical and baseline data are obtained from the E-OBS v20.0e gridded dataset with the same spatial resolution. The three RCPs are selected based on the availability of data and include **RCP 2.6 (compatible with a 2°C global warming limit by 2100), RCP 4.5 (compatible with a 2.4°C global warming limit), and RCP 8.5 compatible with a 4.3°C global warming limit).**

Systematic errors inherent in climate modeling are reduced through the utilization of multi-model ensembles for climate projections and bias-correction of climate data, resulting in probabilistic projections (i.e., climate variables are projected in ensemble ranges with upper and lower limits at 95% confidence interval). The means of the ensembles are reported as they represent the most probable values. The results are reported as future changes in climate variables compared to the base period (1991-2010). The historical period (1961-1990) is also used to compare the results with older studies and the changes that have already taken place between this period and the baseline.

Forestry impact assessment. The forestry assessment was conducted using Vorobjov's climate-related forestry typology model and Didukh's model of suitable environmental condition for plants. Vorobjov's forestry typology model consists of three climate indexes with the most significant effects on forest growth, condition, productivity, and biodiversity: humidity (the ombro-regime), continentality, and frostiness (the cryo-regime). Based on these three indexes, the lower critical (minimum) and upper critical (maximum) limits and the interval between them (referred to as "zone of ecological amplitude") are established for each of the eight forest-forming species, using the methodology developed by Didukh.

Key climate variables are used to calculate Vorobjov's three indexes to determine changes in the zones of ecological amplitude for these species in three future periods compared to the baseline of 1991-2010. An open-source geographic information system application (Q-GIS) was used to perform spatial analysis and visualize the results.

Agricultural impact assessment. The World Food Studies Crop Simulation (WOFOST) model is used to assess the biophysical impacts of climate change on yield potentials of five key crops in the near future and mid-century, relative to the baseline period (2006 – 2015), using meteorological inputs from climate projections. The WOFOST was calibrated and adapted for Ukraine by the Ukrainian Hydrometeorological Institute (UHMI). The yield projections were then combined with changes in land areas under each crop in 2030 and 2050 and changes in prices for those years under the combined SSP2 – RCP 8.5 scenario from the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) developed by the International Food Policy Research Institute (IFPRI) to estimate changes in production and production values relative to the baseline period. The reported results are centralized values for 2010, 2030 and 2050 in three sets of projections: low, mean, and high, which reflect an uncertainty range associated with the uncertainties in climate projection.

Distributional analysis. The analysis utilizes comprehensive data collected for 250- 500 individual households for each oblast, which allows for identification of variations in income distribution due to climate-induced changes in the agricultural sector. It provides two key outputs: increases in the prices of key food products as a result of climate change, which allows for estimates of 2030 price increases for key agricultural commodities under RCP 8.5 and RCP 4.5; and changes in agricultural incomes as a result of the effects on yields, production, and production values.

Identification of "hotspot" oblasts. Using the results from climate impacts on agriculture, "hotspot" oblasts are grouped based on the: i) change in oblast GDP due to the projected changes in agricultural production; ii) change in agricultural production values; and iii) change in household incomes, poverty, and inequality.

The study also does not consider the effects of pests and diseases on agriculture and forestry and analysis of more climate change scenarios. Damage caused by pests and diseases is triggered by a warmer and drier climate, which could be more relevant for Ukraine's south and east, were not analyzed. (See Figure 31.) The Coupled Model Intercomparison Project (CMIP6) is expected during the latter part of 2021, and further analysis using CMIP6 data can provide information on these parameters. It should be also noted that climate projections were available from only three regional climate models (RCMs) at the time of the study to estimate precipitation for RCP 2.6 scenario, while for RCP 4.5 and RCP 8.5, the full ensembles consist of 43 and 34 RCMs, respectively. Therefore, results for RCP 2.6 are only indicative and are not used in further agriculture and forest vulnerability assessments.

CHAPTER 2:
HOW WILL UKRAINE'S CLIMATE CHANGE IN THIS CENTURY?

2.1 Summary

Winters are expected to be warmer, and summers hotter; a consistent trend of increases in annual average temperatures is expected across the country with progressively higher increases towards the end of the century. Over the course of the year, daily minimum temperatures rise most sharply in the cold season, while daily maximum temperatures increase the most in the summer season. The projected ranges of average annual temperature increase for the three periods [the near future (2021-2040); mid-century (2041-2060); and end of the century (2081-2100)] and under RCP 4.5 already exceed the observed historical range of changes during the 1991-2010 baseline period. The highest increase in average annual temperature for the entire country – by nearly 4.3°C – is projected under RCP 8.5 at the end of the century.

In all scenarios, monthly precipitation will increase by 2100. Precipitation also follows a complex trend in all three future periods, with its pattern changing in different ways in colder and hotter seasons. In the period at end of the century, wetter weather is expected in colder months and drier weather in warmer months, particularly in the south and east, but this pattern is not consistent and there are significant variations across regions. By the end of the century, the projected precipitation changes spread increases, with higher ranges anticipated under RCP 8.5. The precipitation pattern is characterized by major increases in winter months for most of Ukraine. The ranges of changes are much lower in summer months. The projected mean increase rises to almost 10 mm in December in the far future. The projections made under RCP 4.5 show comparatively smaller precipitation ranges.

Annual seasonal cycles will be altered. In particular, the projected monthly temperature increases are generally higher in all three periods during the summer months in warmer regions and during the winter months in colder regions. These temperature increases will likely result in continuing reductions in the annual temperature ranges already observed. Additionally, the number of ice days and frost nights are expected to decrease while the number of tropical nights will increase. These changes will have significant implications for ecosystem dynamics and vegetation growth.

The southern and central oblasts will become drier, and northern oblasts will become wetter. At the end of the 21st century, the southern regions will experience an average daily maximum July temperature above 34°C, a level never before observed in Ukraine, with the southern steppe remaining the hottest area until the end of the century. Rising temperatures in summers will result in heatwaves and increased aridity in the south and east. Under RCP 4.5, summer days will start earlier in the year and end later; and under RCP 8.5, the number of summer days will increase by an average of 42 days by the end of the century. The largest temperature increases are expected in the east and northeast of Ukraine (Sumska, Kharkivska, Luhanska) and the smallest in the west (Volynska, Lvivska, Ivano-Frankivska). Higher

increases in average daily minimum temperatures indicate warmer nighttime temperatures, which could increase the need for indoor cooling for longer periods each year.

The largest precipitation increases are projected for the northern oblasts (Rivnenska and Volynska), while the lowest precipitation increase (and even a decrease in the warm months) are expected for the southern and central areas. Changes under RCP 8.5 show broader ranges of precipitation variability across oblasts, suggesting strong spatial differences.

Cities are projected to experience intense temperature increases toward the end of the century (over +5.0°C in summer in Luhansk and winter in Kyiv), aggravated by the urban heat island effect. The highest warming in summers is expected for Kyiv in July. During the end of century period, warming will reach +5.0°C in cities in almost every part of the country in every month.

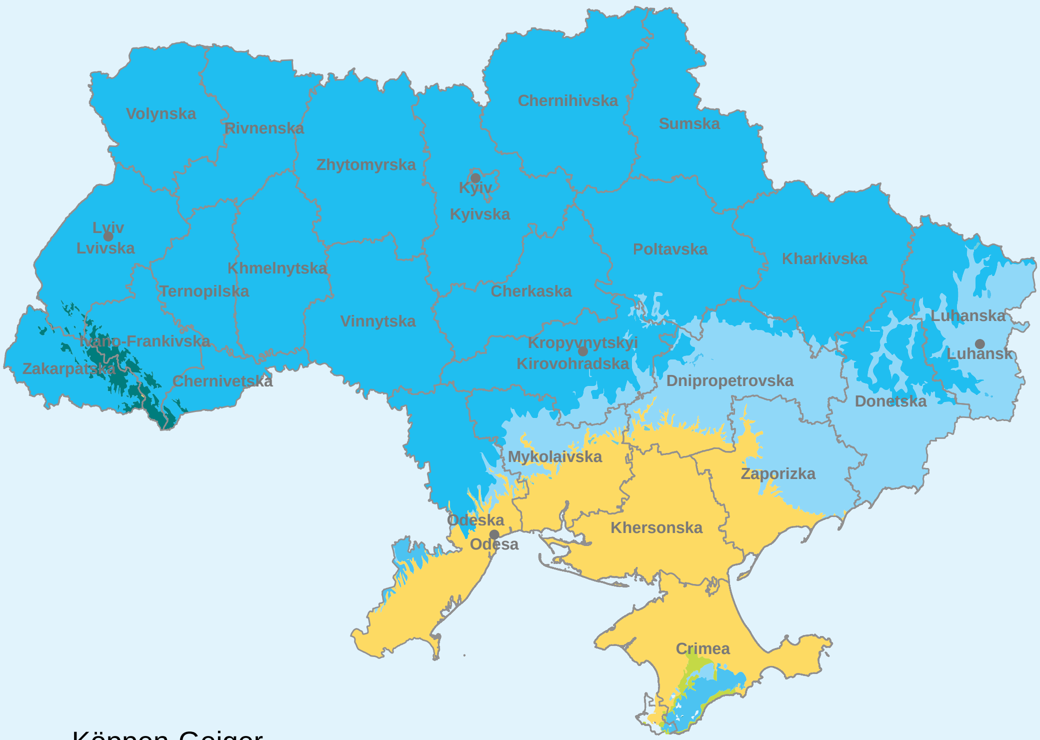
2.2 Recent Climatic Changes in Ukraine

Ukraine's current climate reflects significant changes that the country has been experiencing as the result of climate change. The current climate of most of the country (85%) is temperate continental, or "cold," as classified according to the Koppen-Geiger climate classification (see Figure 3). The country consists of several climate zones. The cold zone with no dry season and warm summer (Dfb) covers over 70% of the territory in the west, north, and central parts of the country, as well as the Crimean Mountains, and corresponds to the forest and forest-steppe eco-regions. The zone with hot summer humid continental climate (Dfa) includes over 14% of the country, across the southeast and the northern steppe. The cold semi-arid climate zone (BSk) corresponds to the southern steppe and covers over 14% of the south including most of the Crimean Peninsula. The subarctic climate zone (Dfc) covers the Carpathian Mountains, where tundra climate (ET) is found at the highest altitudes. The humid subtropical climate zone (Cfa) and temperate oceanic climate zone (Cfb) cover the southern coast and northern part of the Crimean Mountains. Each of these four climate types account for less than 1% of the country's territory.

Ukraine's climate has changed significantly over the last 60 years, with temperatures rising at an increasing rate. Since the late 1990s, the mean annual air temperature has been consistently higher than that between 1961 and 1990. Since 2007, it has exceeded the norm by 1.5° C. The last decade, especially the years since 2015, were the warmest ever in Ukraine, and in the Northern Hemisphere in general. In some years, the increase in mean annual air temperature surpassed 2.0 °C (2.2°C in 2007, 2.3 °C in 2015, and 2.7 °C in 2019). The daily minimum temperature rise is largest in the cold seasons, while maximum daily temperature increases the most in summer. Such changes have led to a decrease in the duration of the cold season, the number of frost days, and the severity of winters. At the same time, the changes have resulted in a longer and hotter growing season, an increased number of summer days, and, accordingly, a longer recreation season. Consequently, the number of hot days and the duration of the hot spells, heat load, and heat stress on the human body are also increasing.

The precipitation regime in Ukraine has also changed: While total annual precipitation has not changed, there has been a redistribution of precipitation levels among different seasons. Increases in precipitation levels are observed in autumn, and decreases in winter, with even greater decreases in the summers. Furthermore, the unevenness of precipitation and its intensity have increased, causing an extension in the duration of the dry periods. Rising air

Figure 3: Climatic Zones in Ukraine, 1980-2016



Köppen-Geiger
climate classification
(1980–2016)

- BSk Arid, steppe, cold (14.3 %)
- Cfa Temperate, no dry season, hot summer (0.3 %)
- Cfb Temperate, no dry season, warm summer (<< 0.1 %)
- Dfa Cold, no dry season, hot summer (14.1 %)
- Dfb Cold, no dry season, warm summer (70.4 %)
- Dfc Cold, no dry season, cold summer (0.9 %)
- ET Polar, tundra (<< 0.1 %)

Source: Beck et al. 2018.

temperatures and uneven precipitation have resulted in lower accumulations of moisture in the soil, leading to an increase in the frequency and intensity of droughts. Drought episodes have almost doubled in the last twenty years with the dangerous tendency of increasing the recurrence of arid conditions in the Polissya eco-region, which was previously sufficiently wet, and also causing aridity in the northern regions of the forest-steppe.

2.3 Annual Temperature and Precipitation Projections

The temperature and precipitation trends show greater changes toward the end of the century. The expected increases in average annual temperature and precipitation during this century are presented in Table 1. Projected average annual temperature change by the end of the century for RCP 4.5 and RCP 8.5 scenarios, compared to the base period and the differences between the two scenarios, are presented Figures 4a, 4b, and 4c.

Table 1: Increases in Average Annual Temperature and Precipitation

	2021-2040 temperature / precipitation	**2041-2060** temperature / precipitation	**2081-2100** temperature / precipitation
RCP 2.6	0.8±1.4°C / 3 %	1.0±1.7°C / 2 %	0.9±1.8°C / 6 %
RCP 4.5	0.9±1.4°C / 6 %	1.5±1.7°C / 5 %	2.1±1.8°C / 6 %
RCP 8.5	1.1±1.5°C / 4 %	2.0±1.7°C / 5 %	4.3±2.1°C / 8 %

Figure 4 : Projected Annual Mean Temperature Increases

Figure 4a: Projected Annual Mean Temperature Increase (compared to baseline 1991-2010) for RCP 4.5 at the End of the Century

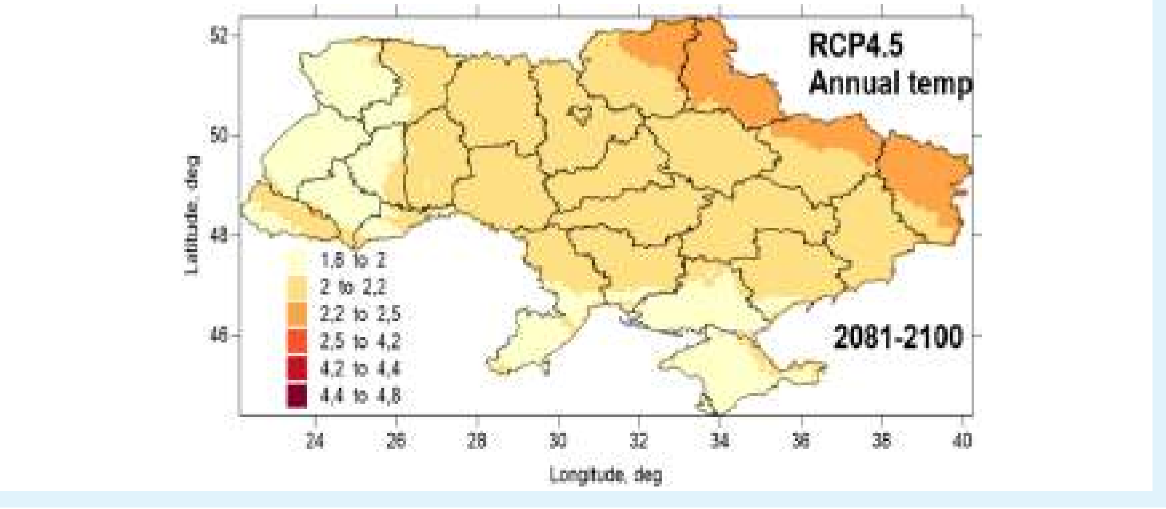


Figure 4b: Projected Annual Mean Temperature Increase (compared to baseline 1991-2010) RCP 8.5 at the End of the Century

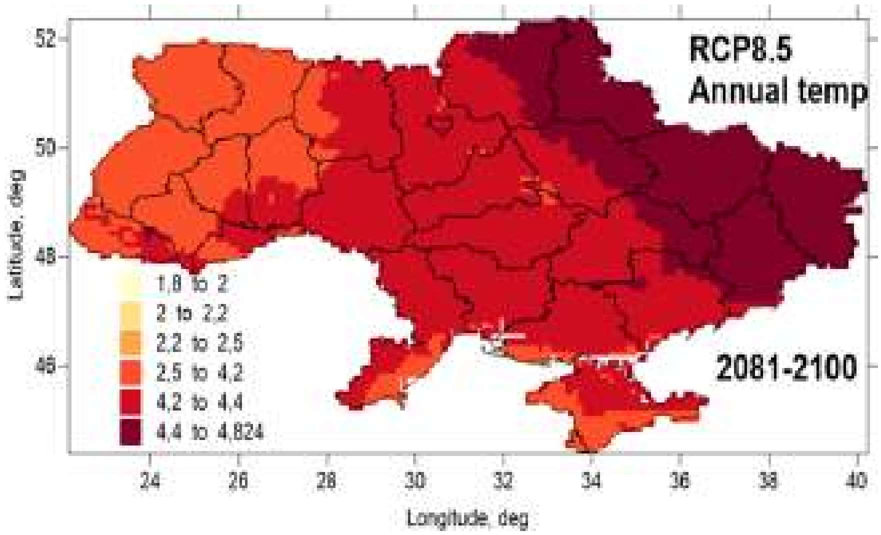


Figure 4c: Temperature Differences Between the Two Scenarios at the End of the Century

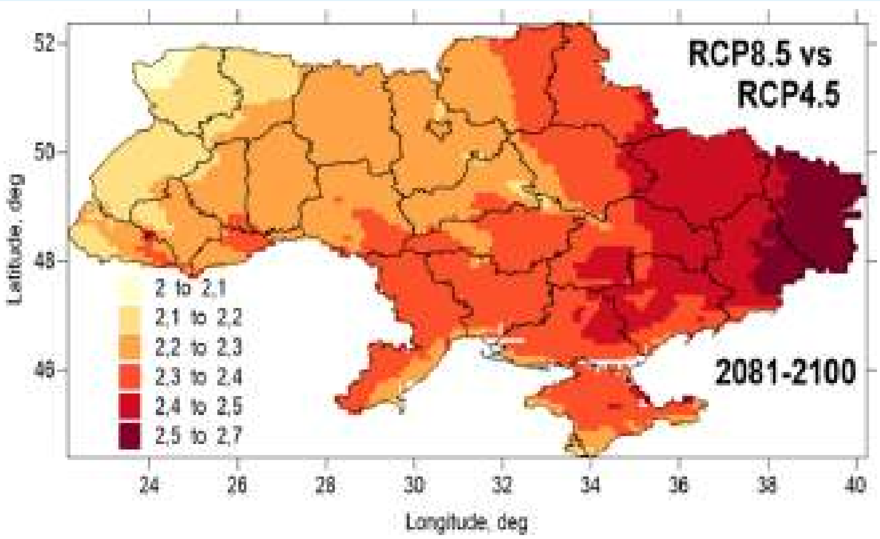


Figure 5: Annual Temperature Change

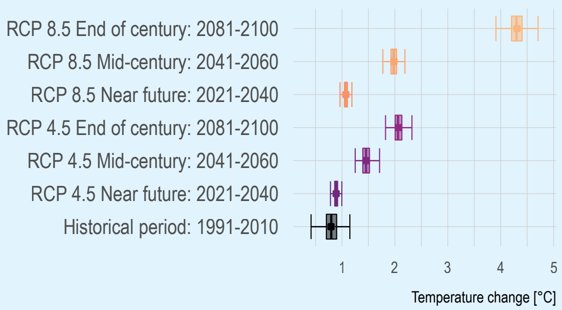
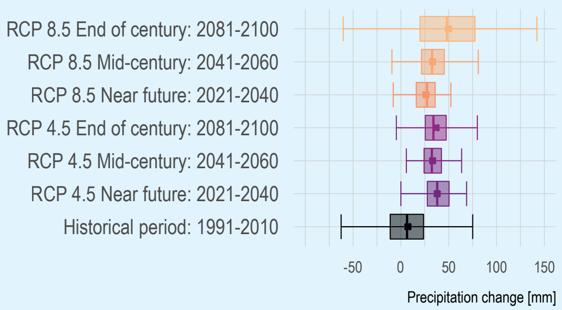


Figure 6: Annual Temperature Change



The RCP 4.5 emission scenario (which assumes some climate policies) causes a minor difference in temperature increase in the near future but has a greater impact in mid-century and even more so at the end of the century. The range of mean changes in annual air temperature is approximately +2.0±0.2°C under RCP 4.5 and is much more pronounced (4.2±0.2°C) under RCP 8.5. The difference between the projected temperature changes under RCP 4.5 and RCP 8.5 rises sharply from 0.5°C in 2041-2060 to 2.2°C in 2081-2100. The spatial distributions of temperature rise under both RCP 4.5 and RCP 8.5 are similar over time, with the highest temperature increases in the northeast and the lowest in the west and northwest and near the Black Sea coast. The highlighted territories are most exposed to warming under the highest emission scenario (RCP 8.5) without mitigation measures. Small increases in the annual precipitation totals are projected for all periods across all RCP scenarios. The ranges for the projected changes in precipitation and temperature and historical data for the base period (1991-2010) are given in Figure 5 and Figure 6 on the box-whisker-plots.[3] These figures present the spreads of changes in average annual temperature and precipitation over the territory of Ukraine, showing the mean, minimum, and maximum values under each RCP in every period.

In all three future periods, precipitation follows a complex trend, diverging between colder and hotter seasons. The pattern of monthly changes in precipitation is expected to be wetter in colder months and dryer in warmer months, particularly in the southern and eastern regions. However, significant differences are expected across regions, and this pattern is not observed everywhere. In general, monthly precipitation projections confirm the previous findings of precipitation

[3] This figure and later the box and whisker diagrams: the lower and upper hinges of boxes correspond to the first and third quartiles (the 25th and 75th percentiles). The upper whisker extends from the hinge to the largest value no further than 1.5º (inter-quartile range) from the hinge. Inter-quartile range is the distance between the first and third quartiles of data distribution.

Figure 7: Annual Precipitation Change (mapped)

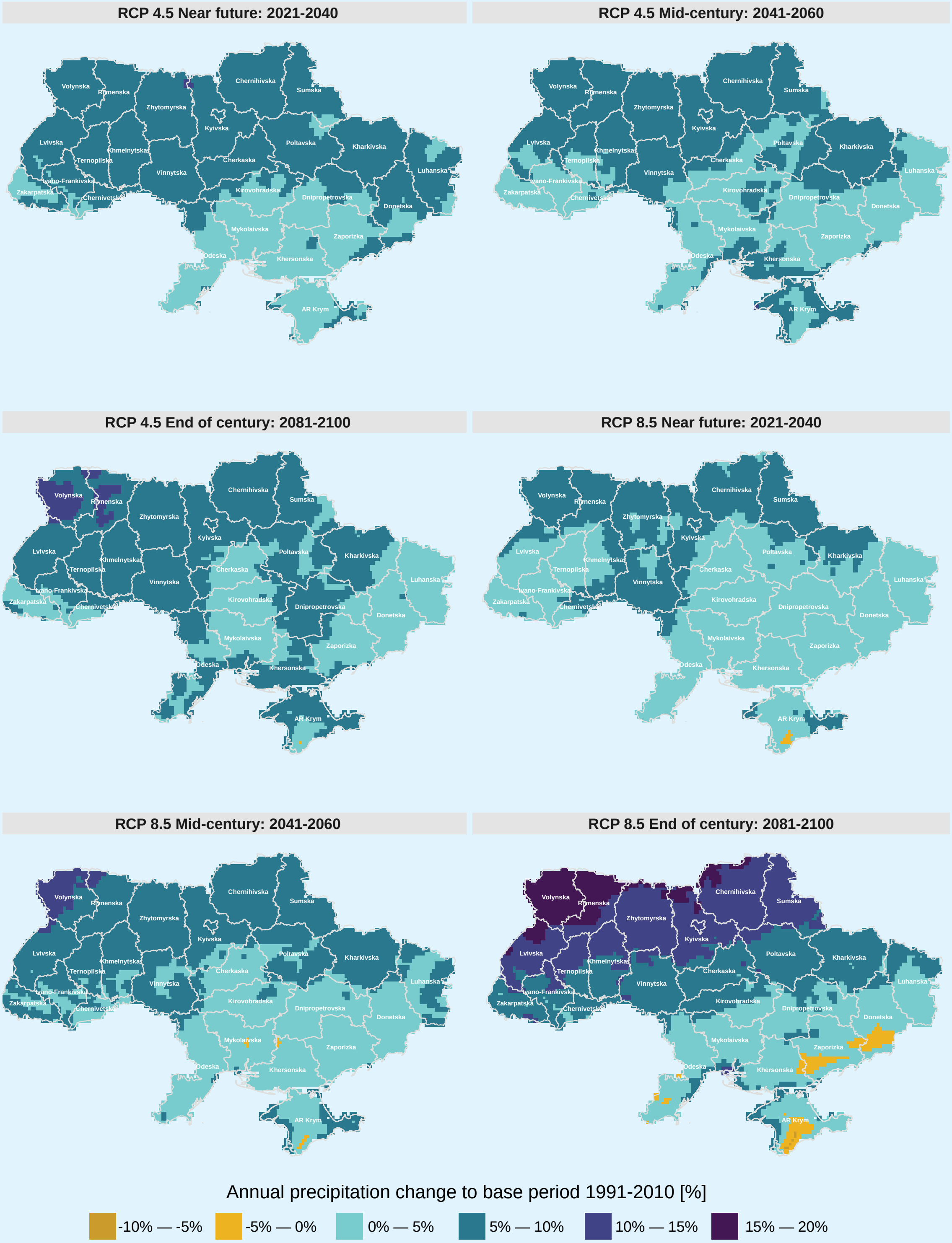


Figure 8: Monthly Precipitation Change in RCP 4.5 – End of Century Compared to Baseline

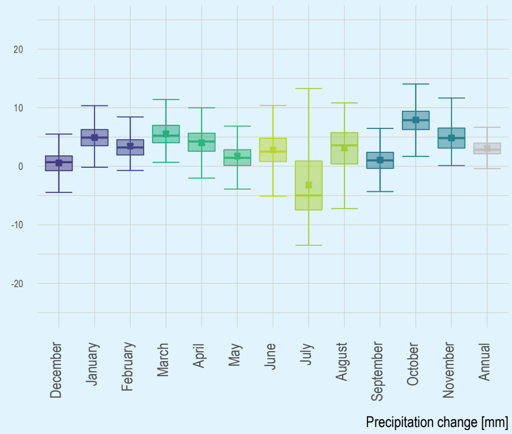
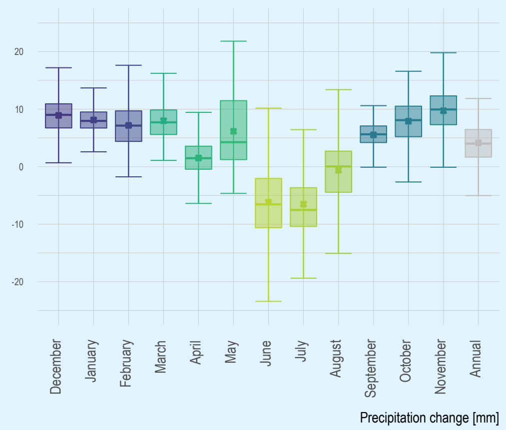


Figure 9: Monthly Precipitation Change in RCP 8.5 – End of Century Compared to Baseline



redistribution in the annual cycle with more noticeable changes under RCP 8.5, particularly during summers (Figure 8). Monthly precipitation is projected to increase under both RCPs by 2100 (Krakovksa et al. 2017), by which time the impacts become more pronounced, especially during winters.

The projected monthly temperature increases in all three future periods are generally higher in the summer months in hotter regions and in the winter months in colder regions. Monthly temperature changes, particularly changes in the annual temperature range (ATR), are of special interest for future climate impact assessments. The ATR signifies the difference between the average temperatures of the warmest and coldest months in a year. Historical data show that ATR has generally been declining in Ukraine (Balabukh and Malitskaya 2017), and the projections indicate that this decline is likely to continue. The main reason for this decline is the relatively higher increase in temperature during the coldest months.

2.4 Projections at the Oblast Level

Regional temperature changes show a consistent increase until the end of the century under RCP 4.5 and RCP 8.5, with increases higher in average daily minimum temperatures than in daily maximum temperatures. Figure 10 shows both precipitation and temperature projections for each oblast for both scenarios. For each projected period, the increase in minimum, maximum, and mean temperatures [°C] is compared to the base period. Under RCP 8.5, temperatures are higher than under RCP 4.5, but most notable is the increase in minimum temperatures (blue bars) in both scenarios. It is much more intense than the increase in maximum temperatures, indicating increasing aridity and warming in the summer months and fewer cool days in the winter. The width of the bands describing the range of precipitation changes in the scenarios and projection periods shows a significant increase in regional variability, which becomes more pronounced at the end of the period. The projected warming temperatures and shift in precipitation patterns caused by global warming will, in turn, lead to increased water demand due to higher evapotranspiration rates.

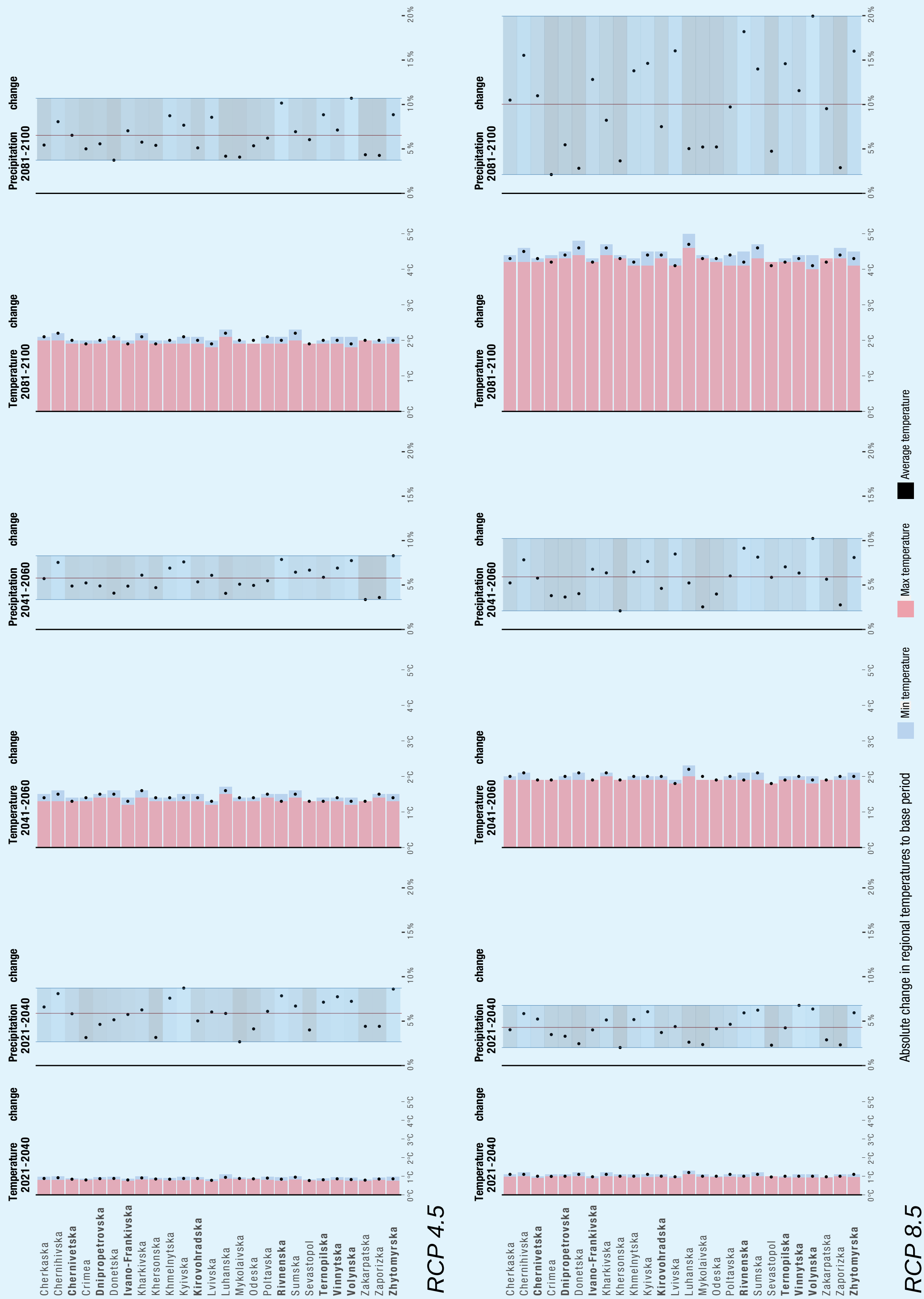
These climate trends are of critical importance for regions with a higher proportion of rural population which is dependent on agricultural income, as distributional effects of climate change on household incomes are expected to be stronger in oblasts where households rely on agricultural production. These oblasts are Chernivetska, Dnipropetrovska, Ivano-Frankivska, Kirovohradska, Rivnenska, Ternopilska, Vinnytska, Volynska, and Zhytomyrska.

The regional variations in precipitation become stronger by the end of the century. For precipitation, projected changes are more heterogeneous across RCPs and time horizons. In general, the southern and central areas are characterized by the lowest increase in precipitation, with decreases even in warm months. In case of RCP 4.5, in both near future and middle-of-century periods, a low increase in the average annual precipitation level, with the highest decrease in summers, is registered for the southeastern (Khersonska, Zaporizka, Donetska, Luhanska, Mykolaivska, and Odeska) and western oblasts (Zakarpatska). In contrast, larger precipitation increases are recorded in the northern oblasts (especially in Rivnenska, and Volynska in the northwest).

2.5 Projections at the City Level

Cities are projected to experience intense temperature increases through the end of the century (over +5.0°C in summer in Luhansk and in winter in Kyiv), aggravated by the urban heat island effect (see Box 2). Monthly mean temperatures and precipitation — as annual cycles with their projected changes over the base period (1991-2010) — are presented and analyzed for five representative cities in different geographical regions of Ukraine, including Kyiv (north), Lviv (west), Kropyvnytskyi (center), Luhansk (east), and Odesa (south). They are also aggregated for the entire country. For all periods, the annual cycle of air temperature has the same pattern, with July as the hottest month and January as the coldest. Historical monthly temperature data from E-OBS (1991-2010 period vs. 1961-1990) shows that the most warming has taken place in winter and summer months, with slight cooling in December in all cities except Lviv; Luhansk (-0.3°C in May) and Kropyvnytskyi (-0.1°C in May). Warming during the other winter months (from historical to the baseline period) is comparable with temperature increases projected throughout the mid-century period under RCP 8.5 and increases in max-

Figure 10: Projected Changes in Temperatures and Precipitation by Oblast



imum temperatures are projected in the cities of Kyiv (+2.4°C) and Luhansk (+2.3°C), where lower winter monthly temperatures are typically observed. The highest summer temperature increases have been recorded in Kyiv in July (+1.8°C/ from historical to baseline period), caused by the urban heat island effect.

In the near future projections, the highest temperature rises are in March for all cities under both RCP scenarios. And the warming is over the 5-95% range only in March for RCP 4.5 in the ensemble of RCMs. In other months and scenarios, uncertainties of the ensemble of RCMs are significant, resulting in low confidence of the estimates.

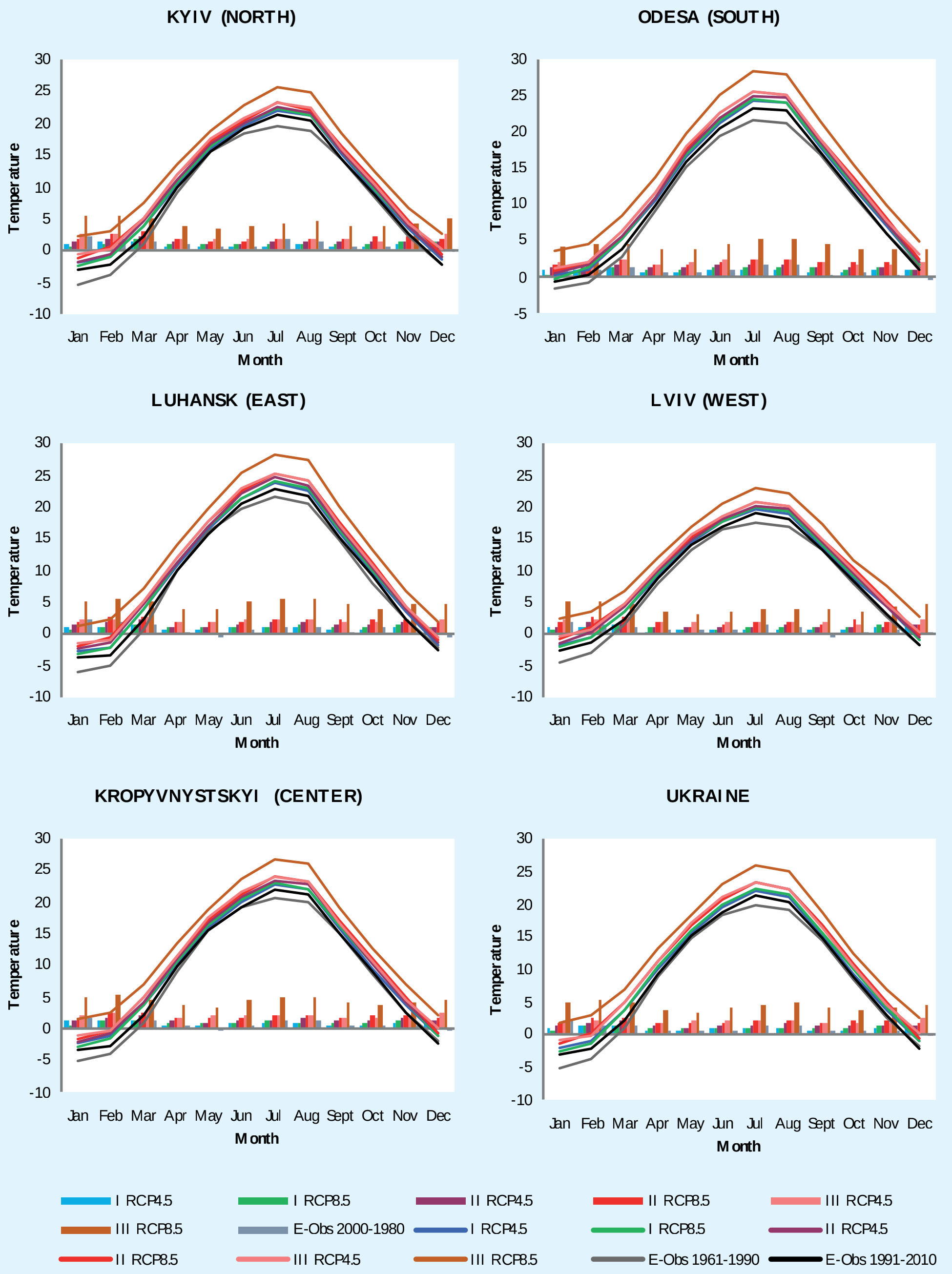
During the middle of the century period between 2041-2060, the differences between the two scenarios become apparent, and in Ukraine's cities, strong temperature signals are observed for almost all months, giving rise to high confidence in the warming projections. Warming in other winter months is comparable to the temperatures projected – through the middle of the century under RCP 8.5 and through the end of the century under RCP 4.5, with the maximum increases projected for Kyiv (+2.4°C) and Luhansk (+2.3°C), where lower winter monthly temperatures are typically observed.

During the end of the century period (2081-2100), the tendency for increased warming in colder regions in both the winter and summer months is even more pronounced than previously understood, and the difference between scenarios is the largest (between +2.0°C to +2.7°C). During the 21st century's last 20-year period, warming will reach +5.0°C in almost for every month in cities in every region.

With further warming, annual precipitation will increase for all regions during all periods, with redistributions occurring during different months throughout the year.

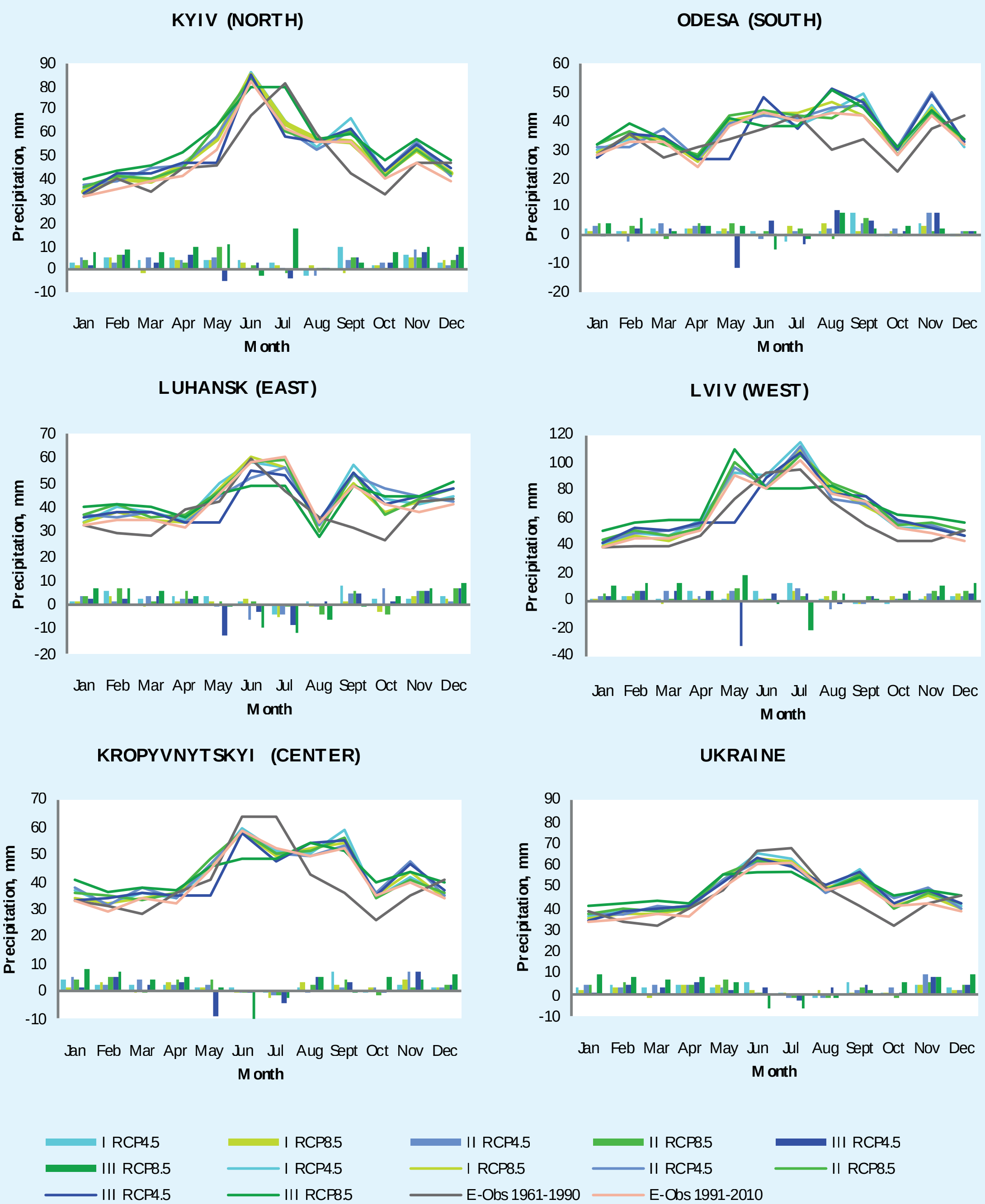
- **Kyiv (north)**: The highest warming has been recently recorded during winter in January (+2.4°C) and during summer in July (+1.8°C), caused by the urban heat island effect. Further warming is expected through the end of the century under the highest emission scenario, RCP 8.5, which can result in higher monthly temperatures each year; this means an absence of winter seasons, even in the north of the country, and mean monthly summer temperatures over +25°C. We see the month with maximum precipitation shift from July to June. This shift has already begun, and is visible in a comparison of historic data (1961-1990) to the baseline period (1991-2010). It continues for most periods under both RCPs (with the exception of the warmest period 2081-2100 under RCP 8.5, during which the same precipitation amounts are projected for both June and July).
- **Lviv (west)**: Precipitation in the annual cycle reaches its maximum in June-July in the historic period (1961-1990). The annual distribution of precipitation changes in the base period, with more precipitation in May than June. This trend continues in all three future periods. Increased warming is likely to result in a completely new shape of the annual precipitation cycle, with maximum precipitation amounts in May and July through all three future time periods, except under RCP 4.5, when the annual cycle will likely be similar to the shape of the historic period (1961-1990) at the end of the century, with one sharp maximum in July.

Figure 11. Multi-Year Mean Monthly Temperature and Temperature Change for Different Climatic Periods and the Baseline[4]



[4] In these graphs, lines indicate absolute values, while bars show incremental value compared to the baseline (1990 – 2010).

Figure 12. Multi-Year Mean Monthly Precipitation Amounts (lines) and Projected Changes (histograms) for Different Climatic Periods, Observations, and Scenario Datasets for Cities in Different Regions and Ukraine as a Whole



Box 2: Urban Vulnerability to Temperature Extremes

With climate change, high temperature extremes will become more frequent and more severe, while the intensity and frequency of extreme low temperatures will gradually decrease (Naumann et al. 2020).

A **heat wave** is a period during which the maximum daily air temperature over five consecutive days exceeds the mean maximum historical air temperatures by 5°C (Shevchenko et al. 2014a). Ukraine had the highest incidence of heat waves during 2001-2010, with the longest being the 24-day heatwave in **Luhansk** (Shevchenko et al. 2014b). Heatwaves are likely to become more frequent, intense, and long-lasting following a 20% increase in projected average daily maximum temperatures (see Figure 13) in the south of the country compared to the period 1990-2001. If global warming reaches 2°C and 3°C, the occurrence probability of heat waves will increase by a factor of 10 to 20, respectively, compared to the 1981-2010 period (Naumann et al. 2020). With a disappearing winter season and mean monthly summer temperatures over +25°C, heat waves are likely to increase in frequency. This is particularly important for **Kyiv**, **Kharkiv** and **Luhansk**, which are already affected by heat waves (Shevchenko et al. 2014b).

Impact on health, infrastructure, and the economy. Heat stress affects quality of life, especially in cities due to the urban heat island effect — increased air temperature in the central part of a city compared to its suburbs. With an increasing number of hot days (Figure 15) heatstroke and cardiovascular, cerebrovascular, and respiratory diseases could become more prevalent (Naumann et al. 2020). Extended high temperatures can damage concrete infrastructure and public transportation, and adversely affect the operation of thermal and nuclear power plants (Platts 2018).

2.6 Other Climate and Vulnerability Indicators

Significant increases in the regional average daily maximum temperatures in the hottest month are projected under both RCP 4.5 and RCP 8.5. Monthly means of daily maximum temperatures over 30°C in the hottest month were observed mainly in the southern steppe of Ukraine in the baseline period (1991-2010). This region will remain the hottest until the end of the century under both the RCP 4.5 and RCP 8.5 scenarios, but projections show that the area with daily maximum temperatures above 30°C will expand to the entire southern and central parts of Ukraine (Figure 13). In the south of the country, the average daily maximum temperature in July will exceed 34°C. Such a temperature has never been observed in Ukraine in the recent past (Balabukh and Malitskaya 2017).

The number of ice days and frost nights will decrease dramatically—by 22 days—in the south of Ukraine under RCP 4.5, as shown in Figure 14. An increase in air temperature, especially minimum temperature during the cold season, will cause a significant reduction in the number of frost nights by the end of the century for both scenarios. Under RCP 4.5, by the end of the century Polissya may experience an additional decrease of 34 (or more) frost nights.

More than 100 tropical nights and up to 135 summer days per year are projected for the southern steppe during the end of century period under RCP 8.5. Rising summer temperatures will result in heatwaves and increased aridity in the south and east.

Figure 13: Temperature in the Hottest and the Coldest Months for the Baseline Period (1991-2010) and at the End of the 21st Century Under RCP 4.5 and RCP 8.5

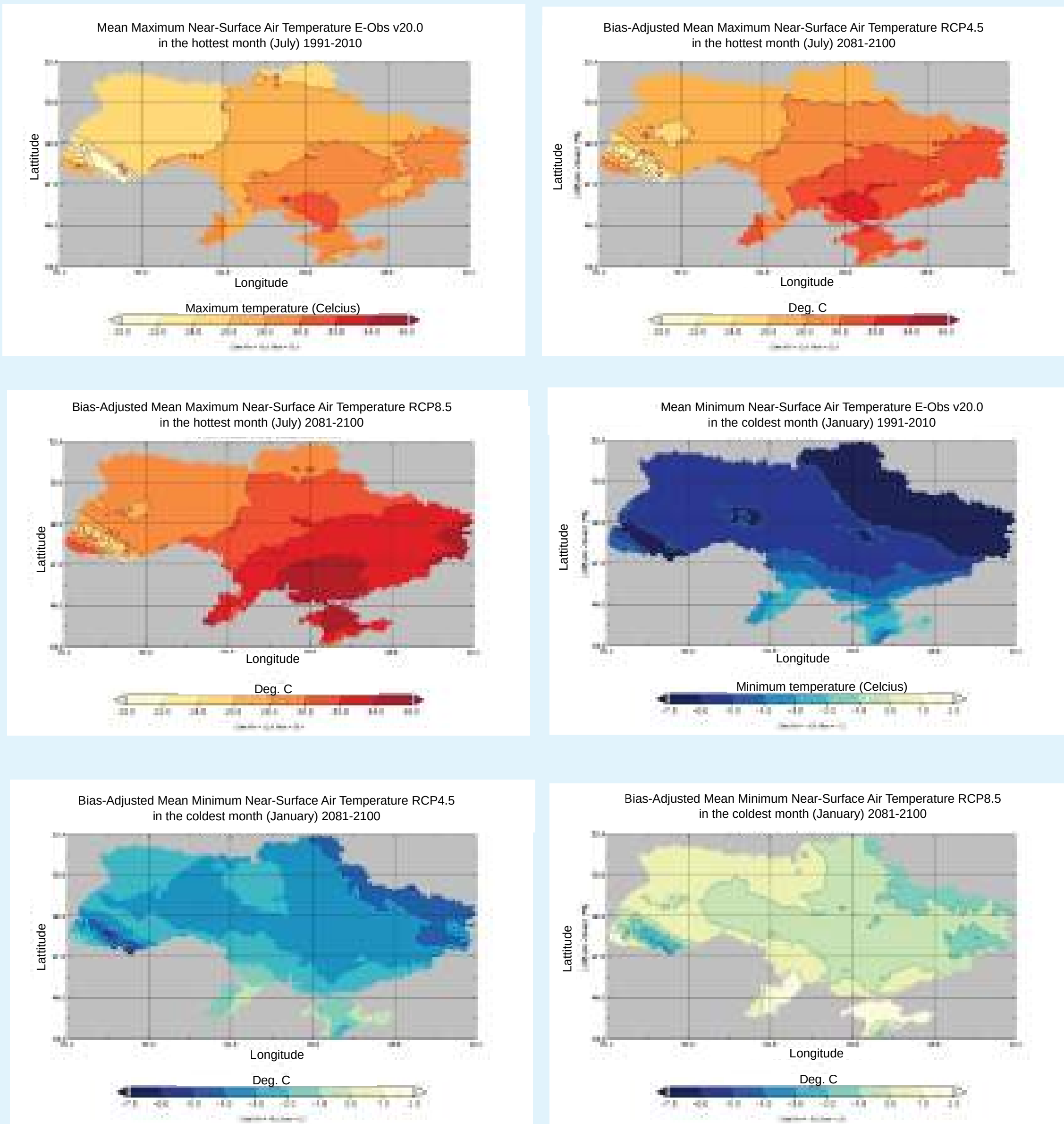
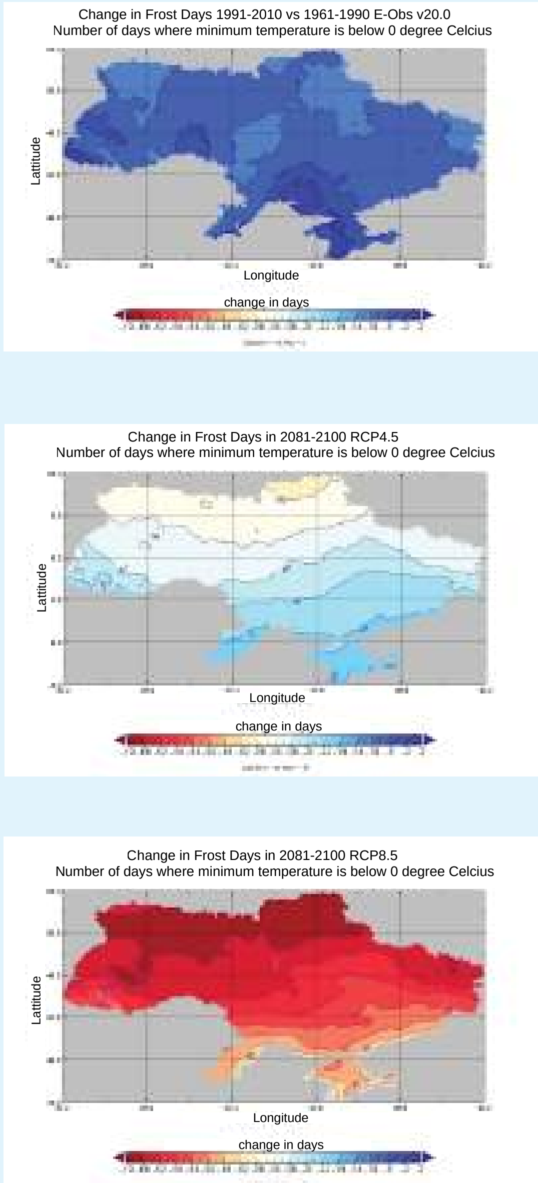
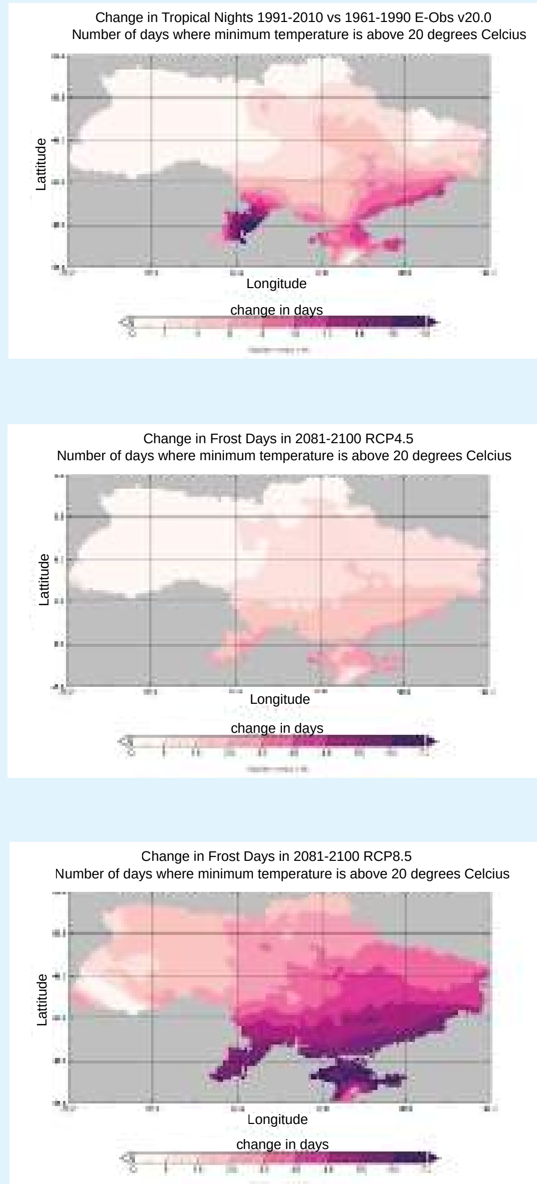


Figure 14: Changes in Frost Nights



Note: The scale shows a decrease in number of frost days from the baseline period (top) to mid-century (middle) to far future (bottom). Shades of blue represent a range from 2 to 30 fewer frost days in a year compared to the baseline. Shades of red mark a more dramatic decrease in the number of frost days predicted for RCP 8.5: from 34 to 70 fewer frost days in a year compared to the baseline

Figure 15: Changes in Tropical Nights



Note: The scale shows how tropical nights increase in a range between 8 to 72 tropical nights a year from the baseline (top) to mid-century (middle) to end of century (bottom). Lighter colors indicate a smaller increase in tropical nights over the year compared to darker shades.

The highest warming in summers is forecast for July in Kyiv, the capital of Ukraine, demonstrating the effects of urbanization. Under the RCP 4.5 scenario, in the southern steppe, the number of summer days will significantly expand as compared to the base period, with Odeska and Luhanska oblasts reaching more than 100 summer days and rising by an additional 19 days (in the range from 5-32 days) in the end of century period (Figure 15). These changes will be more than twice as high under RCP 8.5, with summer days projected to increase by an average of 42 days (the full range being 19 to 62 days) by the end of the century, exceeding 90 days in almost all of Ukraine, except the Carpathians, Prykarpattia, and Polissya, and reaching a maximum of over 135 days in the southern steppe.

CHAPTER 3:
IMPACT OF CLIMATE CHANGE ON AGRICULTURE

The impact of climate change on agriculture is assessed by modeling change in yields of key crops. The World Food Studies Crop Simulation (WOFOST) Model[5] was used to assess the biophysical impacts of climate change on yield potentials of five key crops for the near future and mid-century periods, relative to the baseline period (2006 – 2015), with the latest climate projections. The yield projections were combined with changes in land areas under each crop in 2030 and 2050, and changes in prices for those years under the combined SSP2 – RCP 8.5 scenario from the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) by the International Food Policy Research Institute (IFPRI) to estimate changes in production and production values relative to the baseline period.

Variability and uncertainty in the projections of future yields and production due to climate change is reflected in the "low," "mean," and "high" agriculture projections for each RCP scenario.[6] The specific uncertainty ranges (+/- values) allow for systematic interpretation of the modeling results. The mean projection represents the mean value of the modeled yield potential throughout the oblast. Low and high projections are the lower and upper limits of the modeled yield potential, as determined by the confidence interval. This highlights the uncertainty associated with the variations of local soil and climatic conditions within an oblast territory; such variations can be significant and are critical for estimating potential production and values of agricultural outputs.

3.1 Summary of Key Findings

An increase in crop yields for almost all oblasts is expected under the "high" projection scenario, and in the mean projections scenario for soybean and wheat in both 2030 and 2050 under both RCPs. Under a low projection scenario, yields of barley, maize, and sunflower would decrease in almost all oblasts. As the range of projected yield changes across the oblasts is large, so is the risk of outcomes below expectations in any given year. In the mean projections, the yields of barley under RCP 4.5 range from negative to positive in 2030, all negative values in 2050, and all negative for both periods under RCP 8.5. The yields of maize and sunflower vary from negative to positive under both RCP 4.5 and RCP 8.5, but the decreases will be

5 Elevated atmospheric CO_2 concentrations can increase yields at lower temperature increases. The WOFOST model accounts for CO_2 fertilization. Higher levels of CO_2 can significantly increase photosynthesis causing an increase in the total biomass generation and yield for wheat, barley, sunflower, and soybean and are less relevant for maize.

6 Mean scenario can be interpreted as the most likely realization of climate conditions that affect the crops' yield and productivity. Respectively, low and high projections resemble the most unfavorable and most favorable realization of climate conditions affecting the crop yield and productivity. High projections promote higher crops' yield and productivity with strong regional differences due to volatility of local climate conditions.

more pronounced for both crops in all oblasts under RCP 8.5 in 2050. The simulations show a consistently negative trend for barley and sunflower production and a clear positive trend for wheat and soybean under both RCPs. However, these trends should be interpreted as indicative, with considerable uncertainty ranges in the production of each crop in each region.

The projected higher prices for wheat and maize make it especially attractive to increase land areas under these crops, especially in oblasts where the yield gains through the mid-century period are significant. The increase in productivity, combined with a growing trend in price of wheat, is expected to make it a very advantageous crop in the future. The value of wheat production goes up by 29%- 59% in 2030, and by 57%- 120% in 2050. The price of maize is expected to increase sharply by 2030 and to almost double by 2050, making it attractive to grow even if yields decline. The price of soybean is also expected to increase, but less so than maize (by 32%- 48% relative to 2010, respectively). All oblasts are expected to see increases in the value of their soybean crops by 2030, and even more so by 2050, as compared to 2010.

The value of barley production in 2030 and 2050 decreases in all oblasts despite the increase in prices due to the drop in yield. Therefore, the changes in the values of barley production both in 2030 and 2050 are not significantly different from the baseline.

In the mean projection scenario, the value of production goes up in all oblasts but more so in the eastern and central-eastern oblasts. Under the low projection, all oblasts experience declines in the values of production in 2030, but twelve out of the 25 oblasts will see increases by 2050. Under the high projection, all oblasts experience increases in production values, with even larger increases in 2050 than in 2030, assuming the stated adaptation measures will take place.

Comparisons of results without adaptation[7] and with simulated adaptation measures clearly indicate the benefits of adaptation for all oblasts, especially those with higher reliance on agriculture (Cherkaska, Dnipropetrovska, Kirovohradska, and Poltavska). With adaptation measures the total production value of the five crops is projected to increase by 29% (with an uncertainty range of -32% to +91%) in 2030 and 56% (with an uncertainty range of -1% to +112%) in 2050, compared to 2010. The uncertainty range of climate change impacts on production values is large in both sets of projections (with and without adaptation), but the uncertainty range for simulation with adaptation shifts towards the possible increase in value, signaling strong confidence in risk reduction potentials of adaptation measures.

3.2 Yield Projections

Changes in seasonal precipitation and temperature are the primary drivers of projected yield [tons[8]/ha] changes in Ukraine.[9] The results on yields show a complex set of projections for the different crops under two scenarios in the two time periods, 2030 and 2050. The projections also have a certain degree of uncertainty, reflected in a probability distribution. Table 2 below shows the ranges of changes in yields for the different oblasts. Under RCP 8.5, all

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7 Change in land allocation, availability of water and shift in sowing times.

8 Ton is used throughout this document to indicate Metric Ton equal to 1000 kg.

9 The De Martonne Aridity Index was also used for this analysis. See Annex I.

oblasts will face a decline in yields in the range of -12% to -15% in 2030, with the negative trend continuing until 2050. The decreases in yields for maize and sunflower become more pronounced for both crops in all oblasts under RCP 8.5 in 2050, with a range between -23% and +3% for maize and -21% to +8% for sunflower. Additional measures aimed at maintaining optimal water balance are needed to ensure sunflower and maize yields until 2050. For wheat, yields show an increase for all oblasts in both 2030 and 2050 under both RCP scenarios. An expected high return is partially offset by a relatively high risk of outcomes below expectations in any given year.

While projected precipitation changes are complex, the upward trend in temperature coupled with an increasing CO_2 concentration in the atmosphere are crucial factors for estimating crop yields. As detailed in Chapter 2 of this report, the temperature trend is increasing overall for all seasons. In general, winters are becoming wetter and summers dryer.

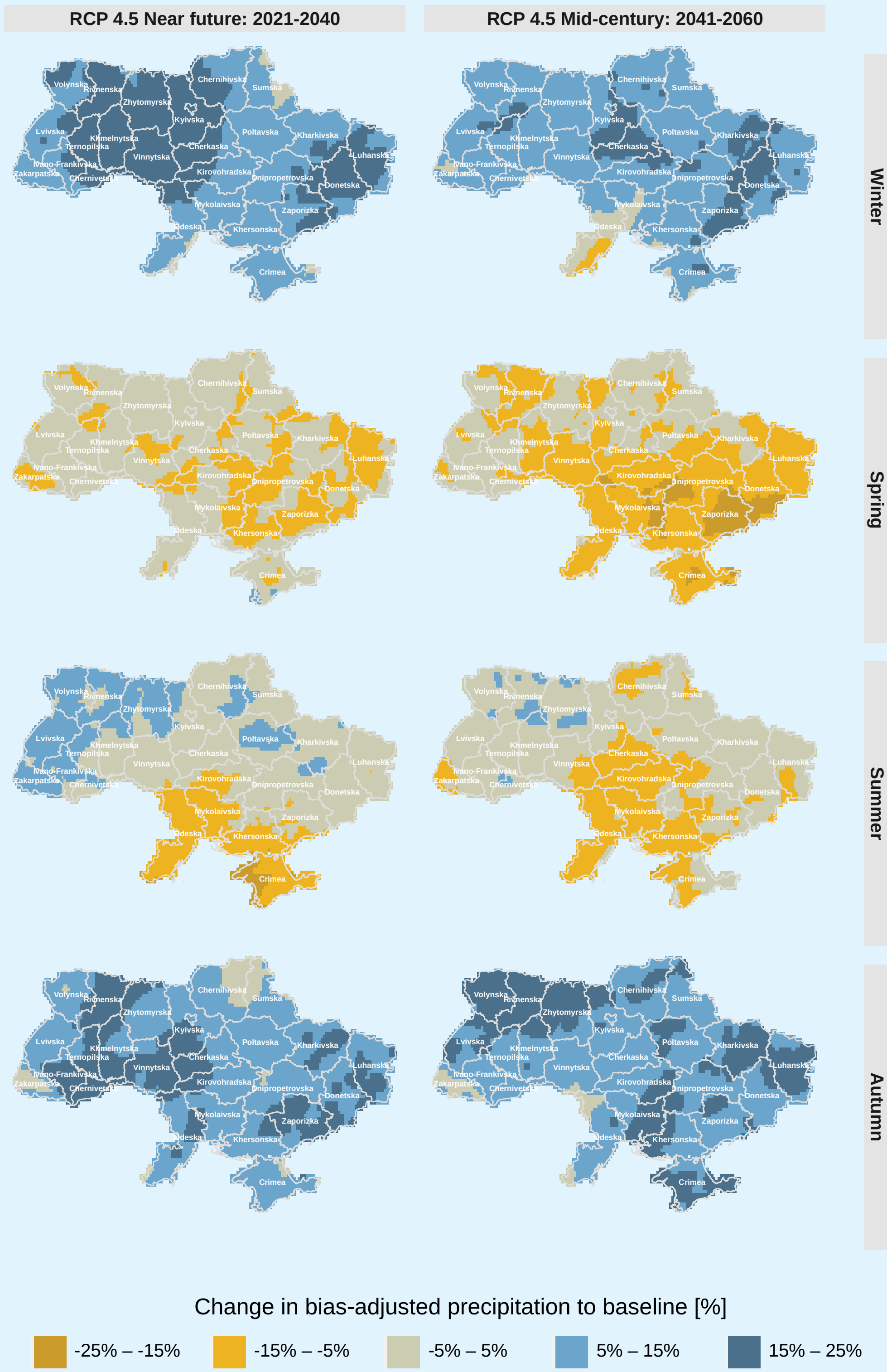
The range of possible yield changes across the oblasts is large, as is the risk of outcomes below expectations in any specific year. The modeling of yields gives a probability distribution for the ranges of values (see Table 2). The modeling also provides a low- and a high-projection scenario based on the distribution: the 5th percentile of the distribution (low) and the 95th percentile (high). These data points show the risk ranges at the two ends of the distribution. The changes in high projection are positive and often more than double the mean scenario, while the low scenario changes are often negative. The high yield projection shows an increase in crop yields for almost all oblasts in the country, and the low projection indicates a decrease in yields of barley, maize, and sunflower for almost all oblasts. Given the high resolution of the analyzed data (7,400 grid cells), yield ranges reflect regional differences in climatic conditions. The detailed map representation of yields is provided in Figure 17.

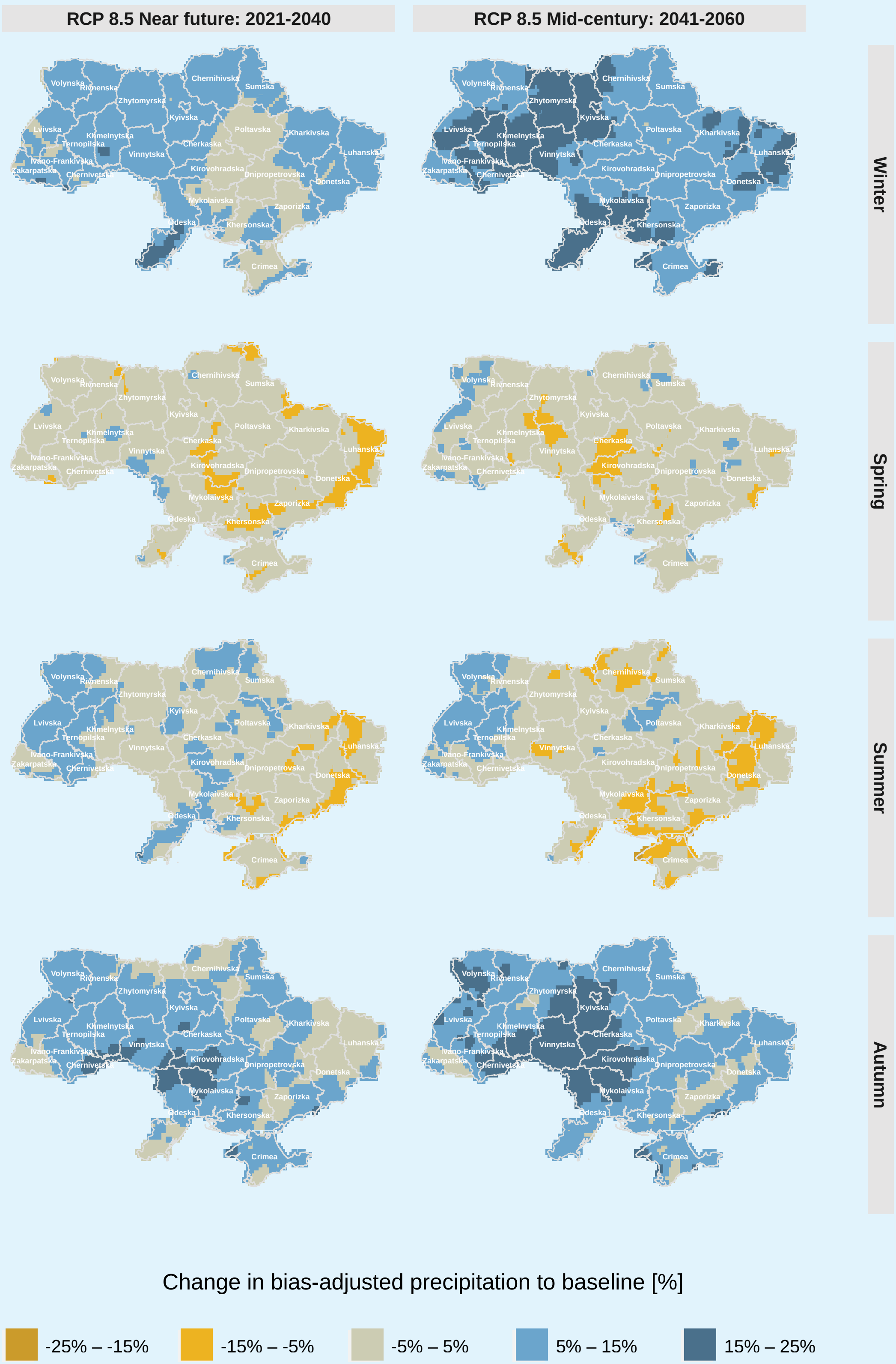
Table 2: Changes in Yields Across Oblasts for Major Crops Due to Climate Change[10]

	2030		**2050**	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Barley	-2.3% to +7.5%	-15.1 to -11.5%	-11.0% to -0.3%	-15.8% to -5.2%
Maize	-17.2% to +14.1%	-22.0% to -2.3%	-18.8% to +4.3%	-22.9% to +3.0%
Soybean	+8.6% to +27.9%	+8.8% to +31.7%	+18.3% to +30.4%	+21.1% to +46.7%
Sunflower	-25.1% to +8.1%	-9.4% to +6.1%	-10.6% to +16.0%	-20.9% to +7.6%
Wheat	+8.6% to +44.1%	+13.9% to +40.7%	+11.9% to +49.1%	+20.8% to +63.5%

10 Figures are for the mean projection and changes in yield [tons/ha] relative to 2010 levels.

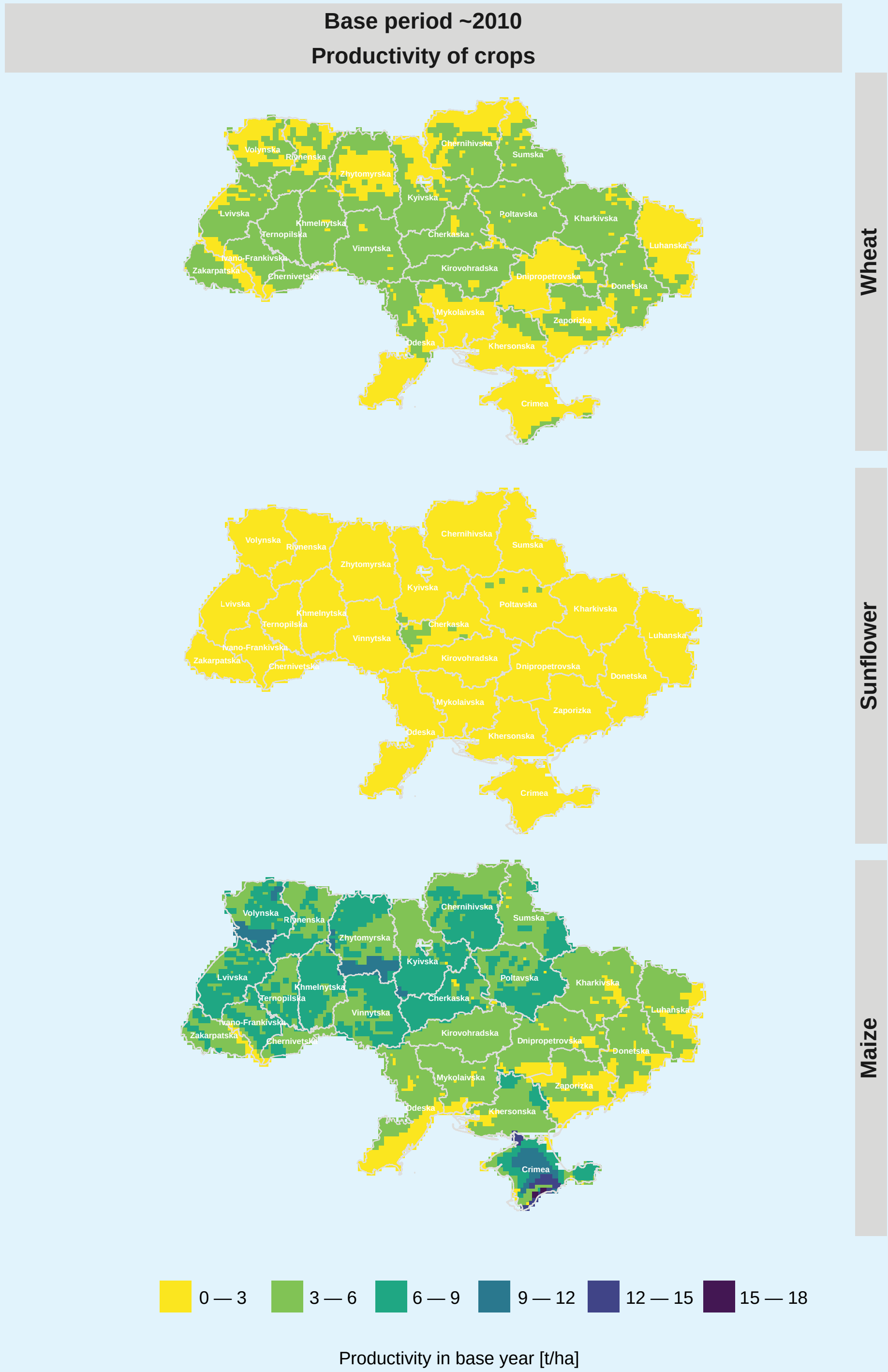
Figure 16: Seasonal Precipitation in RCP 4.5 and RCP 8.5

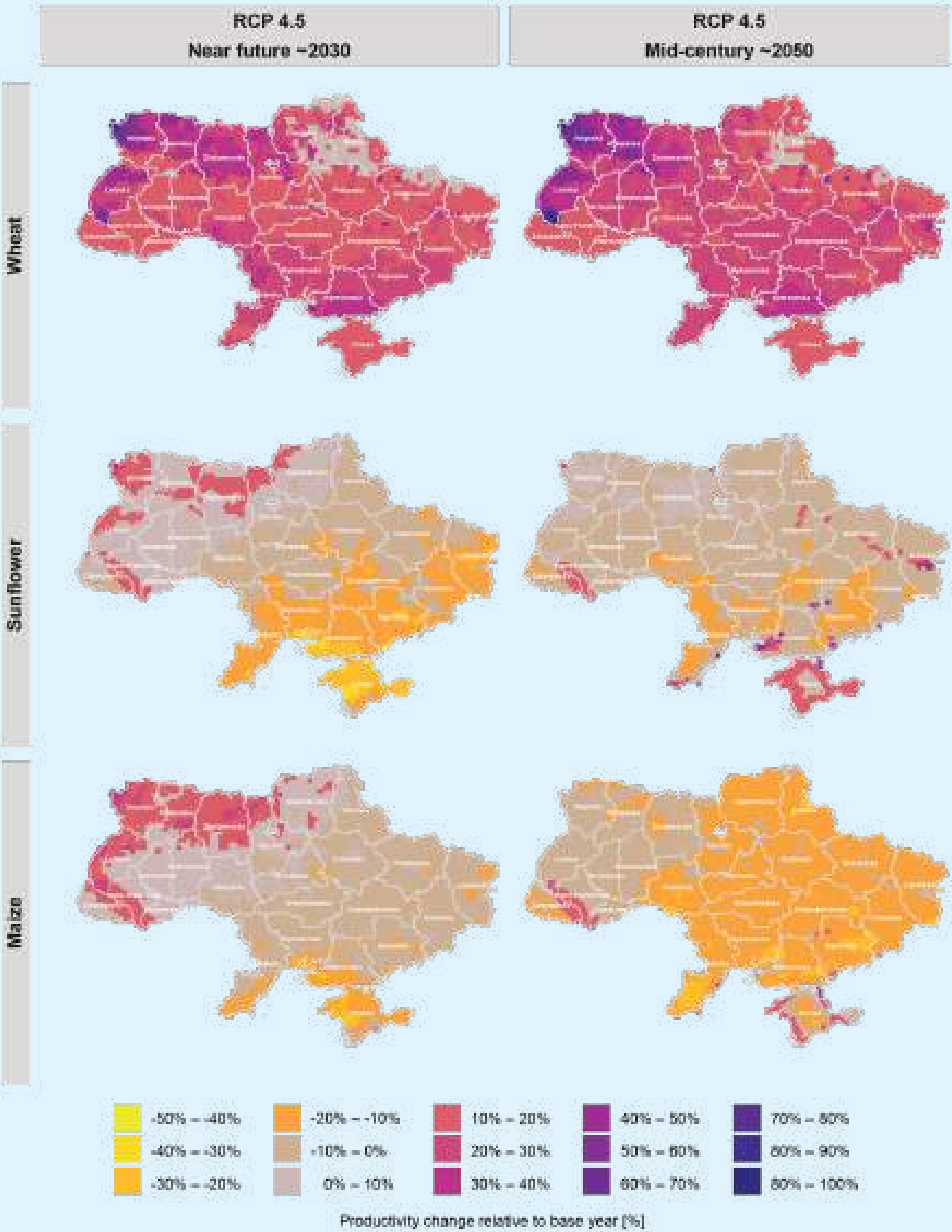


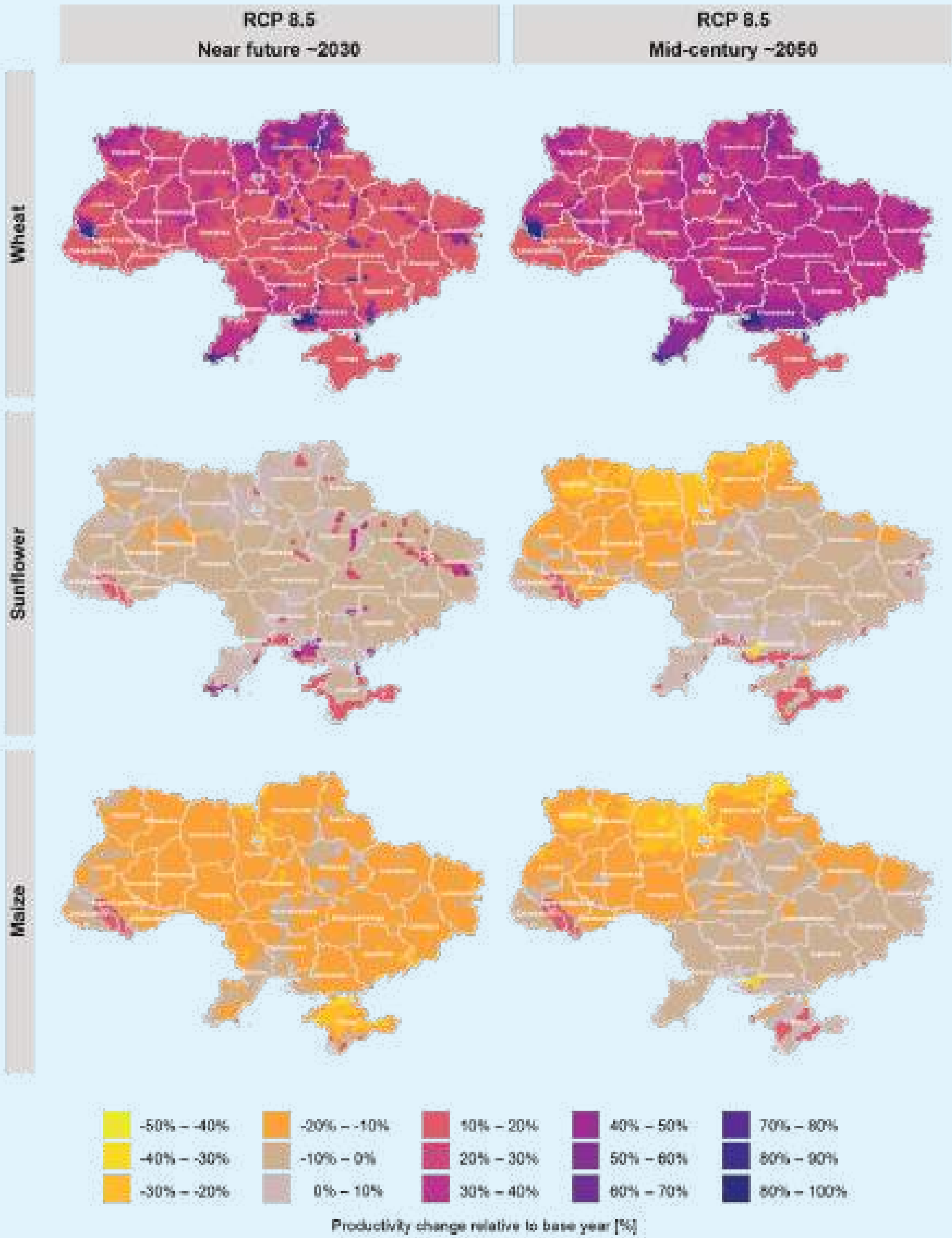


RCP 8.5 Near future: 2021-2040
RCP 8.5 Mid-century: 2041-2060
Winter
Spring
Summer
Autumn
Volynska
Rivnenska
Zhytomyrska
Chernihivska
Sumska
Kyivska
Lvivska
Khmelnytska
Ternopilska
Poltavska
Kharkivska
Cherkaska
Luhanska
Ivano-Frankivska
Zakarpatska
Chernivetska
Vinnytska
Kirovohradska
Dnipropetrovska
Donetska
Mykolaivska
Zaporizka
Odeska
Khersonska
Crimea
Change in bias-adjusted precipitation to baseline [%]
-25% – -15%
-15% – -5%
-5% – 5%
5% – 15%
15% – 25%

Figure 17: Crop Yields [tons/ha] in 2010 and Changes in Yields [%] in 2030 and 2050 for Selected Crops




RCP 4.5
Near future ~2030
RCP 4.5
Mid-century ~2050
Wheat
Sunflower
Maize
-50% – -40%
-40% – -30%
-30% – -20%
-20% – -10%
-10% – 0%
0% – 10%
10% – 20%
20% – 30%
30% – 40%
40% – 50%
50% – 60%
60% – 70%
70% – 80%
80% – 90%
90% – 100%
Productivity change relative to base year [%]



RCP 8.5
Near future ~2030
RCP 8.5
Mid-century ~2050
Wheat
Sunflower
Maize
-50% – -40%
-40% – -30%
-30% – -20%
-20% – -10%
-10% – 0%
0% – 10%
10% – 20%
20% – 30%
30% – 40%
40% – 50%
50% – 60%
60% – 70%
70% – 80%
80% – 90%
90% – 100%
Productivity change relative to base year [%]

3.3 Impact of Water Availability on Crop Yields

For this analysis, the WOFOST model estimates the water-scarce crop yields by oblast in 2030 under RCP 4.5 and RCP 8.5 scenarios in the absence of adaptation measures. To estimate the potential benefits of adaptation measures, water-scarce crop yields can be compared with yield projections under optimum water availability (i.e., when the water limitations are overcome) for two crops, maize and sunflower, for which the impact is the highest (Figure 11). In the WOFOST model, crop productivity is defined by the planting date, CO_2 concentration, radiation, and temperature. In the case of optimal water availability yield, the WOFOST model assumes that there is no water supply constraint — i.e., that water supply is optimal. The model does not have specific assumptions on measures to maintain optimal water availability.

The simulations show a considerable increase in yield assuming optimal water availability for maize (about 20%- 40%) and sunflower (about 60%- 80%) in both RCP 4.5 and RCP 8.5 scenarios (Figure 18). Moreover, irrespective of the RCP scenario until mid-century, the impacts of climate change will depend on other factors, such as solar radiation, if water supply is sufficient. For some oblasts, these other factors are likely to play minor roles in the overall climate change impacts on agriculture (Figure 19).

3.4 Agricultural Production Projections

Simulations of agricultural value at the oblast level are based on projected yields and assumptions of changes in agricultural land areas driven by relative changes in yields and relative prices for relevant crops in future years. Higher prices for wheat and maize make it more attractive to increase land areas under these crops, especially in oblasts where the yield gains from climate change are significant. The changes in allocation of crop lands were based on the analysis carried out by IFPRI (see IFPRI 2016, 2019). These changes are further discussed in are further discussed in Chapter 7 in the discussion on the benefits of adjusting land areas as a form of adaptation. The projected changes in areas allocated for each crop for the entire country are as follows: barley: +2% in 2030 and -6% in 2050; maize: +12% in 2030 and +29% in 2050; soybean: 0% in 2030 and -6% in 2050; wheat: +10% in 2030 and +15% in 2050. No changes are projected for sunflower, as it was not modeled by IFPRI.

Wheat and soybean show a clear positive trend to mid-century in both scenarios, whereas barley and sunflower show a consistently negative trend. The changing climate conditions until mid-century will become beneficial for maize. However, these trends should be interpreted as indicative, with considerable uncertainty ranges for the production of each crop in each region. It is important to note that the crop production simulation assumes the reallocation of land for each crop. The estimated changes in yields, combined with simulated changes in land areas for each crop, based on the IFPRI model, were used to estimate changes in production under RCP 4.5 and RCP 8.5, with and without shifting of land allocation for each crop, respectively (Figure 20).

[11] Impact of water availability was estimated for soybean, but the impact is significantly lower.

Figure 18: Impact of Optimal Water Availability in 2030

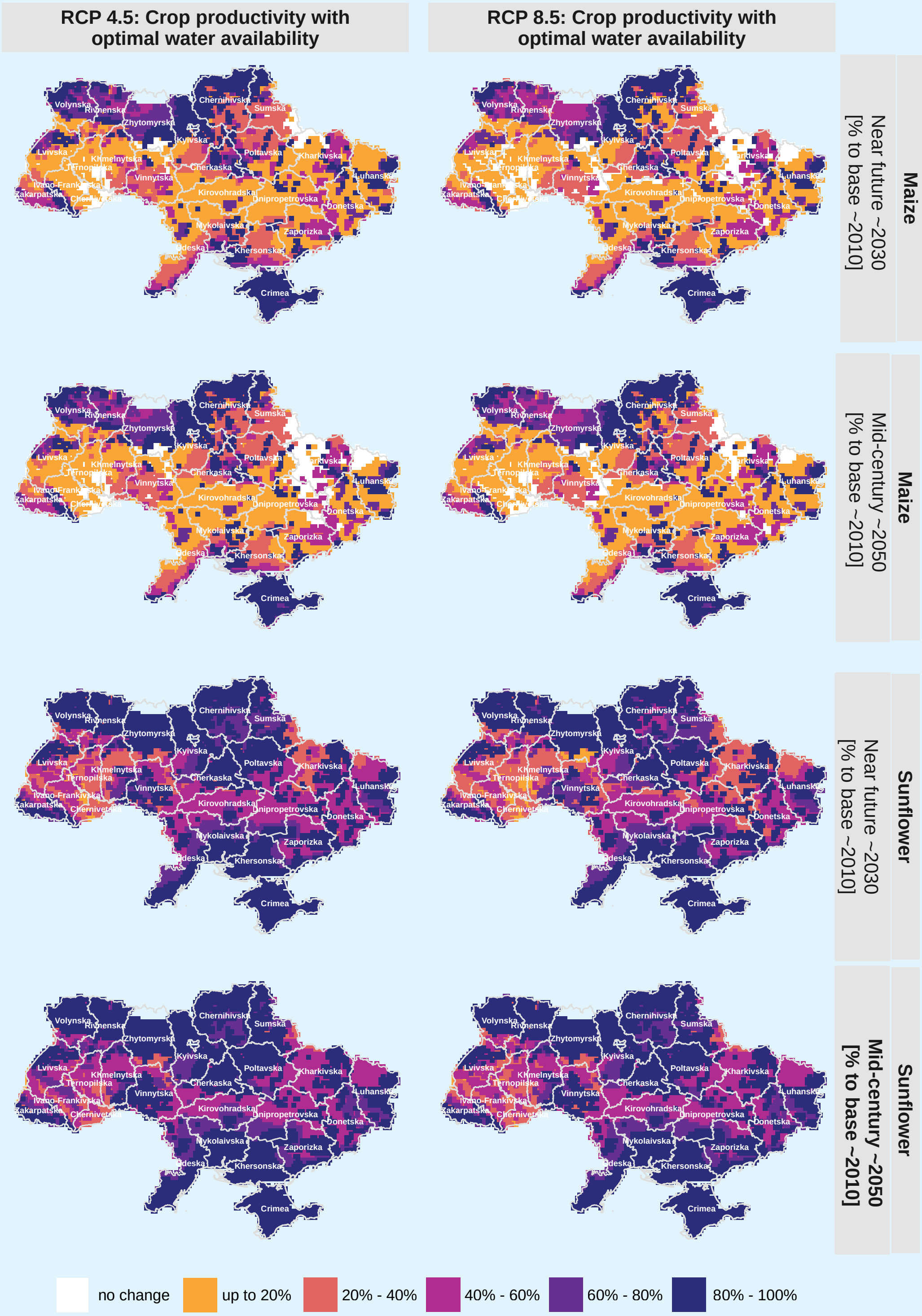


Figure 19: Difference Between RCP 4.5 and RCP 8.5 for 2030

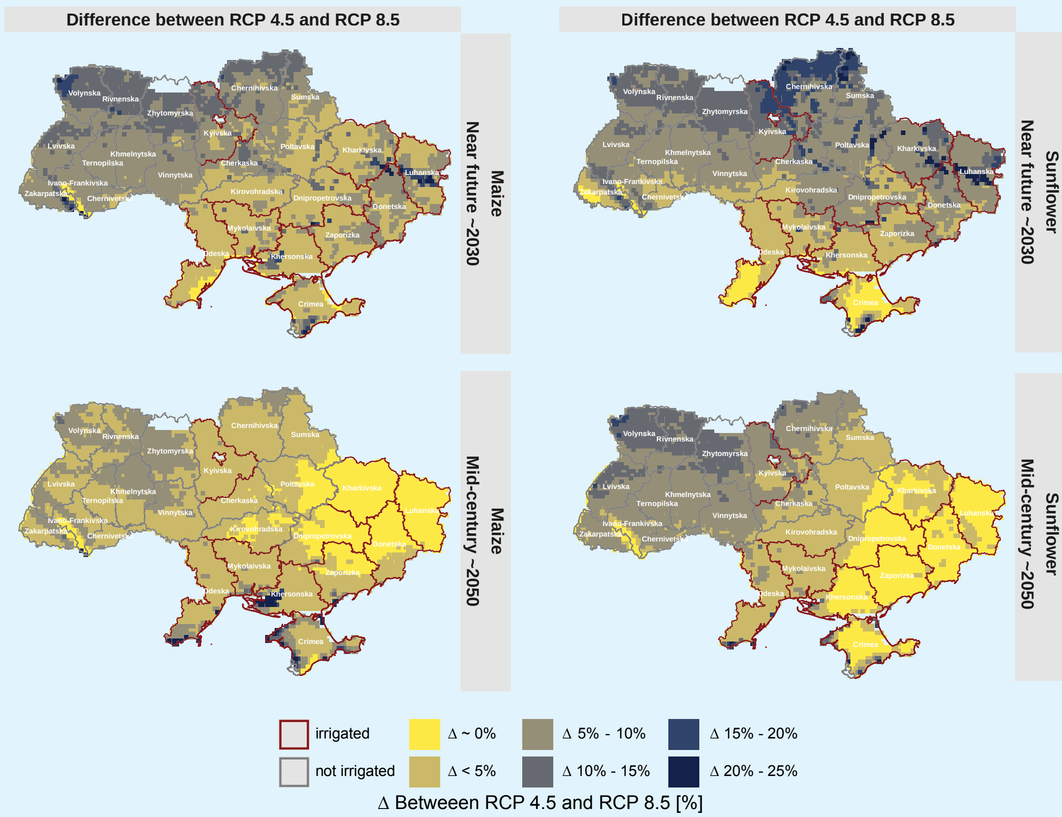


Table 3: Change in Total Production (Millions of Tons) for Major Crops as Compared to the Baseline (with Change in Land Area Allocation for Each Crop)[12]

	2030		2050	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Barley	- 3%	- 11%	- 14%	- 15%
Maize	- 12%	- 3%	12%	15%
Soybean	20%	22%	13%	19%
Sunflower	- 11%	- 3%	- 8%	- 5%
Wheat	32%	34%	43%	55%

12 Figures are based on estimated production [millions of tons] for the mean projection, changes in crop yields [tons/ha] multiplied by the crop areas [ha] in each oblast are relative to 2010 levels.

3.5 Agricultural Value Projections

The total production value of the five crops is projected to increase by 29% (with an uncertainty range of -32% to +91%) in 2030 and 56% (with an uncertainty range of -1% to +112%) in 2050, compared to 2010 (Figure 21). The uncertainty range is clearly large in both sets of projections, with and without changes in land allocation. However, with changes in land allocation the uncertainty range is on the positive side, while without changes in land allocation, negative impacts are quite possible. For example, in 2050 in Kirovohradska oblast, shifting of land allocation has a stronger positive impact on mean agricultural value. The range shifts from between -31% to 56%, to between 0% to 107%. All oblasts follow the same trend indicating that a shift in land allocation helps avoid losses in the value of agricultural production.

Figure 21 provides information on how to identify oblasts where additional support and adjustment measures can be most helpful. The oblasts in bold currently have a large share of the total value of the agricultural sector in Ukraine's GDP; in these oblasts, the agricultural sector has a significant share in the domestic GDP of the oblasts. Adaptation measures can significantly, though not completely, reduce the potential negative impact on the value of the sector through the mid-century period. Under the mean projection, the value of production goes up in all oblasts, with larger increases in the eastern and central-eastern oblasts. Under the high projection, all oblasts experience increases in production values, with even larger increases in 2050 than in 2030, assuming the stated adaptation measures take place.

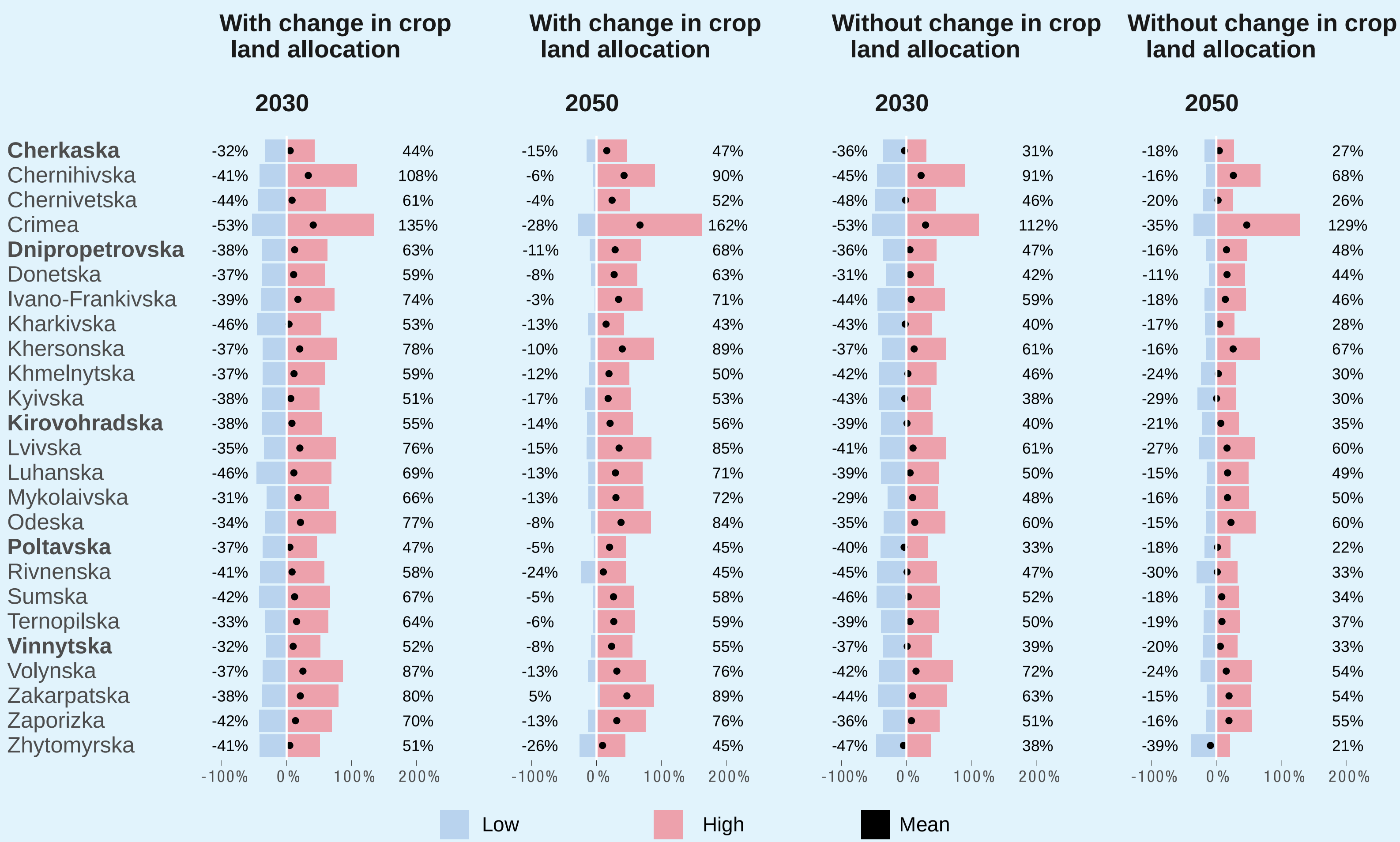
3.6 Effects of Changes in the Growing Season

As shown in Table 4 and Table 5, climate change will result in changes to climatic seasons across the board, most notably to the growing season (t>50C). While the near future changes result in a 7% increase in the length of the growing season under both RCP4.5 and RCP8.5 scenarios compared to the baseline period 1961-90, longer-term projections diverge, with a middle-of-the-century increase of 10% under the RCP4.5 scenario and a 13% increase under the RCP8.5 scenario. By the end of the century, growing seasons are expected to become 13% longer in the RCP4.5 scenario and 27% longer in the RCP 8.5 scenario. The the growing season start day will shift by 13 days under both RCP 4.5 and RCP 8.5 scenarios compared to the baseline period 1961-90. By mid-century, the change will be 17 and 20 days, respectively, and by the end of the century, the growing season will shift by 22 days under RCP 4.5 or 41 days under RCP 8.5. Additional information is presented in Annex 2.

3.7 Limitations of the Analysis of Climate Change Impact on Agriculture

Increases in temperature and precipitation changes have a twofold effect depending on the crop type: contributing to increased productivity of certain crops, but also increasing the risk of extreme weather events which can negatively affect crop production. Temperature increase has a positive effect on winter crops during cold periods of vegetation, reduces the risk of frost damage on spring crops and the time to maturity of certain crops. Together with CO_2, fertilization, and increased precipitation in vegetation periods, this leads to an increase in productivity of winter wheat (Figure 17), and an increase in the value of agricultural output for soybean and sunflower (Figure 34).

Figure 20: Changes in Total Agricultural Production by Oblast, RCP 8.5[13]



[13] Changes in production [millions of tons] are estimated as yields [tons/ha] multiplied by the crop areas [ha] allocated for each crop in each oblast relative to baseline 2010 level of production.

Figure 21: Changes in Total Value by Oblast, RCP 8.5

Table 4. Characteristics of Climatic Seasons in Ukraine in Two Past Periods (E-OBS data) and Three Future Periods Under the RCP4.5 Scenario (Ensemble of 34 RCMs from Euro-CORDEX Data)

	Length of seasons, days				Season start day				Season end day			
	Warm season (t > 0ºC)	Growing season (t > 5ºC)	Active vegetation season (t > 10ºC)	Summer season (t > 15ºC)	Warm season (t > 0ºC)	Growing season (t > 5ºC)	Active vegetation season (t > 10ºC)	Summer season (t > 15ºC)	Summer season (t > 15ºC)	Active vegetation season (t > 10ºC)	Growing season (t > 5ºC)	Warm season (t > 0ºC)
1961-1990	283	219	172	117	56	96	116	142	260	288	314	339
1991-2010	301	223	173	121	39	90	114	143	264	288	314	341
2021-2040	305	235	181	129	37	83	111	137	267	292	318	342
2041-2060	309	241	188	137	35	79	108	134	269	295	318	342
2081-2100	318	247	193	143	29	74	104	130	271	297	320	345

Season start and end days: numbers in the table indicate the day of the year (i.e., 56th day of the year).

Table 5: Characteristics of Climatic Seasons in Ukraine in Two Past Periods (E-OBS data) and Three Future Periods Under the RCP8.5 Scenario (Ensemble of 34 RCMs from Euro-CORDEX Data

	Length of seasons, days				Season start day				Season end day			
	Warm season (t > 0oC)	Growing Season (t > 5oC)	Active vegetation season (t > 10oC)	Summer season (t > 15oC)	Warm season (t > 0oC)	Growing season (t > 5oC)	Active vegetation season (t > 10oC)	Summer season (t > 15oC)	Summer season (t > 15oC)	Active vegetation season (t > 10oC)	Growing season (t > 5oC)	Warm season (t > 0oC)
1961-1990	283	219	172	117	56	96	116	142	260	288	314	339
1991-2010	301	223	173	121	39	90	114	143	264	288	314	341
2021-2040	304	235	185	133	40	83	109	135	268	294	318	344
2041-2060	315	247	194	141	30	76	105	132	273	299	322	346
2081-2100	340	279	213	160	16	55	94	122	283	307	333	356

This could potentially increase the competitiveness of Ukraine's agricultural products in the international market. However, extreme temperature increases combined with insufficient precipitation can lead to droughts and a decrease in the productivity of crops and provoke natural disturbances such as pests and diseases. Thus, the comparative advantage projected with these temperature increases for Ukraine's agriculture may be affected by extreme weather events which were not covered by this study.

Modeling the impact of water resources is limited by the capabilities of the integrated assessment model (Figure 10). The WOFOST model can produce water-limited simulation results when soil moisture determines whether the crop growth is limited by drought stress. In the water availability simulation, the effect of soil moisture on crop growth is optimal. Optimal soil moisture can be achieved through measures such as irrigation and other water balance management approaches.

Uncertainty in food prices and food security under climate extremes is not accounted for in the modeling approach. The food prices projected by the IMPACT model for 2030 did not consider price peaks such as those that occurred in 2010 due to the drought in Russia, which reduced wheat yields by about one third. This drought also had significant long-term effects: in 2011 the lowest income decile spent 17% more on food supplies than in 2007. The distributional effects of extreme events on changes in food prices and food security directly through changes in yields and through disruption of transport and markets remain a challenge for further analysis, as extreme events are likely to become more frequent in the near future.

Box 3: Impact of Water Shocks on Agricultural Yields

Water shocks include both dry shocks and wet shocks, defined as an occurrence of rainfall that is at least one standard deviation below or above the long-term average (LTA) level in the region (Damania et al. 2017).

Dry shocks. The driest regions are most sensitive to rainfall variability. This is particularly important for Ukraine with dry climate types projected to account for about 63.2 to 69.6% of the country's territory in the middle of the century under RCP 4.5 and RCP 8.5, respectively (see Figure 31). Global data indicates that dry shocks can reduce agricultural productivity by approximately 14%, while wet shocks increase agricultural productivity by approximately 17% (Damania et al. 2017). Drought like the one Ukraine experienced in 2010 (Shevchenko et al. 2014b) is likely to return every two-three years when global warming reaches 2°C, or every year when global warming reaches 3°C.

In 2019, a heat wave which led to a strong rainfall deficit was recorded in Ukraine, with substantially drier-than usual conditions in some regions with rainfall accumulations below 5 mm. However, cumulative rainfall was within the limits of the LTA in most of the western, southern, and eastern parts of Ukraine, while the north (Zhytomyrska, Kyivska, Cherkaska, Chernihivska, Sumska, Kharkivska, Donetska and Luhanska) experienced a rain deficit of around 40% relative to LTA (EC 2019a). Those rainfall events slowed the progress of harvesting of summer crops, with maize and soybean experiencing 7.4% and 2.2% lower yields than in 2018, and they also delayed cropping activities and hampered the emergence of winter crops (EC 2019b).

Wet shocks.[14] Historical analysis (1986–2010) shows that heavy rain is the most common climate extreme in Ukraine, accounting for 53% of all occurrences of extreme events in the period (Balabuch et al., 2018). Extreme rains are most common in the western region, specifically in Lvivska, Ternopilska, and Chernivetska oblasts, and the Crimean Mountains and highlands. Extreme rain events have become more common in Ukraine, increasing with a probability of 99% over the 1971–2010 period. Along with the projected increase in annual precipitation (see Figure 7), extreme wet shocks will also increase. Increased annual precipitation is likely in almost the entire country, but most pronounced in Ivano-Frankivska, Chernivetska, Lvivska, Rivnenska, Khersonska, and Zhytomyrska oblasts.

[14] The paragraph is based on Balabukh et al., 2018.

CHAPTER 4: THE DISTRIBUTIONAL EFFECT OF CLIMATE CHANGE ON AGRICULTURE

4.1 Summary of Key Findings

The distributional analysis of the impact of climate change on households' real incomes is assessed through its impacts on the price of foods and agricultural incomes. The increase in food prices is expected to increase household expenditures by 0.7% to nearly 3% across all households, depending on the oblast. The effects are regressive, as households in the lower income quintiles face larger increases in real expenditures. The changes in the values of farm outputs increase household incomes for all oblasts and all household deciles under the mean projection, in a range between 0.2% and 1.6%. The combined effects of the changes in food prices and incomes depend on the projection and share of agricultural income in the households' income structure in each oblast. In the mean projection, the changes range between -1 and +1%. In the high projection, household income gains between 0.5 to 3% for all oblasts. In the low projection, the projected loss of income is between -1 and -3%. The five oblasts with the largest predicted decreases in income are Zhytomyrska, Sumska, Chernivetska, Rivnenska, and Volynska.

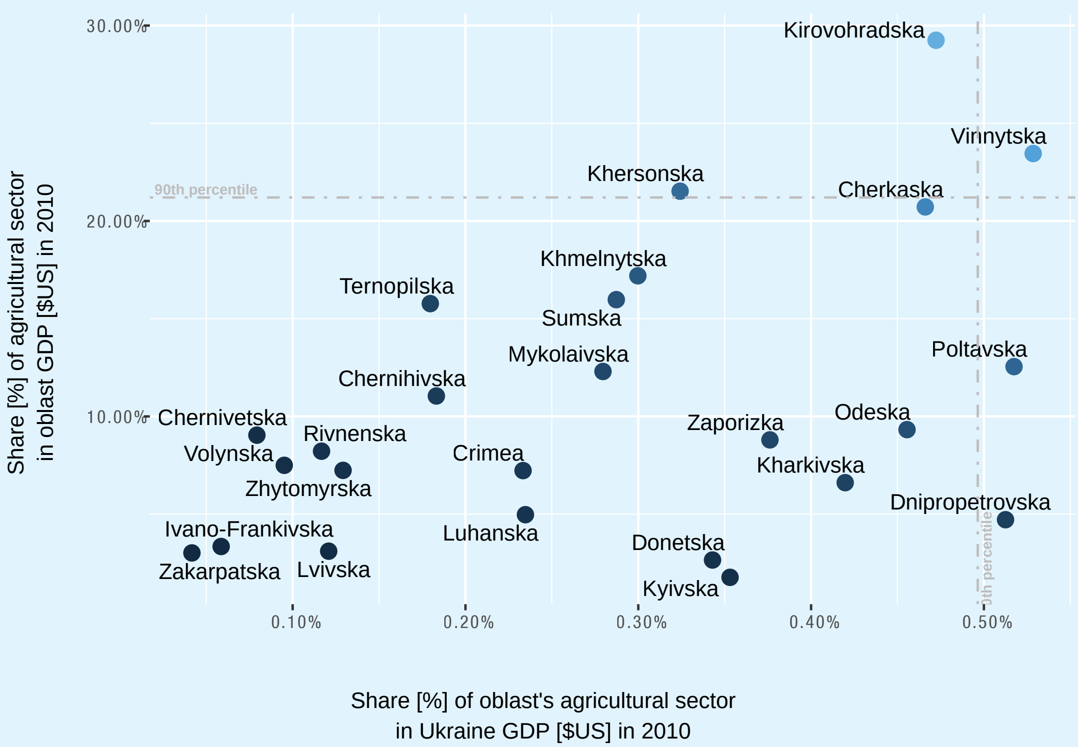
Both the increase in food prices and changes in farm outputs will impact poverty headcounts, however the impact is not significant under any of the projections (low, mean, and high). The poverty gap, however, does not increase in all cases: in seven oblasts, it decreases slightly while in the others, it increases. The severity of poverty also slightly declines in six oblasts but increases in the rest, with the biggest decrease in Chernihivska (1.3%) and highest increase (0.8%) in Khemelnytska.

When considering only food price increase, the Gini coefficient results indicate an increase in inequality in all oblasts, except Ivano-Frankivska. The effect on inequality is tracked through changes in real income per household. The combined effects of price increase and changes in agricultural outputs result in a decrease in inequality for six oblasts in the mean projection scenario but in most cases the decrease is very small. With the low projection scenario, the inequality measure increases by small amounts in all oblasts (i.e., 1.4% in Vinnytska and 1.07% in Sumska), except for Ivano-Frankivska. In the high projection, all oblasts see an increase in inequality, with the most significant increase in Donetska (8.3% increase in the Gini coefficient) and Ivano-Frankivska (3.5%). However, this analysis has not investigated all possible effects of climate change on welfare. Further work should be carried out to examine other factors that influence household incomes, including climate-related morbidities and unemployment, which are not covered in this analysis.

4.2 The Share of Agriculture in the National and Oblast GDP

The share of the agricultural sector in Ukraine's GDP has been declining over time, but the importance of the sector for the GDP of some oblasts is particularly high. The latest data (for 2019) estimates that agriculture, forestry, and fishery account for 9% of GDP, or $13.8 billion. The size of this sector as a percentage of GDP varies considerably across oblasts (Figure 22).[15] For example, agriculture contributes significantly to the GDP (2010 data) in Kirovohradska (29.25%), Vinnytska (23.45%), Khersonska (21.52%), Cherkaska (20.72%), Khemelnytska (17.19%), Sumska (15.97%), and Ternopilska (15.77%), which means that any negative impacts of climate change on agricultural production are likely to have significant impact on their economies. At the same time, agriculture in Kirovohradska, Vinnytska, Cherkaska, Postavska, and Dnipropetrovska oblasts constitutes relatively large shares of the country's GDP, and the climate risks to agriculture in those areas are more likely to impact the national economy. The full set of data is presented in Annex 3.

Figure 22: Agriculture as a Share of GDP ($US) in 2010, by Oblast



15 Annex 3 shows the GDP and agricultural value in 2010 per oblast. In this case, the values for 2010 are presented, as the value of agriculture by oblast is only available for that year. It is also the baseline year used in the report, as explained below.

The distributional analysis assesses the impact of climate change on households' real incomes through its impacts on the price of foods and agricultural incomes. The agricultural impacts assessment in Chapter 3 provides two key outputs: i) increases in the prices of key food products due to climate change and estimates of price increases in 2030 for key agricultural commodities under RCP 8.5 and RCP 4.5 (based on the IFPRI model); and ii) changes in agricultural incomes due to the climate change effects on yields, production, and production values. These data were inputs for the distributional analysis of the impacts on households.

The analysis of income considers three sets of projections: low, mean, and high. They reflect the results of the WOFOST model projecting the impacts of climate change on agriculture, in which, for a given date and climate projection, the model provides a distribution of likely outcomes for changes in yields and production for the selected crops (i.e., barley, wheat, maize, sunflower and soybean) between 2010 and 2030. The resulting changes by oblast are provided in Annex 5 for the selected crops. The low and high projection scenarios represent the 5th and 95th percentile of the distribution of yield changes provided, at a very fine scale for each oblast. Changes in real incomes and indicators of poverty and inequality are estimated for RCP 8.5 in 2030.[16] The analysis is limited to 2030 because by 2050, the baseline expenditure data cannot be considered as a reasonable point of comparison.

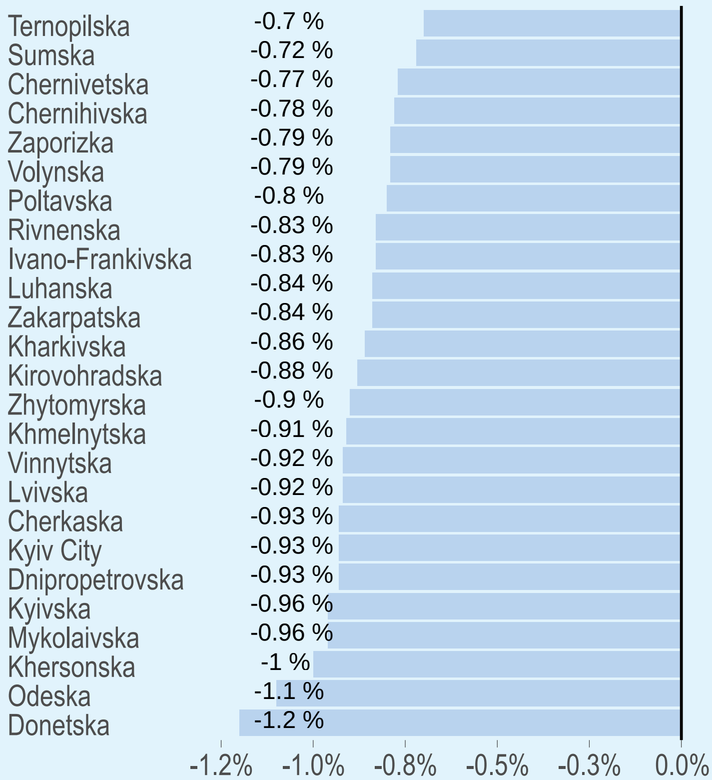
4.3 Impact of Climate Change on Agriculture and Household Income and Expenditure

The increase in food prices is expected to increase household expenditures by between 0.7% and nearly 3% across all households, depending on the oblast. The effects are regressive as households in the lower income quintiles face larger increases of real expenditures up to a maximum of nearly 3 percent (see Annex 5). The increase in food prices is expected to reduce incomes by 0.7% to 1.2% across all households, depending on the oblast (shown in Figure 23).

The changes in the values of farm outputs increase household incomes for all oblasts, and all household deciles, in the range between 0.2 percent and 1.6% under the mean projection (shown in Figure 24). The households in lower (first) income deciles experience an increase of up to 1.6% in Luhanska oblast, where the bottom decile's income rises by 1.6% and the top decile's income by 0.8%. The smallest gain is for Zhytomyrska, with an increase for the bottom decile of only 0.2% and for the top decile of 0.1%. So, for example, in Cherkassy oblast, the bottom decile has a gain in income of between UAH 54 and 265 per month, with the average gain being UAH 132. That is 0.4% of average income for that decile. In the low projection, households in all oblasts experience a decline in income from agriculture, with the highest changes in the lowest three, ranging from -0.9% to -2.8%. The largest losses are in Chernivetska, Sumska, Ternopilska, Volynska and Zaporizka, where households in the lowest decile lose about 2% of income. The smallest losses are in Dnipropetrovska, Donetska, and Mykolaivska (around 0.1% to 0.2% across all deciles). In almost all cases, the changes in income become smaller as we go up the deciles, meaning that the changes in income (whether positive or negative) can be considered progressive.

[16] The distributional effects required price projections, which were taken from IFPRI. These were only made for RCP8.5. Additional information is available in Chapter 2.

Figure 23: Changes in Income by Oblast for 2030 Due to Price Increases



The range between the low and high projections for all income deciles indicates that for some oblasts, the low-income deciles tend to experience a wider range between the low and high projections. As shown in Annex 3, these oblasts include Chernivetska, Lvivska, Ternopilska, and Volynska in the west; Poltavska and Chernihivska in the central north; and Luhanska in the east. This suggests that climate change and associated impacts on agricultural production may have a significant impact on low-income households, more so than on the households in the upper-income deciles in these oblasts.

The combined effects of the changes in food prices and incomes vary by scenario and the share of agricultural income in household income structure in each oblast, as illustrated in Figure 25. In the low projection, there is a 1% to 3% loss of income, with Zhytomyrska, Sumska, Chernivetska, Rivnenska, and Volynska oblasts affected the most. In the mean projection, the changes range between -1% and +1%. In the high projection, almost all oblasts experience gains of 0.5% to 3%. The exceptions are Donetska oblast and Kyiv city, which lose even in the case of the high projection.

Figure 24: Increase in Income from the Change in Value of Agricultural Output due to Climate Change, Mean Projection (2030)

The range between the low and high projections for all income deciles indicates that for some oblasts, the low-income deciles tend to experience a wider range between the low and high projections. As shown in Annex 3, these oblasts include Chernivetska, Lvivska, Ternopilska, and Volynska in the west; Poltavska and Chernihivska in the central north; and Luhanska in the east. This suggests that climate change and associated impacts on agricultural production may have a significant impact on low-income households, more so than on the households in the upper-income deciles in these oblasts.

The combined effects of the changes in food prices and incomes vary by scenario and the share of agricultural income in household income structure in each oblast, as illustrated in Figure 25. In the low projection, there is a 1% to 3% loss of income, with Zhytomyrska, Sumska, Chernivetska, Rivnenska, and Volynska oblasts affected the most. In the mean projection, the changes range between -1% and +1%. In the high projection, almost all oblasts experience gains of 0.5% to 3%. The exceptions are Donetska oblast and Kyiv city, which lose even in the case of the high projection. Figure 26 shows the effect of only price increases on these and other regions which have little income from agriculture and are thus particularly vulnerable to increases in food prices.

Figure 25: Changes in Income Under the Three Projections by Oblast for 2030 (both Income and Price Effects)

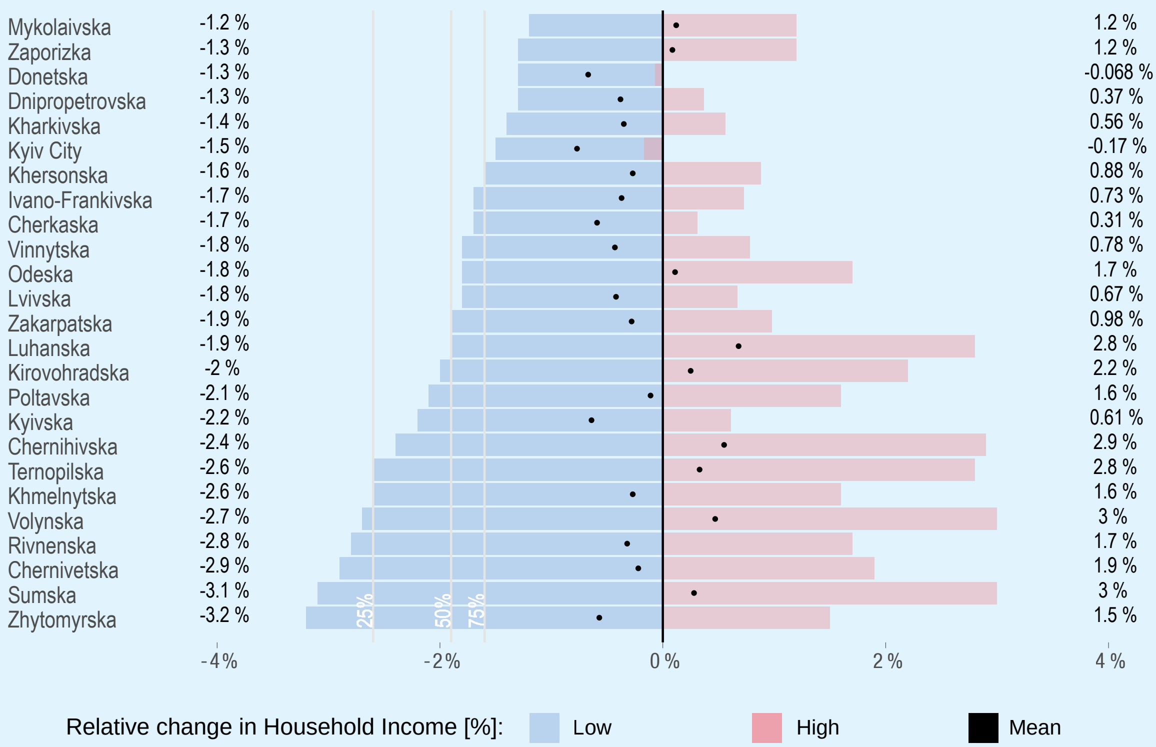
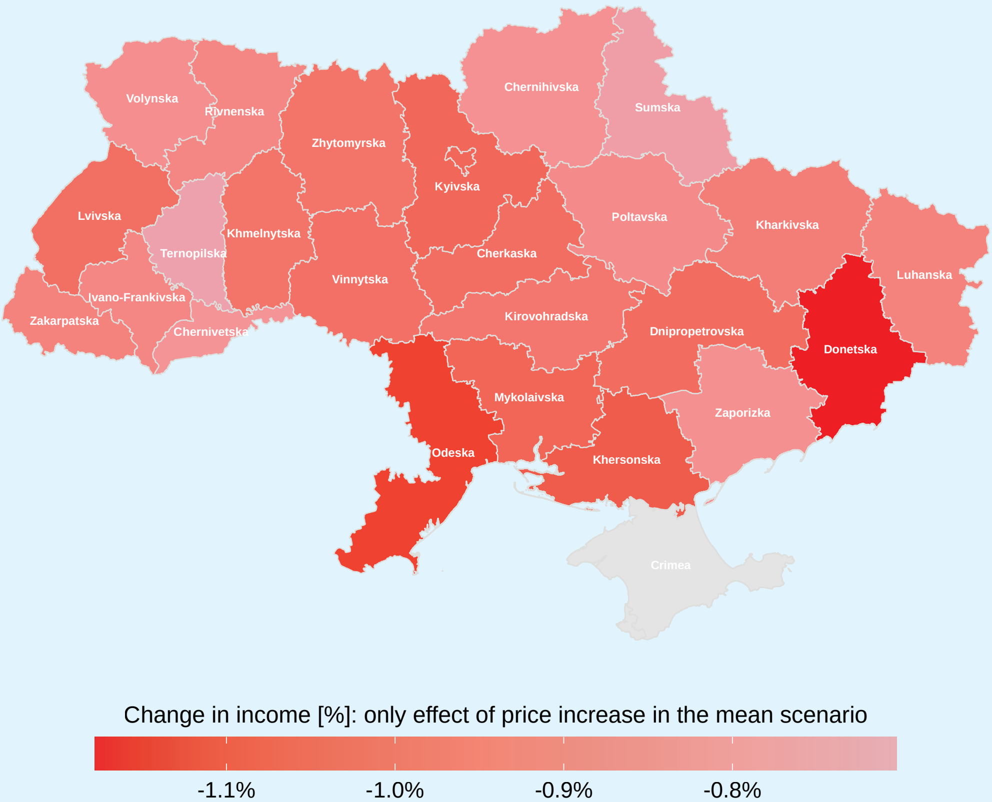


Figure 26: Changes in Expenditure by Oblast for 2030 (Effect of Price Increases only) in the Mean Scenario



4.4 Impact of Climate Change on Agriculture and Poverty

Both the increase in food prices and changes in farm outputs will impact poverty head-counts. The extent of the impact depends on the low, mean, or high projections but the changes are not significant under any of the three.

An increase in food prices alone results in an increase in the headcount poverty ratio by between 0% and 1.6% (see Annex 3). The poverty headcount declines in eight of the 25 oblasts, remains unchanged in four, and increases in the others. The declines are small, between 0.3 and 1.3%, as are the increases: the highest is 1.3%. Under the high projection, poverty headcount declines in all oblasts except five (Cherkaska, Ivano-Frankivska, Kyivska (excluding the city), Vinnytska, and Zakarpatska). The Kyivska oblast (excluding the city) will see an increase, while the remaining four oblasts will not experience any changes to the poverty headcount, (see Figure 27).

The poverty gap,[17] however, does not increase in all cases in the low projection; it declines slightly in seven oblasts while increasing in the remaining oblasts, (see Figure 27). The severity of poverty also slightly declines in six oblasts but increases in the rest. The highest increase is 0.8% (Khemelnytska). The poverty gap does not always increase, because as more households are added to the poverty group, the gap for them is smaller than the average for the group prior to the change. The poverty gap declines in seven oblasts and increases in the rest. The severity of poverty declines in nine oblasts and increases in the others. The highest decline is by 1-3% (Chernihivska) and the highest increase is by 0.95% (Vinnytska). Given the uncertainties regarding the impacts of change on household incomes, this separate analysis is a valuable indicator of the broader effects of climate change on consumers.

4.5 Climate Change Impact on Agriculture and the Gini Coefficient[18] of Inequality

An increase in food prices alone leads to an increase in inequality. The combined effects of price increase and changes in agricultural outputs result in a decrease in inequality in the mean projection. The effect on inequality is tracked through changes in real income per household. With the low projection, the inequality measure increases by a small amount in all oblasts, except for Ivano-Frankivska, where the decline is more substantial at 2.75% (see Annex 3). Other significant increases are in Vinnytska (1.4%) and Sumska (1.07%). Under the mean projection, six of the 25 oblasts experience a decrease in equality, but the decrease is very small in most cases, (see Figure 28). In the high projection, all oblasts see an increase in inequality, with the largest being in Donetska (8.3% increase in the Gini coefficient) and Ivano-Frankivska (3.5% increase). When considering only food price increase, the Gini coefficient results indicate an increase in inequality in all oblasts, except Ivano-Frankivska. The increase is in the range of 0.1 to 1.4%. However, this analysis has not investigated all possible effects of climate change on welfare. Further work should be carried out to examine the other factors that influence household incomes, including climate-related morbidities and unemployment, which are not covered in this analysis.

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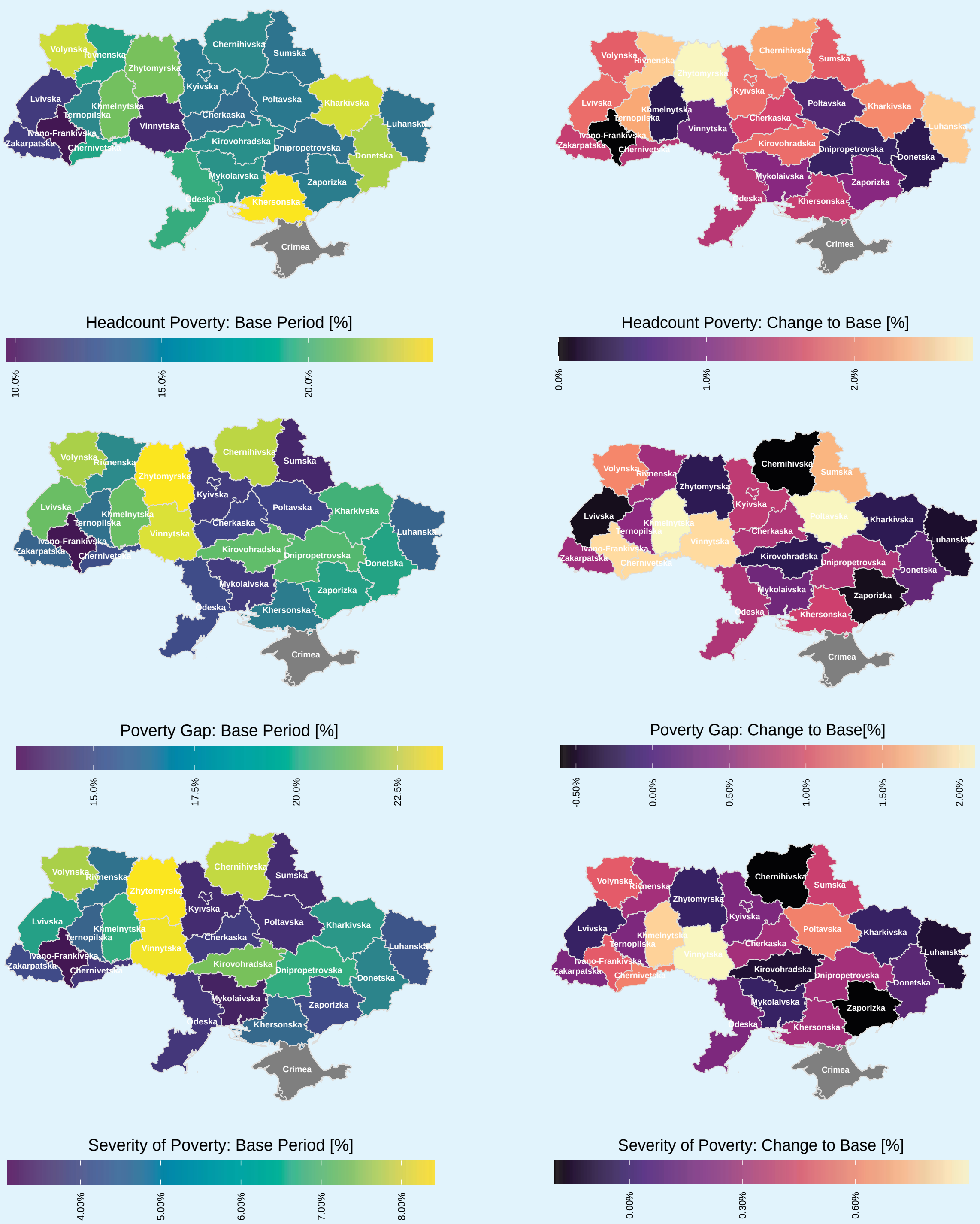
17 The poverty gap is an estimate of the amount by which income must increase across all poor households to take them above the poverty line. It is the sum of the difference between the income level of each household below the poverty line and the poverty line, reported as a percent of the poverty line.

18 Gini index measures the extent to which income distribution among individuals or households within an economy deviates from a perfectly equal distribution (World Bank 2021c).

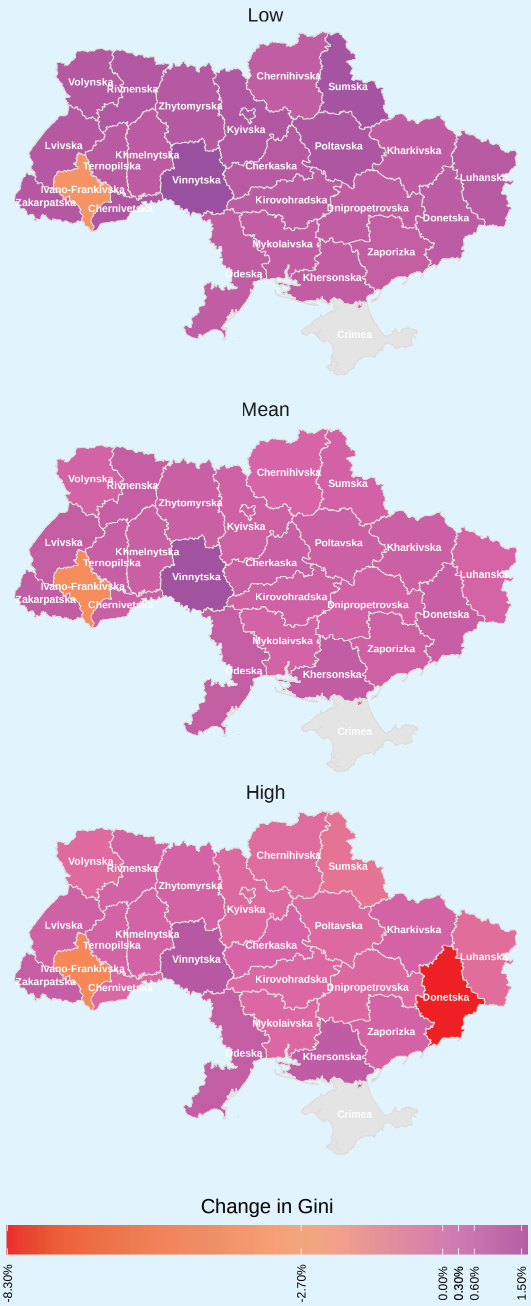
Figure 27: Headcount Poverty, Poverty Gap and Severity of Poverty: Values for the Baseline Period [%] and Changes in 2030 Relative to the Baseline [%], Low Projection



Limitations of the analysis

The study is based on the partial equilibrium approach which gives a good approximation of the likely loss of wellbeing or change in real expenditure from the increase in prices of key agricultural commodities. Thus, future studies can benefit from wider use of input-output tables or microeconomic simulation models which were not available at the time of the study. The impact of changes in consumer prices on food demand was taken from various studies across European countries as similar studies were not available for Ukraine specifically (Femenia 2019). Additionally, Ukraine is in the process of expanding and improving its household income and expenditure surveys using the methodology for the EU Household Final Consumption Expenditure Surveys.[19] The harmonization process it not yet complete and information on several cross-sectional variables have not yet been collected in Ukraine, which complicates data analysis.

Figure 28: Gini Coefficient Changes in 2030 Relative to the Baseline [%]



[19] See https://ec.europa.eu/eurostat/cache/metadata/en/hbs_esms.htm.

CHAPTER 5:
IMPACT OF CLIMATE CHANGE ON FORESTS

5.1 Summary

The projections show a significant shrinking of zones for optimal growth, in term of climate humidity, for most species during the second half of the twenty-first century, especially during the end of century period. The projected changes in climatic conditions, especially under RCP 8.5, will particularly impact adult tree species, as they have low adaptive capacity. This will lead to a deterioration in the condition, productivity, and biodiversity of forest species.

Based on the temperature and humidity conditions projected under both RCPs, a significant reduction is expected in the area on the suitability scale for the growth of spruce, beech, pine and oak. Less than 3% of the country's forest areas would have optimal conditions for Norway spruce, Scots pine, and beech under RCP 8.5 projections. Only 8% of the territory will have optimal conditions for English oak under the same scenario.

Under RCP 4.5 projections, conditions suitable for forest growth will remain only in the Carpathians, western forest-steppe, western part of Polissya (in the form of a new climate type), and parts of the north of Chernihivska and Sumska oblasts. The steppe and Polissya are expected to undergo significant changes in the hydrological regime. These changes will lead to the deterioration of forests and a possible reduction in total forest areas, particularly in the left bank forest-steppe, steppe, and Polissya. In the Carpathians, the forest boundary is expected to move to a higher altitude.

The projected changes are likely to exacerbate disturbances and stressors such as wildfires and insects. During prolonged droughts, a significant proportion of forest biomass becomes combustible, increasing the fuel load of the forest. In addition, pest infestations which have been documented with warming conditions, can result in the deterioration of forest health and increased tree mortality. These will, in turn, enlarge the fuel load available for combustion in wildfire events. Forest fires may increase due to the occurrence of forest diseases and prolonged droughts. According to the PESETA study, forests in the Polissya region with a high concentration of pine trees have a high risk of fire due to the increase of temperature and dry spells expected in most of Europe. In Ukraine, pine forests in the southern and northern steppe and forest-steppe areas will also be at high risk due to the drier conditions expected there under both RCPs.

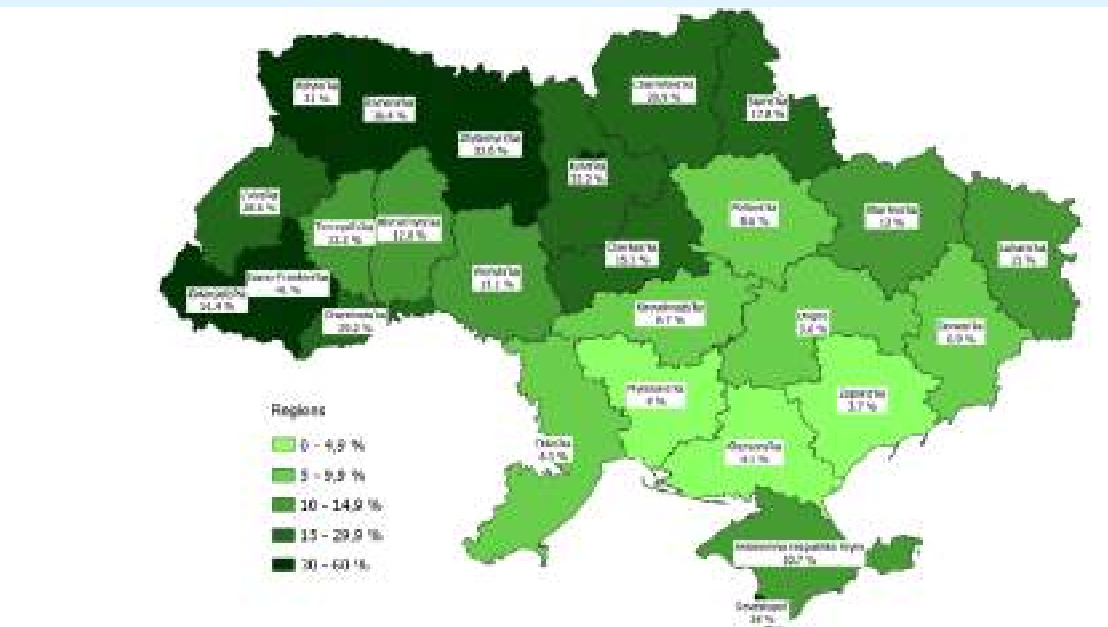
5.2 Climate Vulnerability Indices for Forests

Ukraine ranks 36th among 46 European countries for forest cover. Forest covers about 15.9% of Ukraine's territory, about 9.6 million hectares (see Figure 29). Forest cover in Ukraine is divided almost equally between coniferous forests (about 42%) and hardwood broadleaved forests (43%). The most common species are Scots pine, oak, Norway spruce, European beech, silver birch, black alder, European ash, European hornbeam, and silver fir. Pine accounts for about 35% of the forest cover; oak (Quercus spp.) 28%; beech (Fagus silvatica) 9%; spruce (Picea spp.) 8%; and birch (Betula pendula) 7% (World Bank 2020).

The beginning of this century was marked by several strong waves of decline of forests over nearly the entire country. This decline has had a particularly negative impact on ecosystem functions and services in the country' east and south. Projected trends in key climate indicators such as temperature and precipitation, as illustrated in Figures 30 and 31, indicate further degradation and endangerment of Ukraine's forests. Climate variability and, in particular, frequency and severity of climatic extremes, have the potential to significantly exacerbate future projections.

The longer annual warm period projected under both RCP 4.5 and RCP 8.5 would result in a significantly shorter annual frost period. The increase in the duration of the warm period (t>5 °C) will prolong the growing season for trees throughout Ukraine relative to the baseline period by an average of 20-30 days in the mid-century period, and by 30-50 days (depending on the projections) during the end of century period. The period with a stable temperature above 5 °C will occur earlier in the spring and later in the fall.

Figure 29: Forestland Across Ukraine's Oblast



Based on the projections for both RCP scenarios, the boundaries of climatic zones will shift toward the north. This change happens in terms of heat supply according to Vorobjov's Heat Availability Index[20] for forests. In 1961-1990, Ukraine had four heat zones. These range from relatively moderate (c) in the Carpathians to warm (f) in the southern steppe forest region, predominantly temperate in the plains (d) in Polissya and part of the forest-steppe, and relatively warm (e) in the remainder of the forest-steppe and in the northern steppe. The baseline period (1990-2010) has already seen an extension in the relatively warm (e) (up to 70% of Ukraine's territory) and warm (f) (up to 17.7%). If this trend continues, we will see new types of heat zones (g/very warm, and h/hot), which were not described by Vorobjov in the baseline period (See Annex 4). Heat Availability Index projections are presented in Figure 30. Projections under both RCPs project an increase in annual precipitation relative to the baseline period (1991-2010) in all forested regions except for the Carpathians which will experience a drier climate. These changes are reflected by the changes in Vorobjov's humidity index, accompanied by changes in the hydrological regime, groundwater levels, etc. Climatic conditions cause the formation of respective zonal hydrological conditions (hygrotopes) and intrazonal types under the influence of local landscape, soil type, and moisture availability. For this reason, changes need to be analyzed in high spatial resolution. Vorobjov considers 2 – 6 types of climate humidity as favorable for forest growth. The changes of Vorobjov's humidity index are presented in Annex 4; this change is shown in Figure 31.

Both RCP 4.5 and RCP 8.5 project a further increase in aridity and a shift in the humidity limits to the north. A new type of climate, extremely dry, which was not described by the Vorobjov Index, is expected to appear in the south (see Annex 4). Water scarcity causes forest degradation, as forests are especially sensitive to droughts and other climate extremes that cause changes in hydrological conditions as drop in groundwater levels. Ukraine has a poor water resource endowment and very unstable water flow. In recent years, water reserves in rivers and reservoirs amounted to only 80% of the long-term average (Schvidenko et al, 2018). Intensive processes of drying and morbidity of major forest tree species, including pine, spruce, oak, and beech, are observed in forests. The southern part of the country is under particular risk, with ongoing losses of forests due to drought estimated by remote sensing at about 20-30% of forested area.

Under the RCP 4.5 projections, conditions suitable for forest growth will remain only in the Carpathians, western forest-steppe, western part of Polissya (in the form of a new climate type), and parts of the north of Chernihiv and Sumy oblasts. The areas of wet and fresh climate types are expected to decrease (as shown in Annex 4), and dry climate types to increase. The total area with dry conditions will occupy 63.2% of the country's territory in the middle of the century, and 70.5% at the end of the century.

Under the RCP 8.5 projection, the process of aridification will accelerate. Dry climate types are expected to account for about 69.6% of the country's territory in the middle of the century and 89.7% at the end of the century. Accordingly, the area of climate conditions suitable for forest growth will decrease significantly, up to 30.4% in the middle of the century and 10.3% at the end of the century.

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[20] Other indices which have a strong influence on tree growth, such as the continentality index, were also taken into account for this analysis. Details of the continentality index are given in Annex I.

Figure 30: Relative Changes of Vorobjov's Heat Availability Index to Climate, 1991-2010

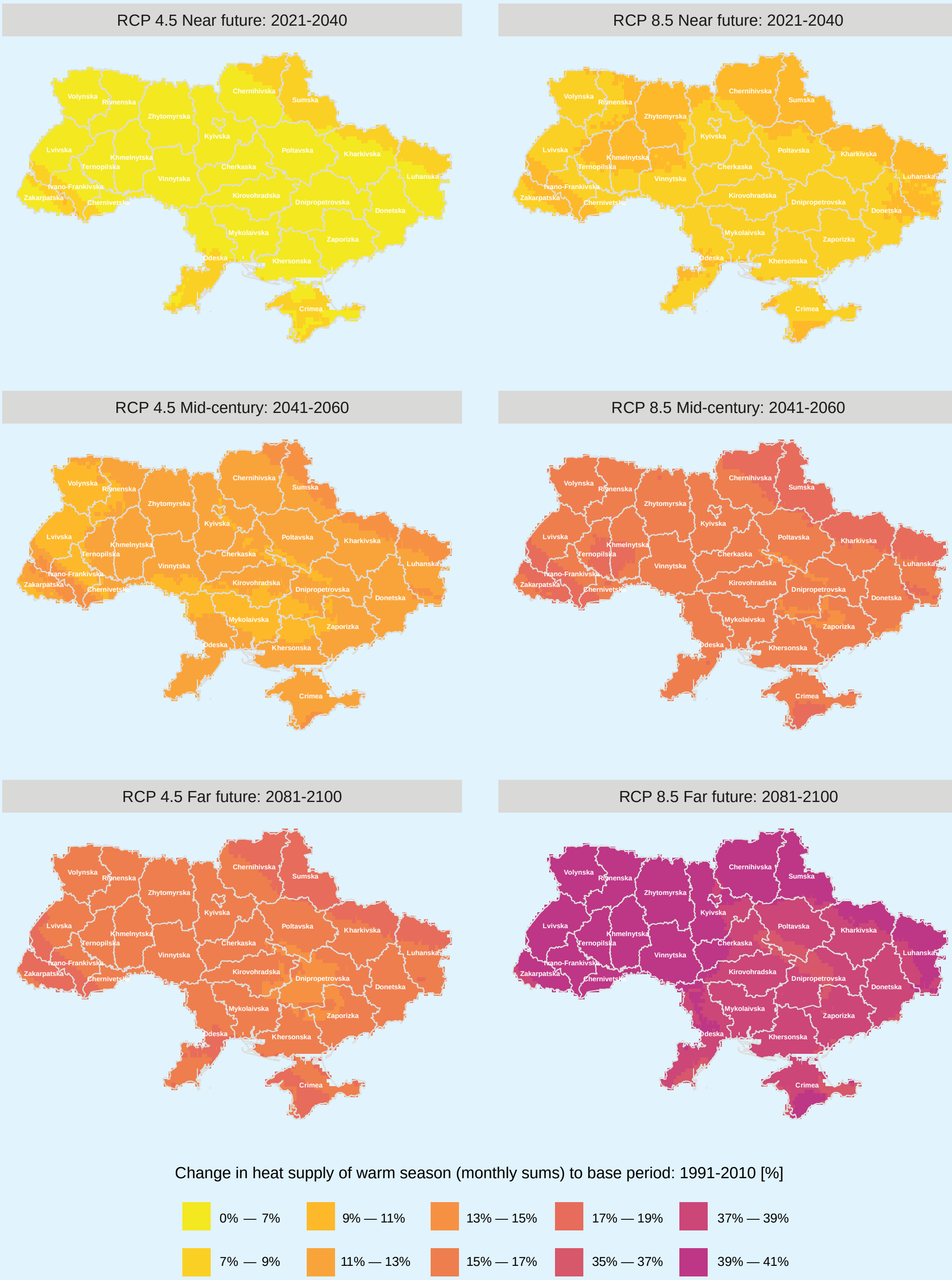
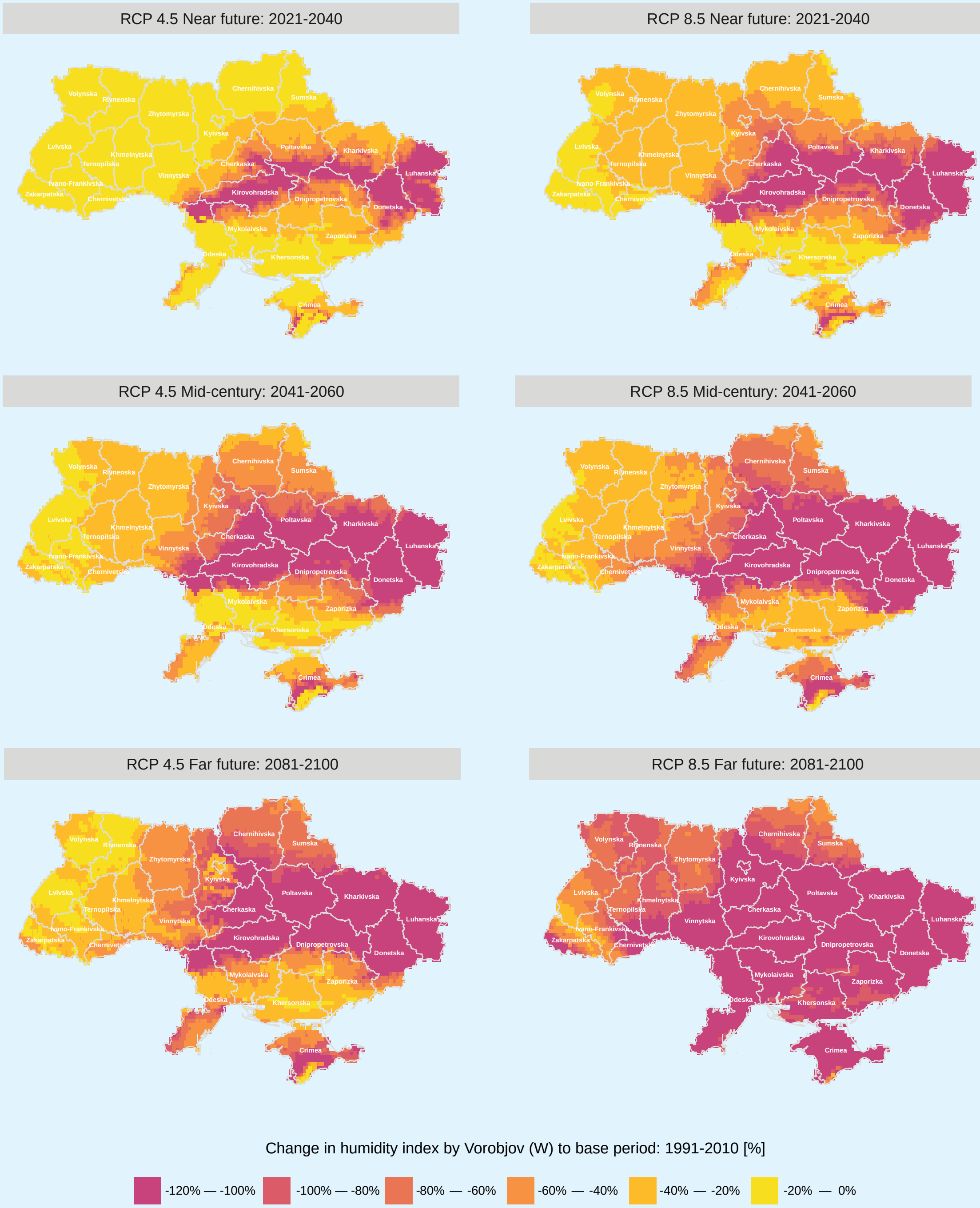


Figure 31: Relative Changes of Vorobjov's Moisture Availability Index to Climate, 1991-2010



5.3 Effect of Climate Change on Key Forest Species

The boundaries of zones with satisfactory conditions for English oak are expected to further shift toward the northwest, while the conditionally unsuitable zone will expand to the south. Conditions in the Carpathians are becoming more favorable for this species. In the middle of century climate, comparatively minor changes are anticipated (Figure 33), including narrowing of the zone of unsatisfactory conditions in the Carpathians and the southern steppe**.** According to the projection under RCP 8.5 at the end of the century, the conditions in the Carpathians are expected to be satisfactory in the highlands and optimal on the plains; and most of Ukraine will be characterized by conditionally unsuitable and unsatisfactory conditions[21] (Figure 33 and maps in Annex 4).

Under RCP 8.5 projections, the areas with optimal conditions for European beech will diminish to 2% of Ukraine's territory. A shift toward the northwest was already taking place in the baseline period (1990-2010). In particular, the optimal zone for European beech in the western part of the forest-steppe decreased. During the same time period, conditions for beech improved in the Carpathians, from unsatisfactory to satisfactory. A further shift of boundaries and shrinking of the area suitable for forest beech growth is anticipated. In the mid-century, under RCP 4.5, conditions suitable for beech could be preserved in 23.8% of Ukraine's territory (Figure 33). By the end of the century, the western part of the forest-steppe and Polissya will consist of mostly unsatisfactory and conditionally unsuitable zones, and the Carpathians and a small area in the western forest-steppe will consist of zones ranging from optimal to satisfactory (Figure 32 and maps in Annex 4).

Conditions suitable for Scots pine growth will remain in the Carpathians (ranging from optimal to satisfactory), the western part of the forest-steppe, and Polissya (predominantly unsatisfactory). Between 1990 and 2010, boundaries shifted slightly toward the north and the zones with optimal and suboptimal conditions narrowed. The south had small zones of conditionally unsuitable areas for pine growth. In the future, minor changes are expected, leading to improved conditions including the expansion of optimal zones in the Carpathians and suboptimal zones in most of Polissya and the western part of the forest-steppe. Conditions will be satisfactory in the forest-steppe and unsatisfactory in the steppe. It is expected that borders will further shift to the northwest, and the conditionally unsuitable zone will expand. By mid-century, under RCP 4.5 the conditionally unsuitable zone will cover about 37.1% of Ukraine's territory, and under RCP 8.5, 45.4% (Figure 33 and maps in Annex 4).

In the mid-century, under both RCP 4.5 and RCP 8.5, only the Carpathians will remain a suitable zone for Norway spruce. In the rest of Ukraine, climate conditions will be conditionally unsuitable for spruce. Regional studies of climate change impacts on forests in the Ukrainian Carpathians came to a similar conclusion. Spruce forests areas are expected to decrease from more than 60% to 25% under RCP 4.5, and to 10% under RCP 8.5 (Kruhlov et al. 2018). In the end of the century, climate conditions suitable for spruce are projected to disappear in the north/northwest (Polissya), and the western part of the forest-steppe, with most Ukrainian territory becoming conditionally unsuitable (Figure 33 and maps in Annex 4).

[21] See Figure 32 for the full suitability scale for growing forest species; the scale ranges from conditionally unsatisfactory to optimal.

The impact of climate change on forests in Ukraine is exacerbated by a simultaneous loss of ecosystem services. Additionally, based on some estimates, carbon sequestration by forests could decrease significantly. Box 4 summarizes some of the impacts which are not addressed in this report, but could negatively affect resilience of natural landscapes, reduce agricultural productivity, and threaten biodiversity in Ukraine.

Figure 32: **Impact of Climate Change on Areas with Growing Potential for English Oak and European Beech, 2100**

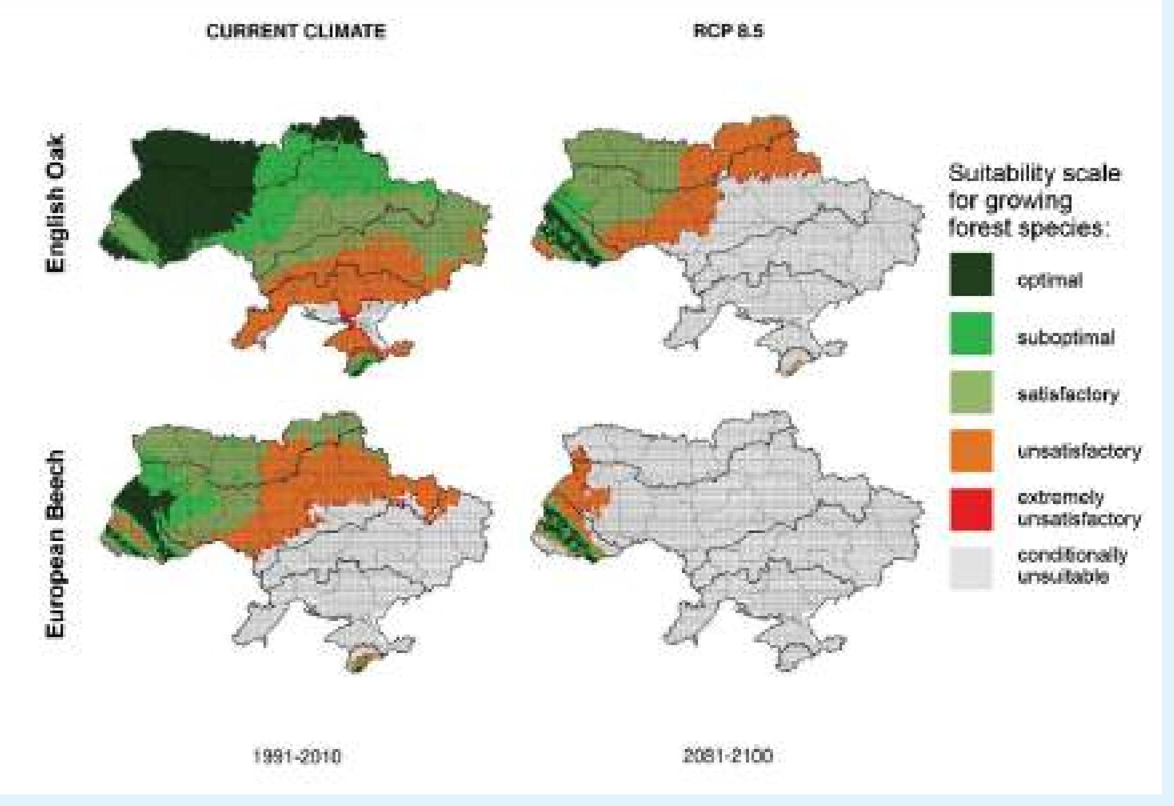
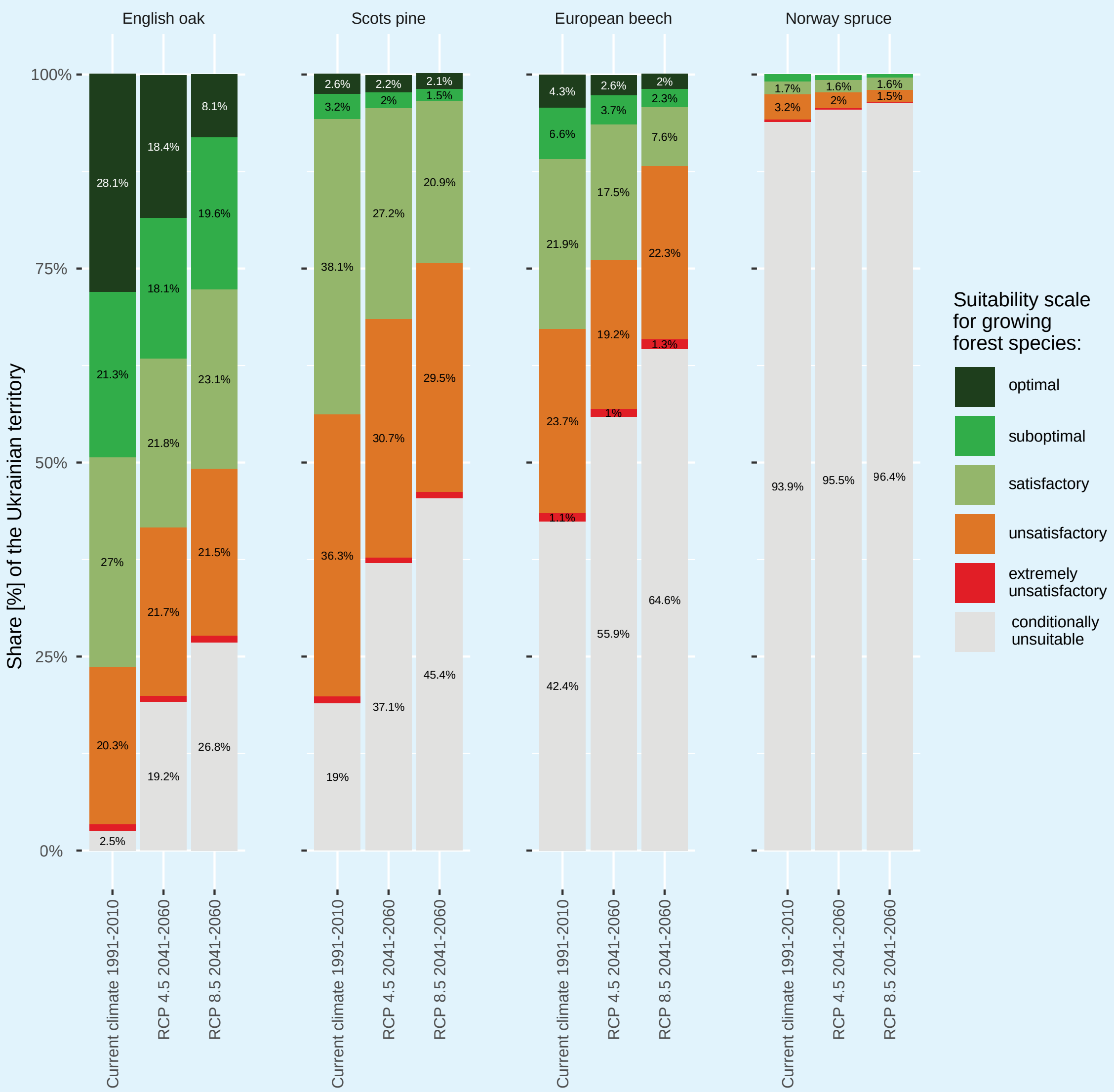


Figure 33: Impact of Climate Change on Areas with Growing Potential for Selected Forest Species, in 2050



Box 4: Impact of Climate Change on Forests and Decline of Ecosystem Services

Carbon sequestration. Ukrainian forests provide very high potential for carbon sequestration – in 2018 about 50 thousand tons of CO_2-equivalent per year, a figure 21% lower than in 1990 (NIR 2020). This is one of the highest values of forest sink in Europe and is explained by a large share of forests with a restricted regime of wood harvest (~50%) and share of young and middle-aged forests (~70%) (Shvidenko et al. 2017). However, following the traditional trends of forest sector development in Ukraine assuming an extensive model of forest management and a "business as usual" scenario (assuming no adaptation), the next 30 years will lead to a more than twofold decline in carbon sequestration potential (Shvidenko et al. 2014). It is very likely that the situation will worsen by the end of this century, as there are high risks of reaching a "tipping point," when an ecosystem is driven to a new state or collapses entirely. Figure 32 indicates change potential for growing the selected forest species by geographic area.

Productivity of forests. The warmer and drier climate will affect the productivity of forests and make pest outbreaks more common. The area of forest affected by pests and diseases doubled from 4% in 2000 to 8% in 2011. More such changes will take place in the future, as temperatures reach 5°C and 10°C earlier in the year (see Table 5). Projected changes in monthly mean temperatures can disrupt the synchronization of tree leaf development and lead to a rise in diseases and pathogens, including fungal infections (Shvidenko et al. 2018a).

Water regulation. Forest degradation can cause water scarcity, as forests are of paramount importance in providing water regulation functions. They can contribute to maintaining sustainable crop yields and the ecological stability of landscapes (Shvidenko et al. 2018b). Forest degradation will disturb hydrological cycles and associated impacts on agricultural yields and can have a significant impact on the economy. However, these effects are not easily modeled even by specialized ecosystem-economy models and the magnitudes of effects can be only anticipated (Johnson et al. 2021).

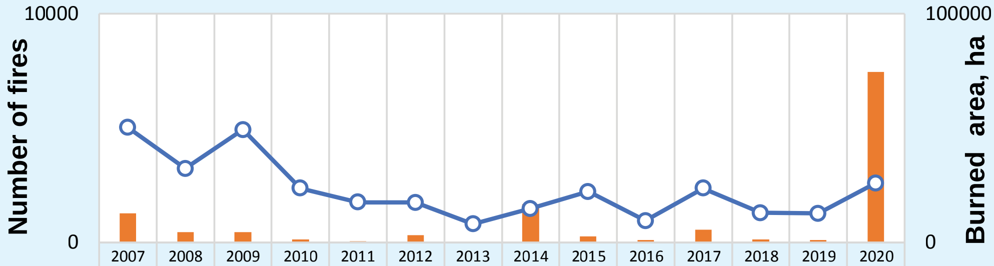
Impact on natural habitats and preservation of biodiversity. The loss of forest species (see Figure 32), which is itself a loss of biodiversity, promotes the ongoing losses (including extinctions) of dependent species and ecosystems. Biodiversity loss reduces the ecosystem's resilience to shocks and limits provision of valuable ecosystem functions and services to people. Loss of forest cover induces loss in pollination sufficiency, especially important for agricultural crops that are dependent on wild pollination (Johnson et al. 2021).

5.4 Impact on Forest Fires

Data for the period 2007-2020 shows a general decrease in the number of forest fires but a sharp increase in the area burned. The analysis of data on forest fires in Ukraine for the period 2007-2020 shows that the 2020 fire season was the most catastrophic in the country's modern history, with a number of fires classified as large on the national forest fire classification scale occurring in the northern and eastern parts of the country, resulting in unprecedented environmental, social and economic damage. This is consistent with the recent trend in other European countries, where large forest fires have become more frequent in recent decades (de Rigo et al. 2017).

Regional forest fire density data shows the highest concentration of incidents in the southeast regions of the country. Research by the Forest Ecology Laboratory of URIFFM determined that the density of forest fires increases from the northwest to the southeast. (See Annex 4.) Typically, forest fires are most highly concentrated in Khersonska (1.9 cases per 1,000 ha of

Figure 34: Total Burned Areas and Numbers of Forest Fires in Ukraine



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Burned area	12731	4521	4575	1239	612	3311	220	16677	2625	1101	5474	1367	1065	74623
Number of fires	5024	3231	4922	2368	1761	1743	806	1486	2225	945	2371	1297	1261	2598

Source: State Forest Resources Agency of Ukraine, 2020.

forested area), Zaporizska (1.4 cases per 1,000 ha), Dnipropetrovska (1.3 cases per 1,000 ha), Luhanska (1.1 cases per 1,000 ha), and Donetska oblasts (1.1 cases per 1,000 ha).

The projected changes in climatic conditions in Ukraine will likely have significant implications for forest fires risk. Climate change projections for Ukraine show a consistent trend of increases in annual average temperature under both RCPs, with progressively higher increases toward the end of the century (2.1±1.8°C under RCP 4.5 and 4.3±2.1°C under RCP 8.5). The spatial distribution of temperature rise under both emission scenarios are similar over time, with the highest temperature increases in the northeast and the lowest in the west, northwest and areas near the Black Sea coast. Rising temperatures in the summer will result in heatwaves and increased aridity in the south and east of Ukraine. The southern regions will experience an average daily maximum temperature above 34°C in July, with the southern steppe remaining the hottest until the end of the century. The Sixth Assessment Report (AR6) by the IPCC indicates that every additional increase of 0.5°C in global average temperature causes discernable increases in the intensity and frequency of heat extremes such as heatwaves and ecological droughts (IPCC 2021). These factors will, in turn, enlarge the stock of forest fuel available for combustion in wildfire events (de Rigo et al. 2017).

The PESETA study assumes a high level of vulnerability to forest fires in the northwestern parts of Ukraine, particularly in Polissya with its large areas of pine forests with high risk of fire. The study projects a rise in the number of days per year with high to extreme wildfire danger nearly everywhere in Europe due to higher temperatures and increased dry spells. The vulnerability is measured as percentage of biomass lost in case of fires. The risk of fires is even higher for the pine forests growing in these regions, although the total area of pine forests here is not as large as that in Polissya.

5.5 Analysis Limitations

Due to the lack of reliable forest inventory data in Ukraine (World Bank, 2020), the study was not able to address the impact of climate change on forest productivity and ecosystem services with the same analytical approach and for the same spatial disaggregation used in other parts of this study. This analysis could be conducted in follow-up studies. Similarly, the impact of climate change on forest fires was assessed using historical data. This analysis could be further improved by complementing climate indexes developed in this study with specific indexes for potential frequency and intensity of forest fires in Ukraine.