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 heatwaves, thunderstorms, heavy precipitation, pluvial and river flooding, droughts, hailstorms, 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-

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[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.

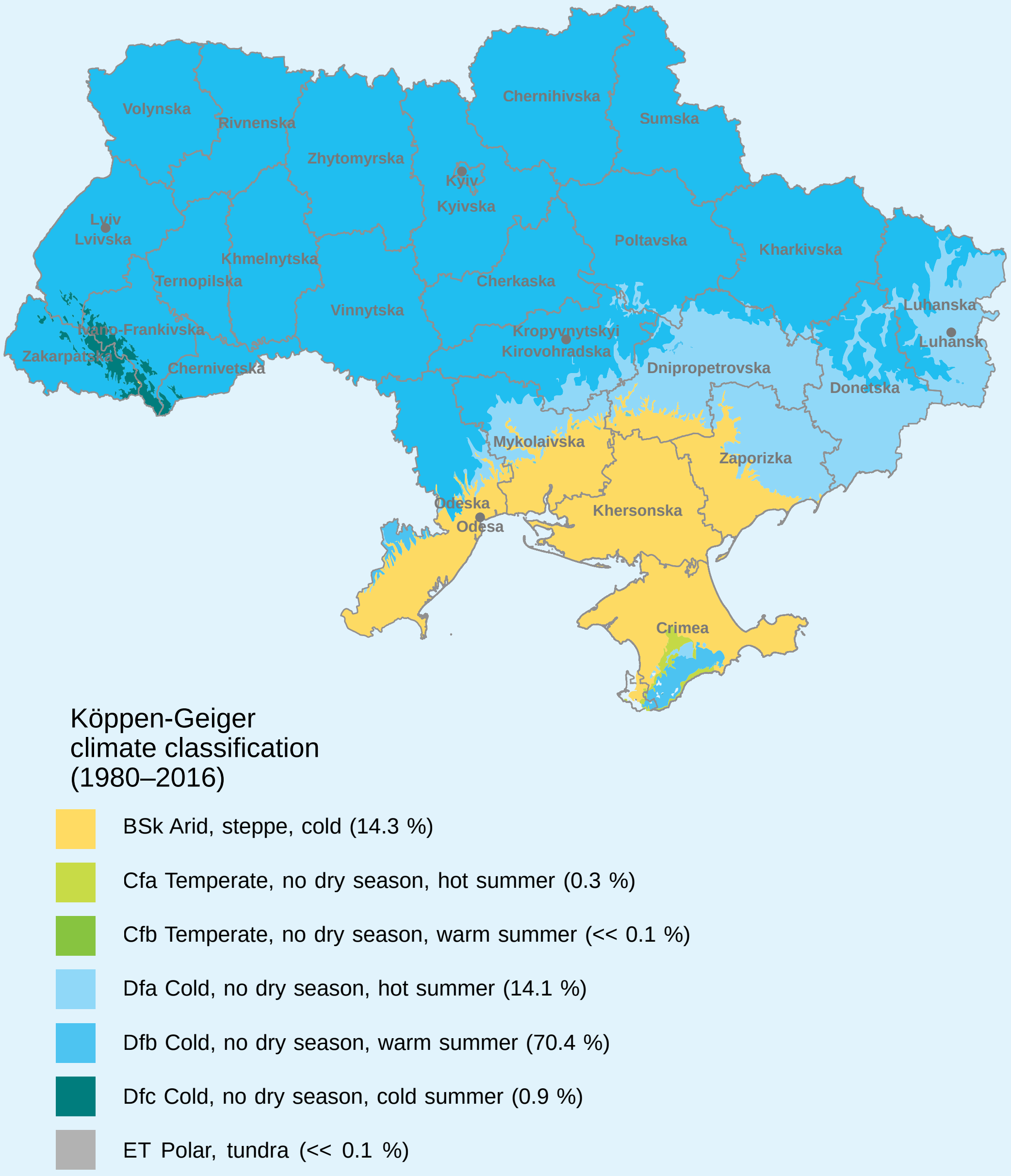
2.2 Recent Climatic Changes in Ukraine

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^{o} 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



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

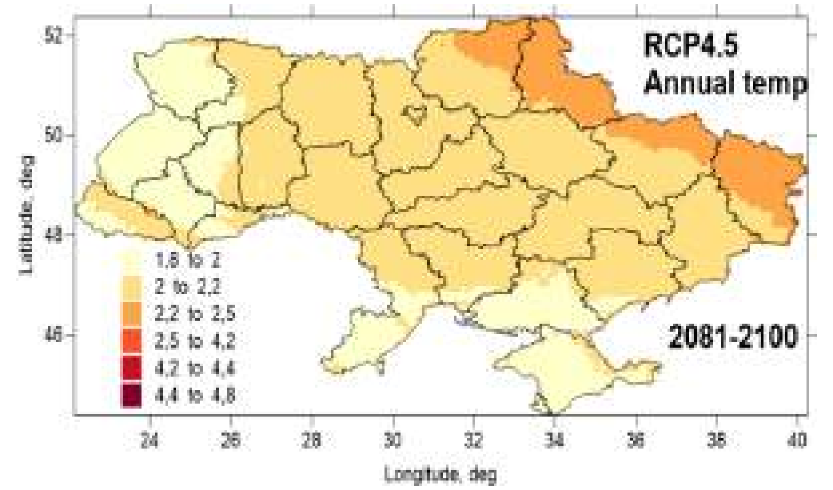


Figure 4b: Projected Annual Mean Temperature Increase (compared to baseline 1991-2010) RCP 8.5 at the End of the Century

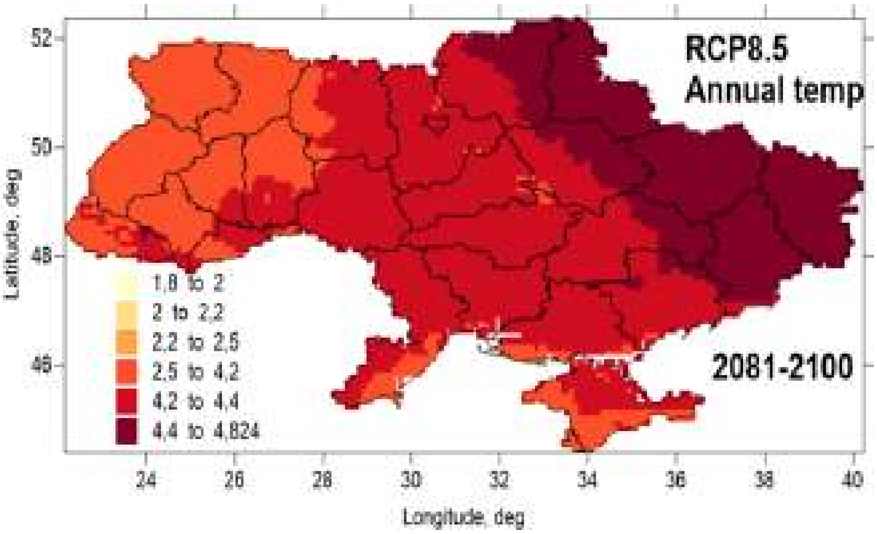


Figure 4c: Temperature Differences Between the Two Scenarios at the End of the Century

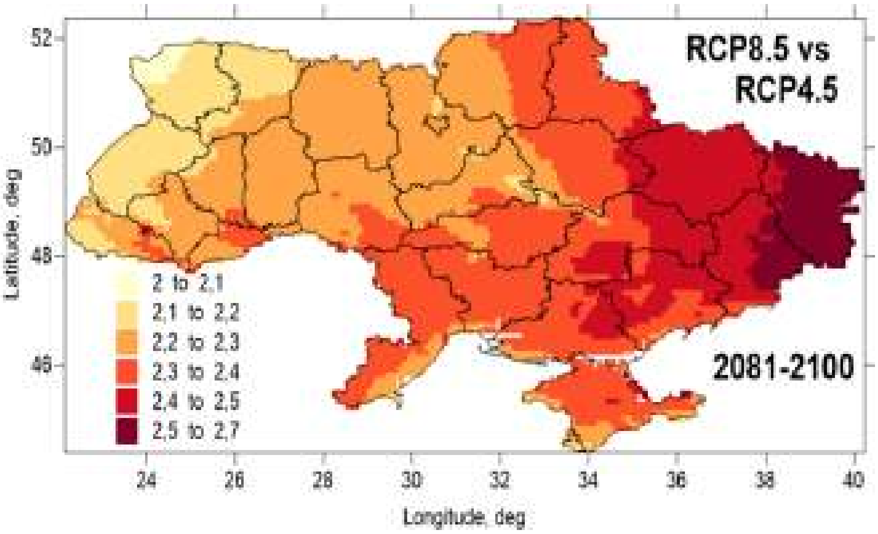


Figure 5: Annual Temperature Change

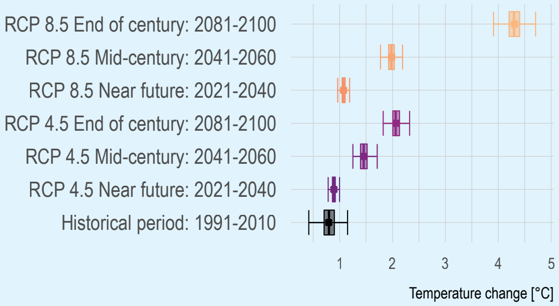
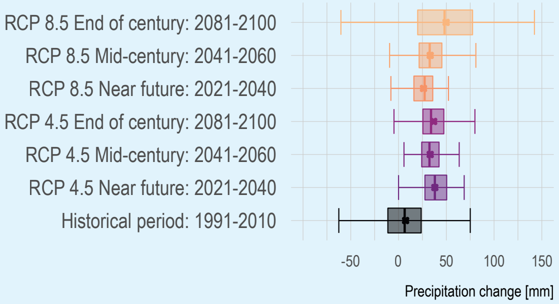


Figure 6: Annual Temperature Change



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

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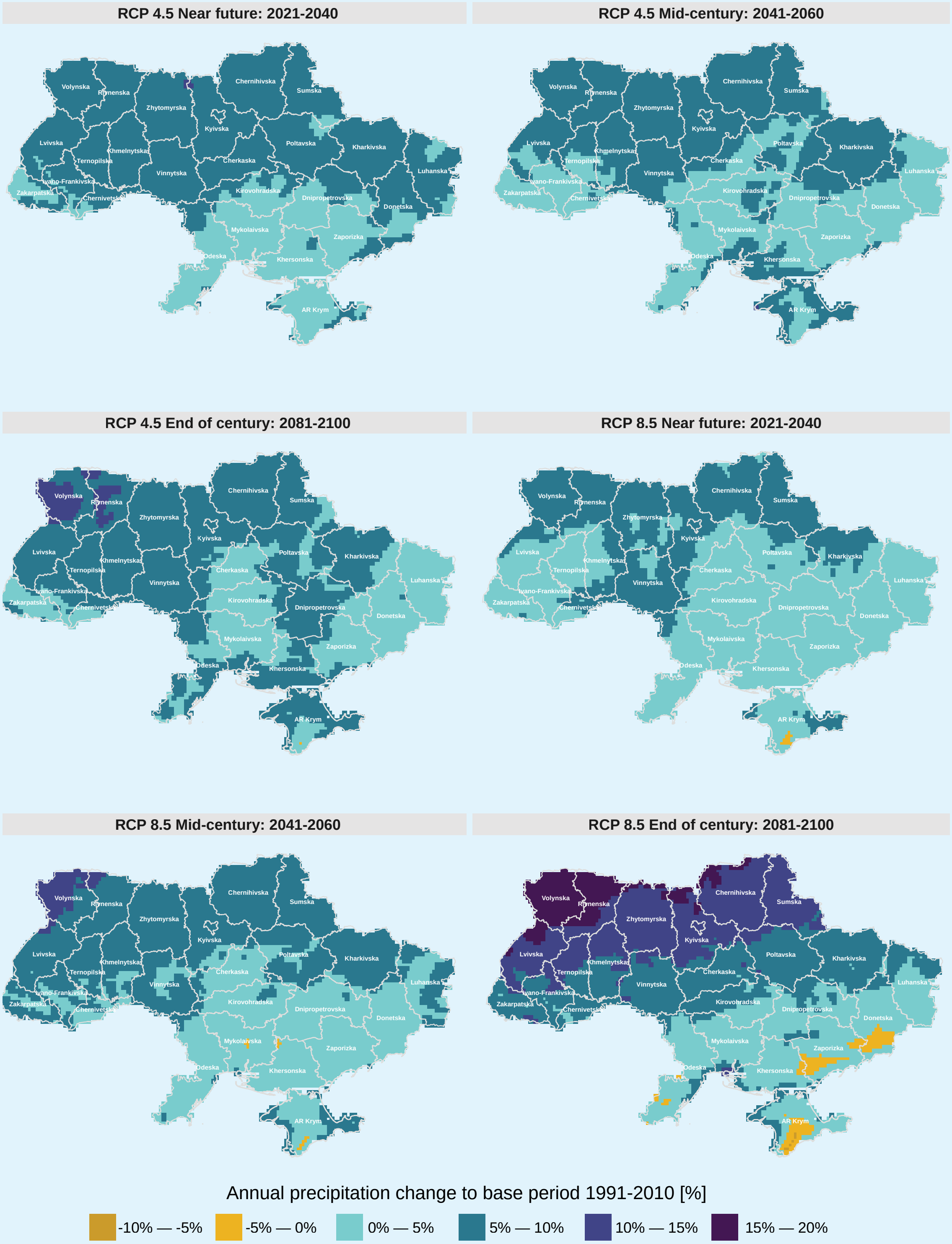
[3] This figure and later the box and whisker diagrams: the lower and upper hinges of boxes correspond to the first and third quartiles (the 25th and 75th percentiles). The upper whisker extends from the hinge to the largest value no further than 1.5º (inter-quartile range) from the hinge. Inter-quartile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

Figure 7: Annual Precipitation Change (mapped)



RCP 4.5 Near future: 2021-2040

RCP 4.5 Mid-century: 2041-2060

RCP 4.5 End of century: 2081-2100

RCP 8.5 Near future: 2021-2040

RCP 8.5 Mid-century: 2041-2060

RCP 8.5 End of century: 2081-2100

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

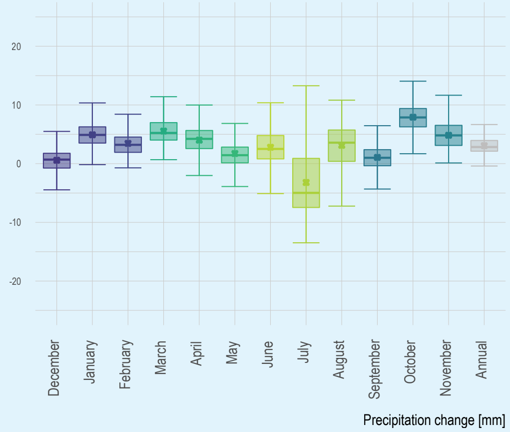
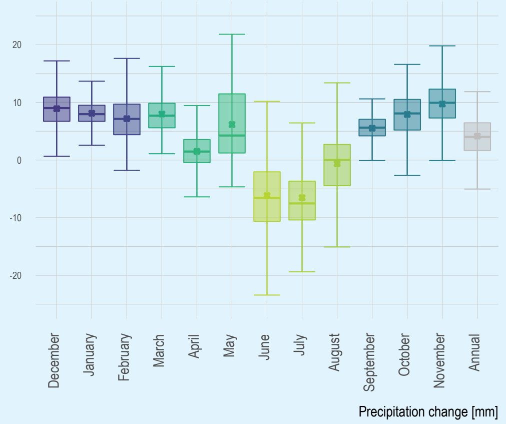


Figure 9: Monthly Precipitation Change in RCP 8.5 – End of Century Compared to Baseline



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.

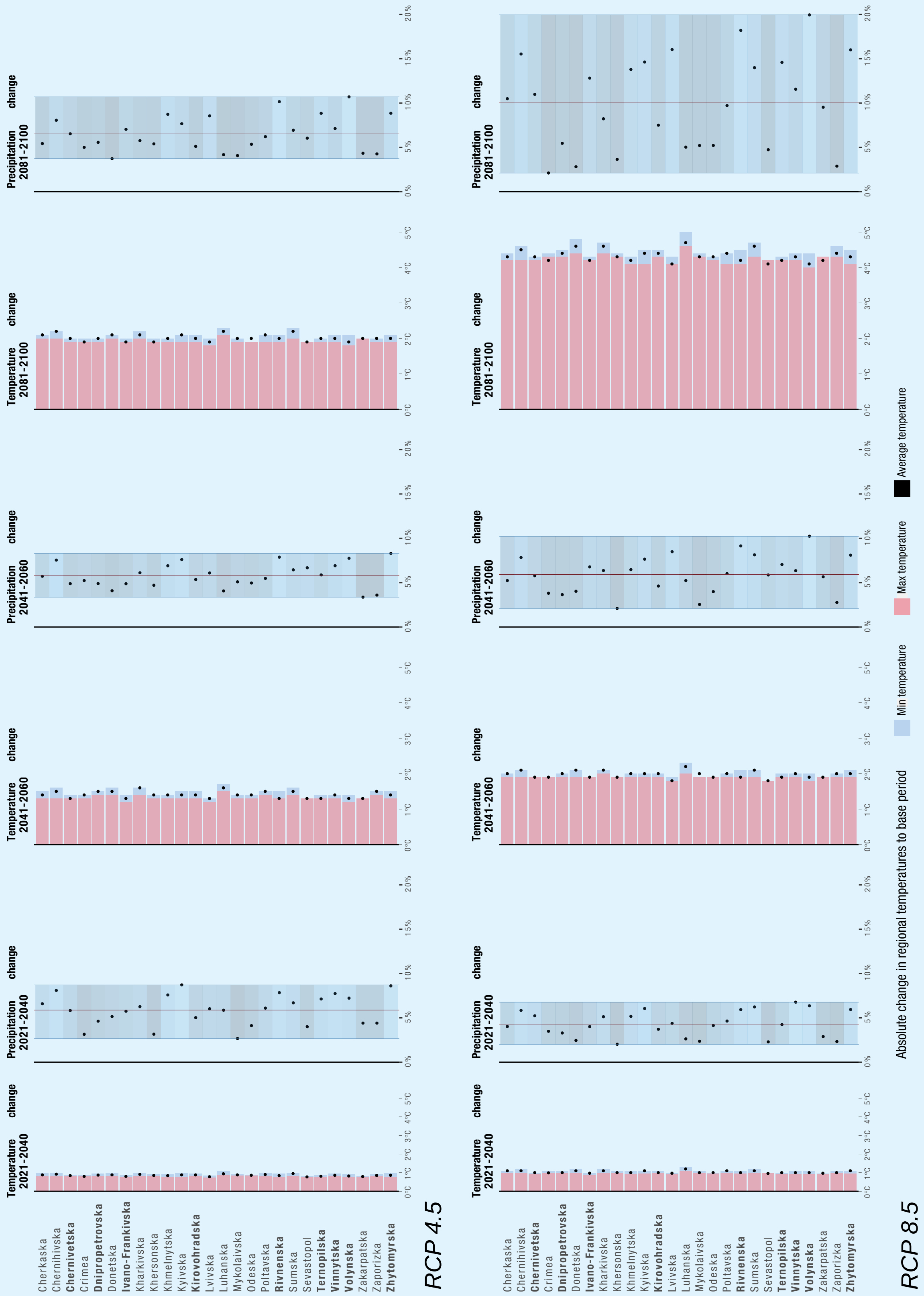
These climate trends are of critical importance for regions with a higher proportion of rural population which is dependent on agricultural income, as distributional effects of climate change on household incomes are expected to be stronger in oblasts where households rely on agricultural production. 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.

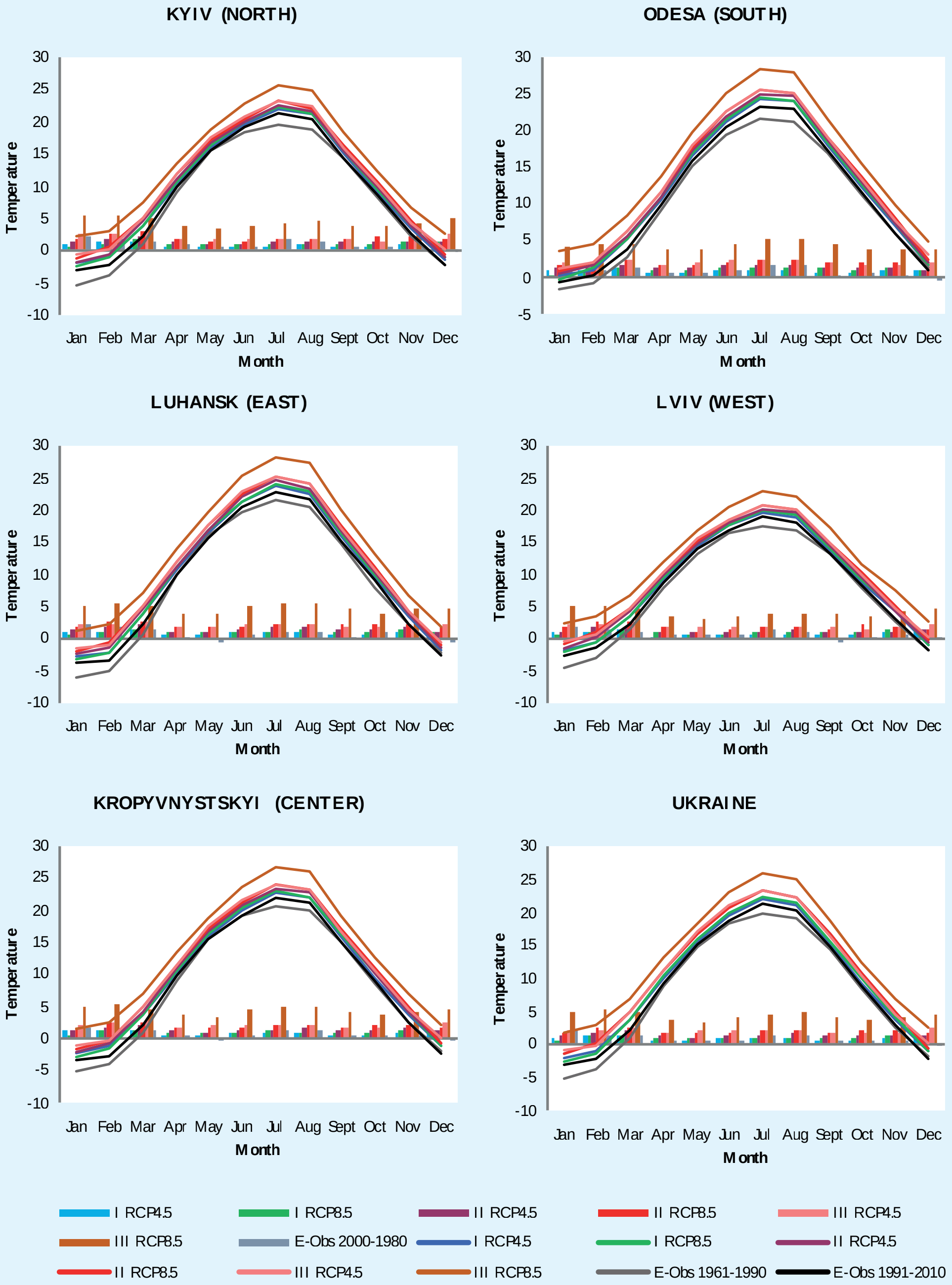
During the middle of the century period between 2041-2060, the differences between the two scenarios become apparent, and in Ukraine's cities, strong temperature signals are observed for almost all months, giving rise to high confidence in the warming projections. Warming in other winter months is comparable 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]



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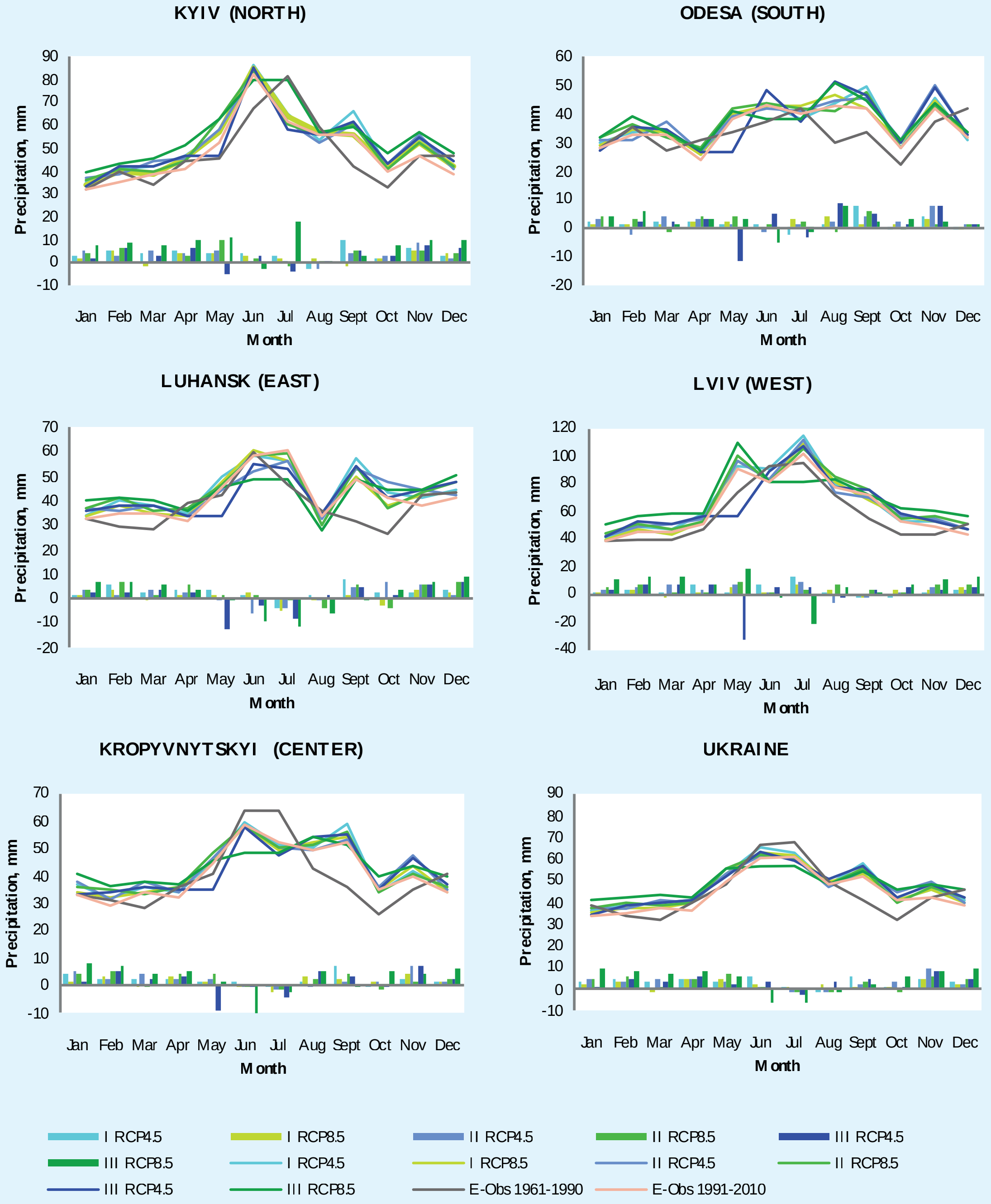
[4] In these graphs, lines indicate absolute values, while bars show incremental value compared to the baseline (1990 – 2010).

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

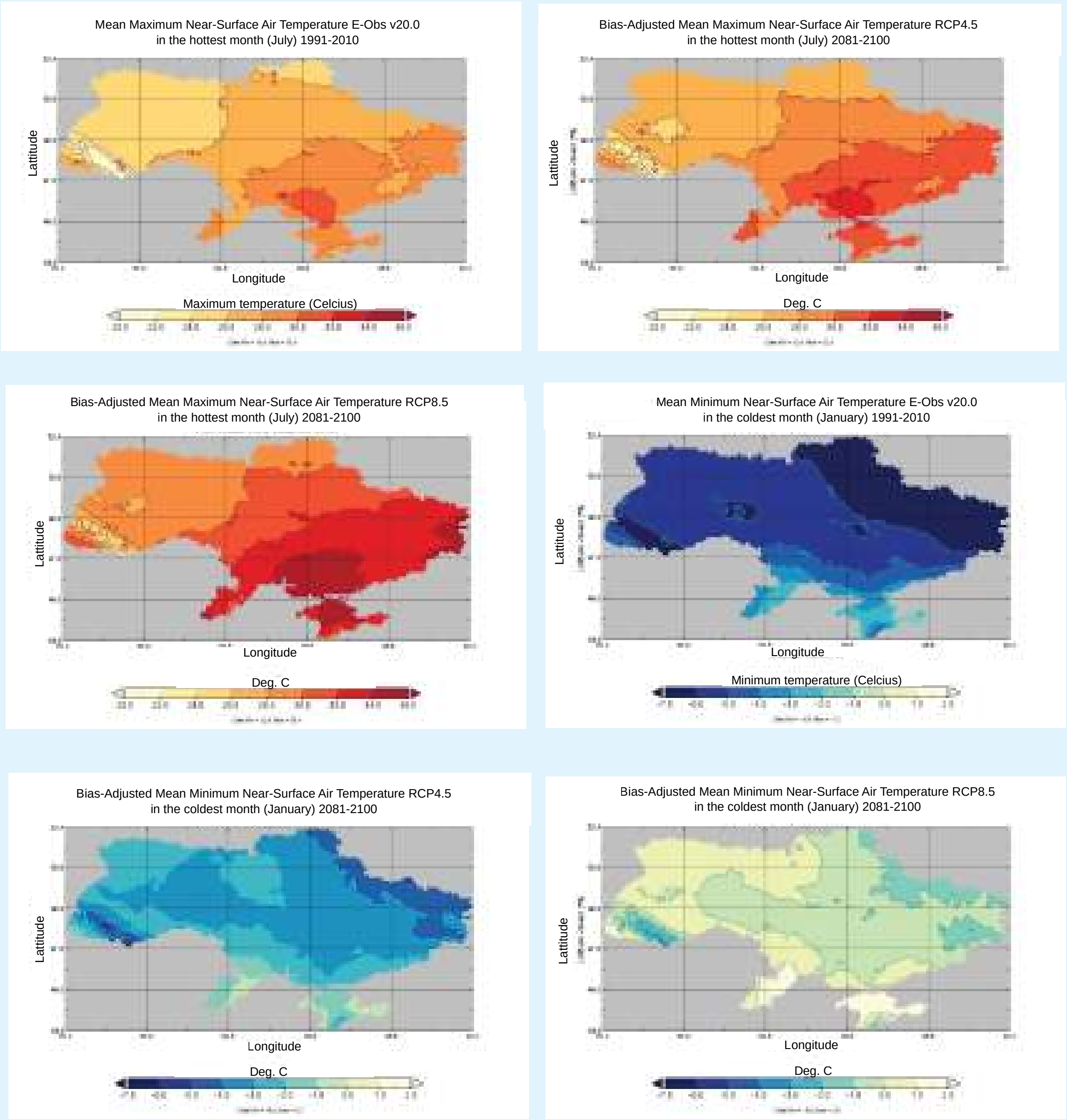
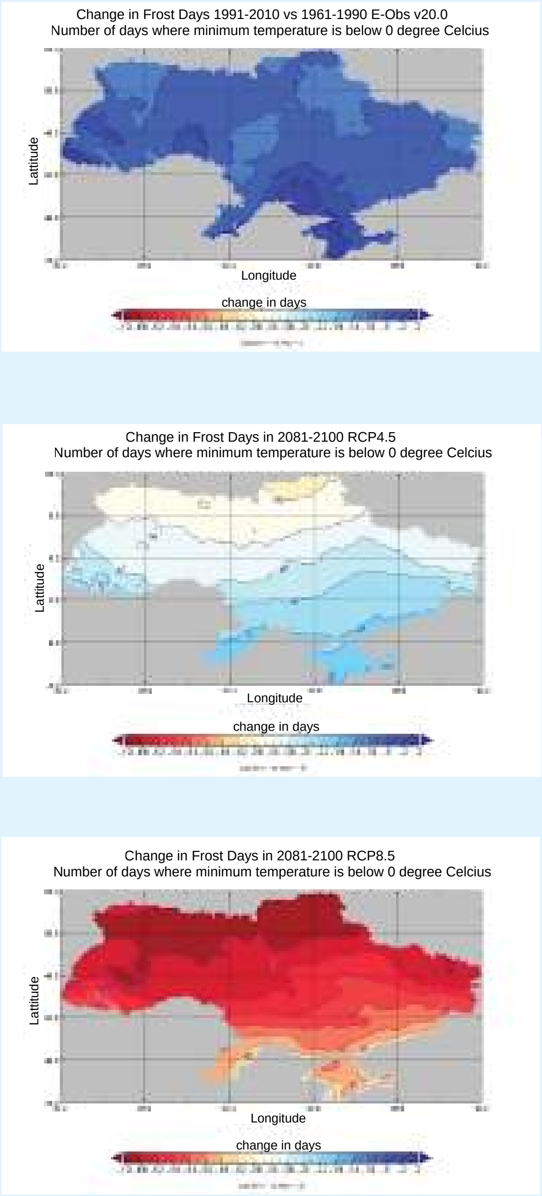
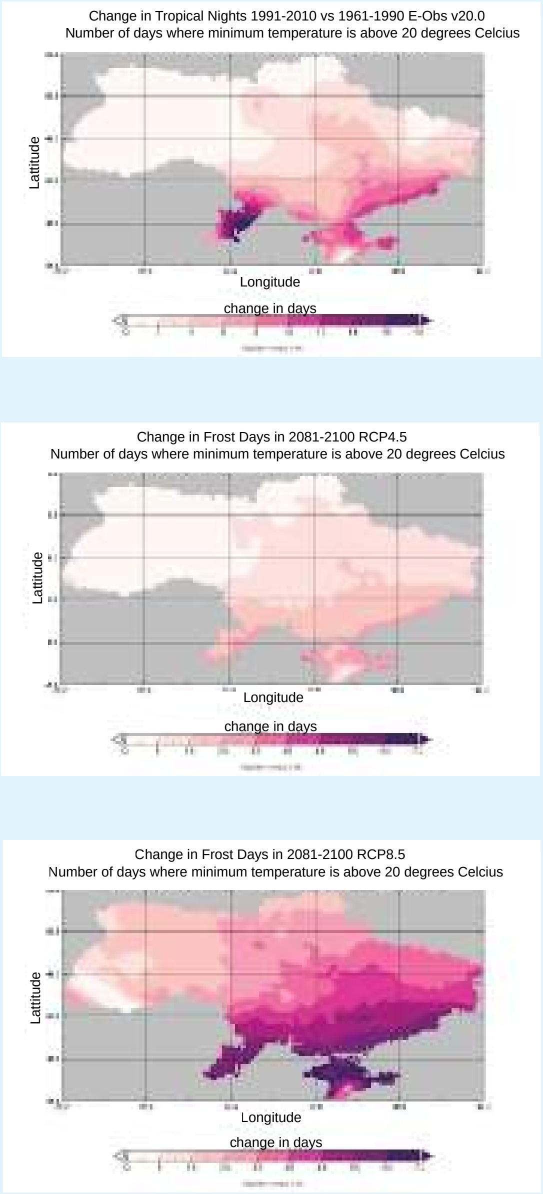


Figure 14: Changes in Frost Nights



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

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[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%

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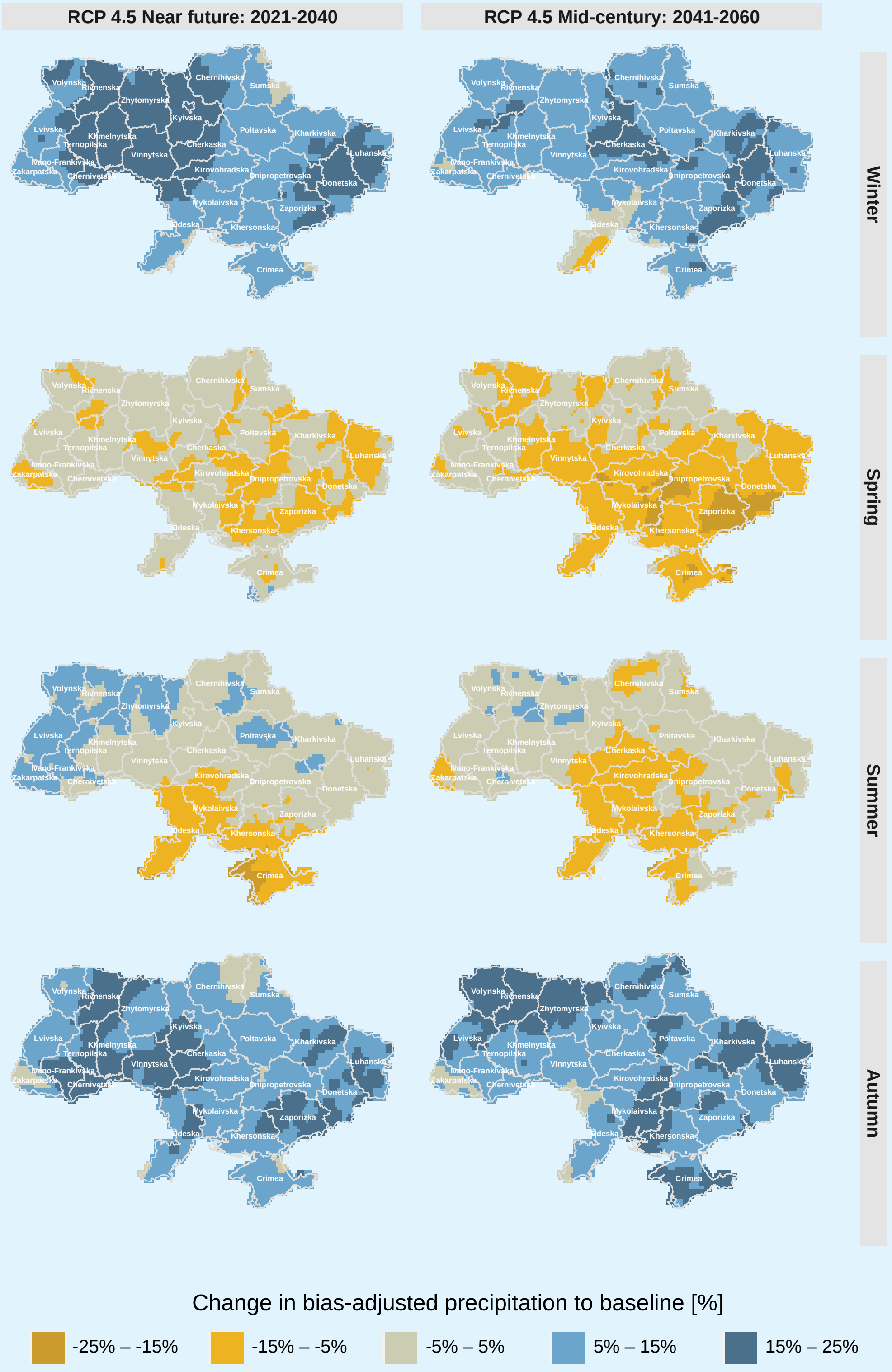
[10] Figures are for the mean projection and changes in yield [tons/ha] relative to 2010 levels.

Figure 16: Seasonal Precipitation in RCP 4.5 and RCP 8.5



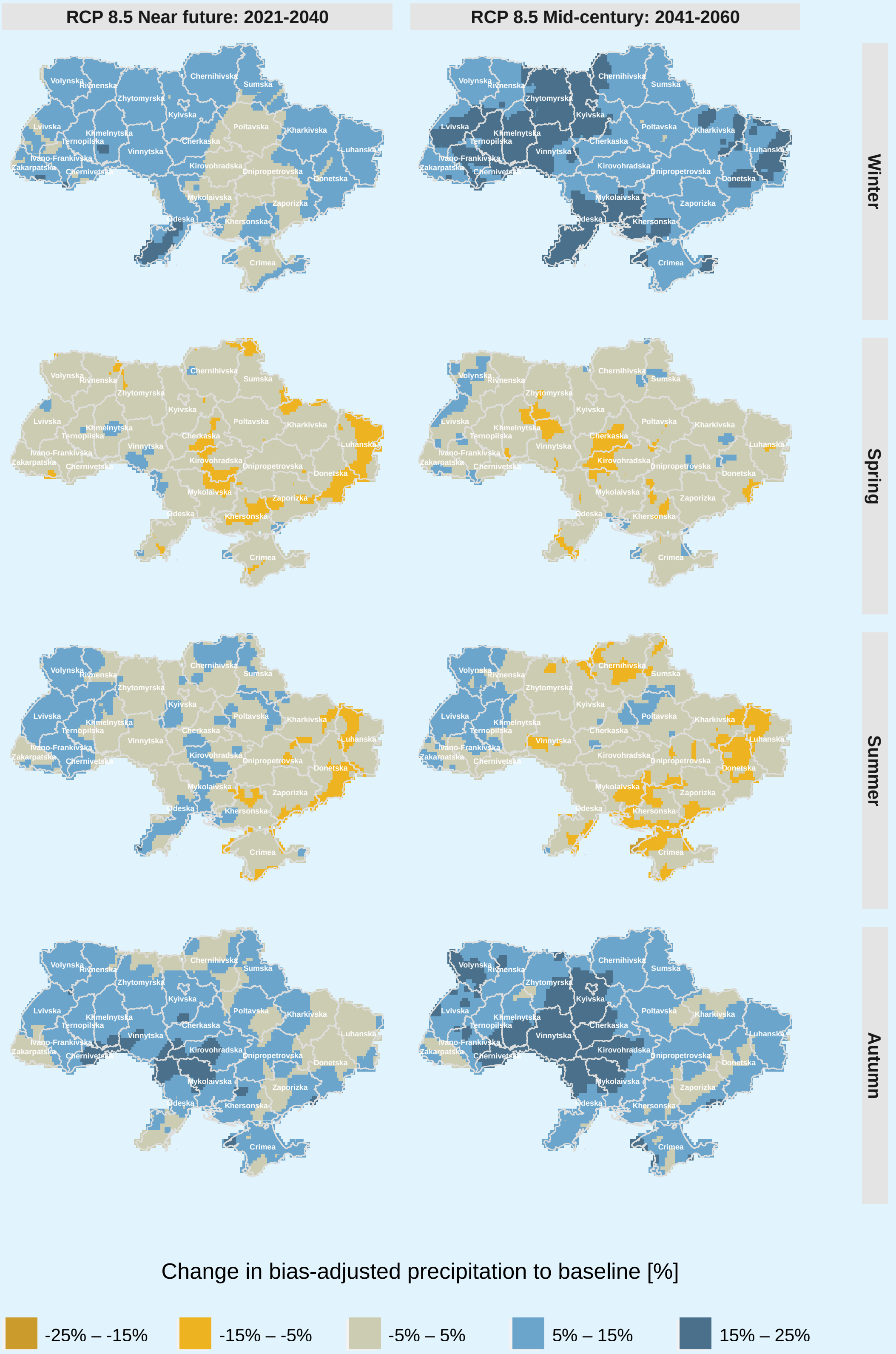
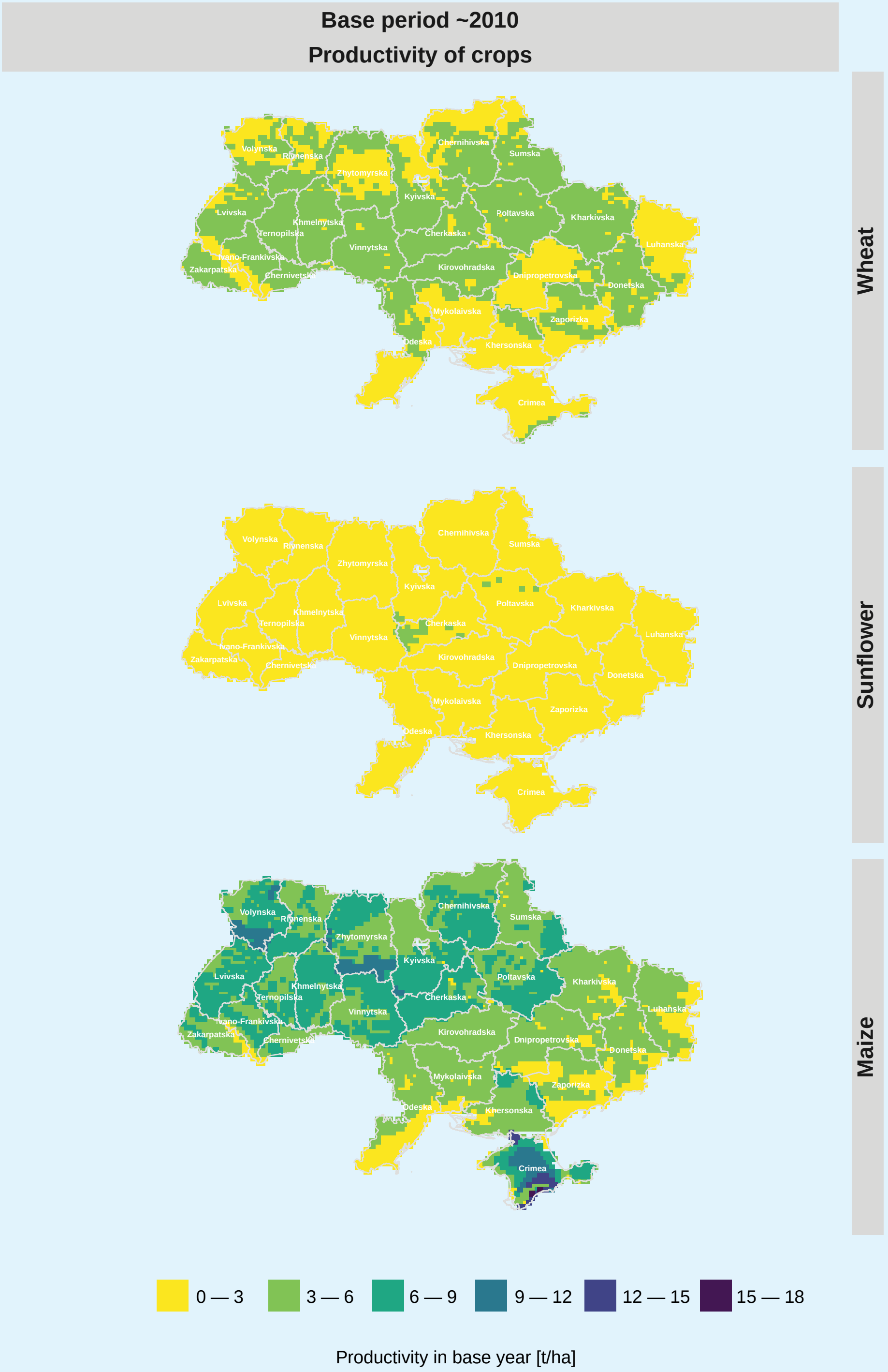
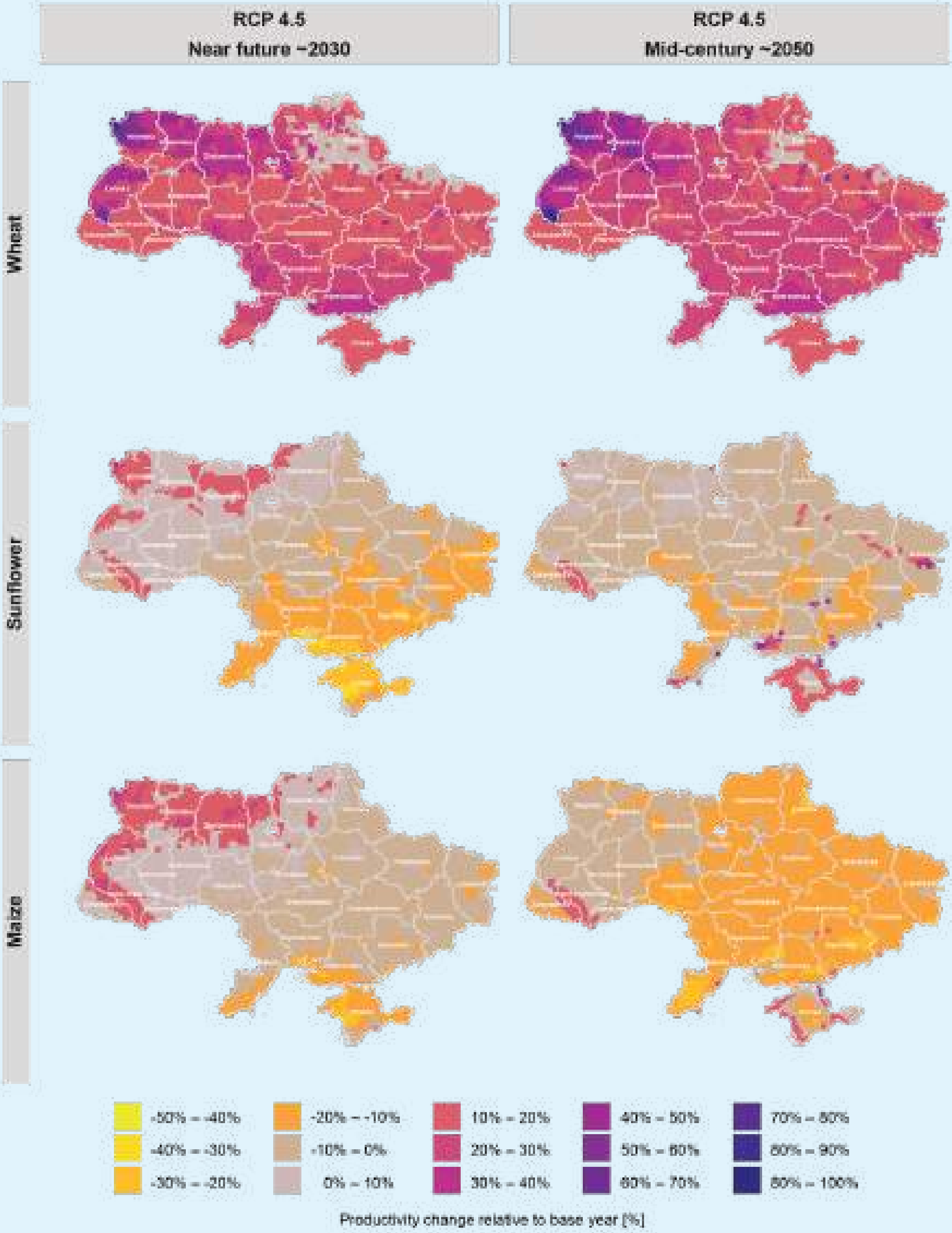
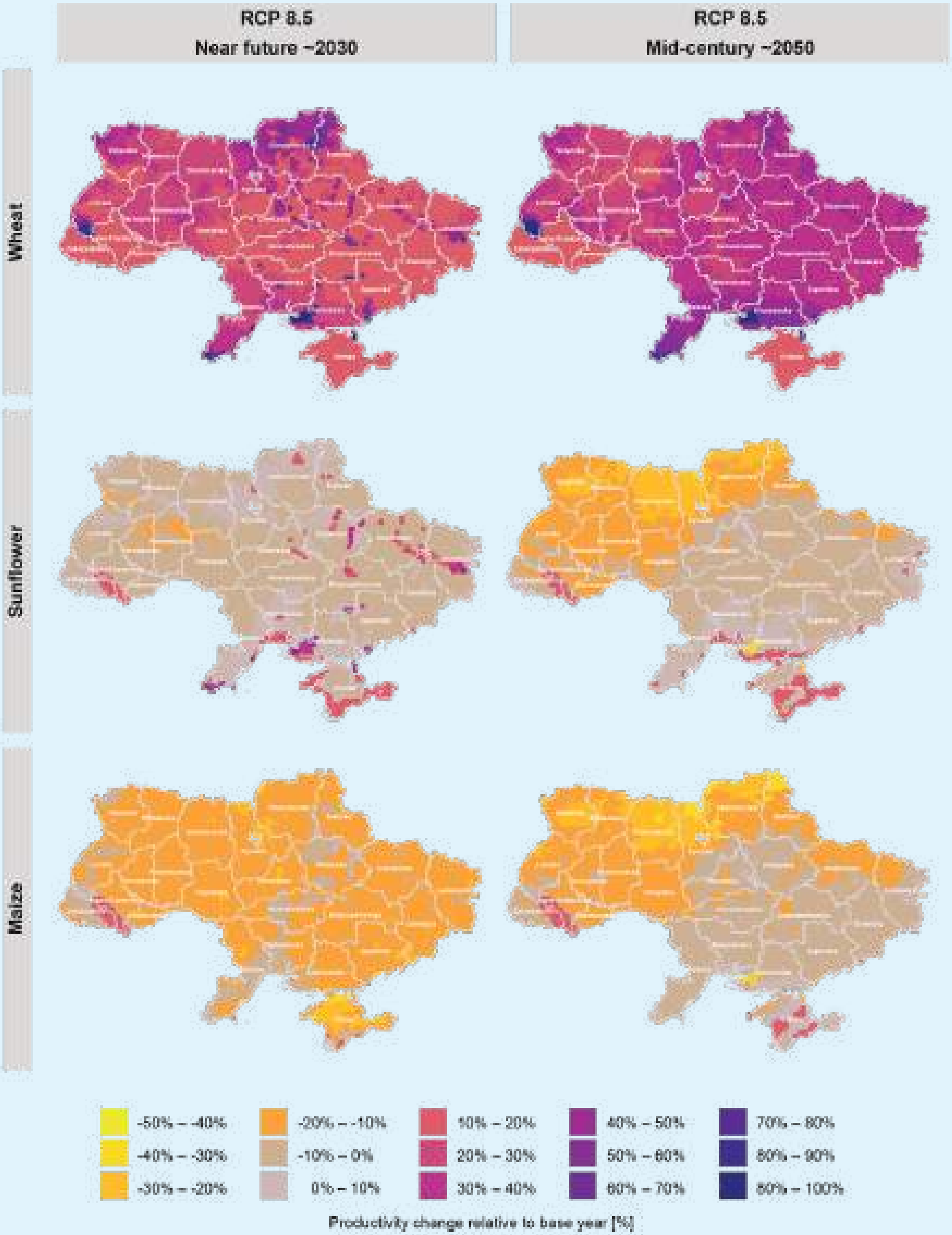
RCP 8.5 Near future: 2021-2040
RCP 8.5 Mid-century: 2041-2060
Winter
Spring
Summer
Autumn
Volynska
Rivnenska
Zhytomyrska
Chernihivska
Sumska
Kyivska
Lvivska
Khmelnytska
Ternopilska
Poltavska
Kharkivska
Cherkaska
Ivano-Frankivska
Zakarpatska
Chernivetska
Vinnytska
Kirovohradska
Dnipropetrovska
Luhanska
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).

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

Figure 18: Impact of Optimal Water Availability in 2030

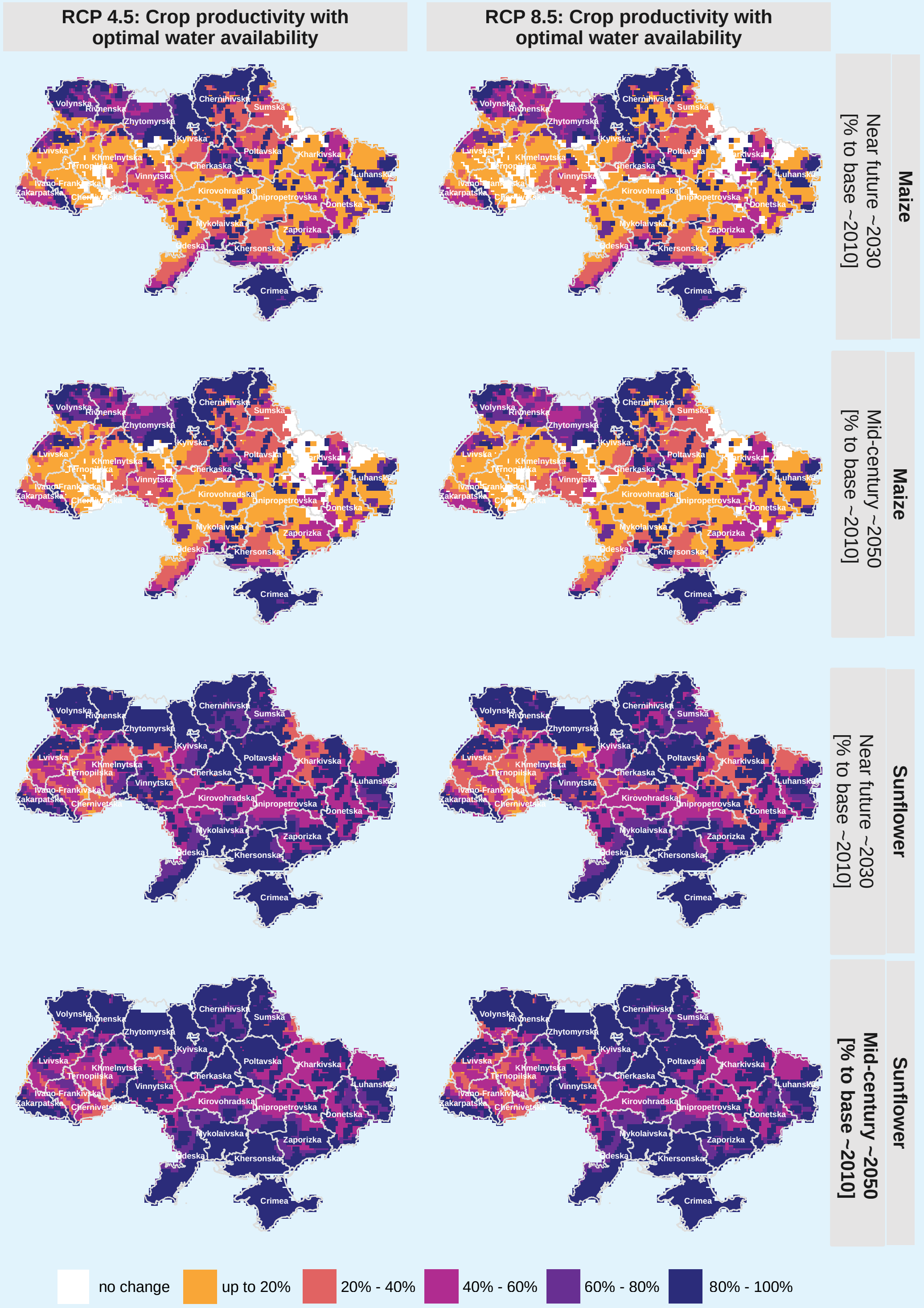

Figure 19: Difference Between RCP 4.5 and RCP 8.5 for 2030

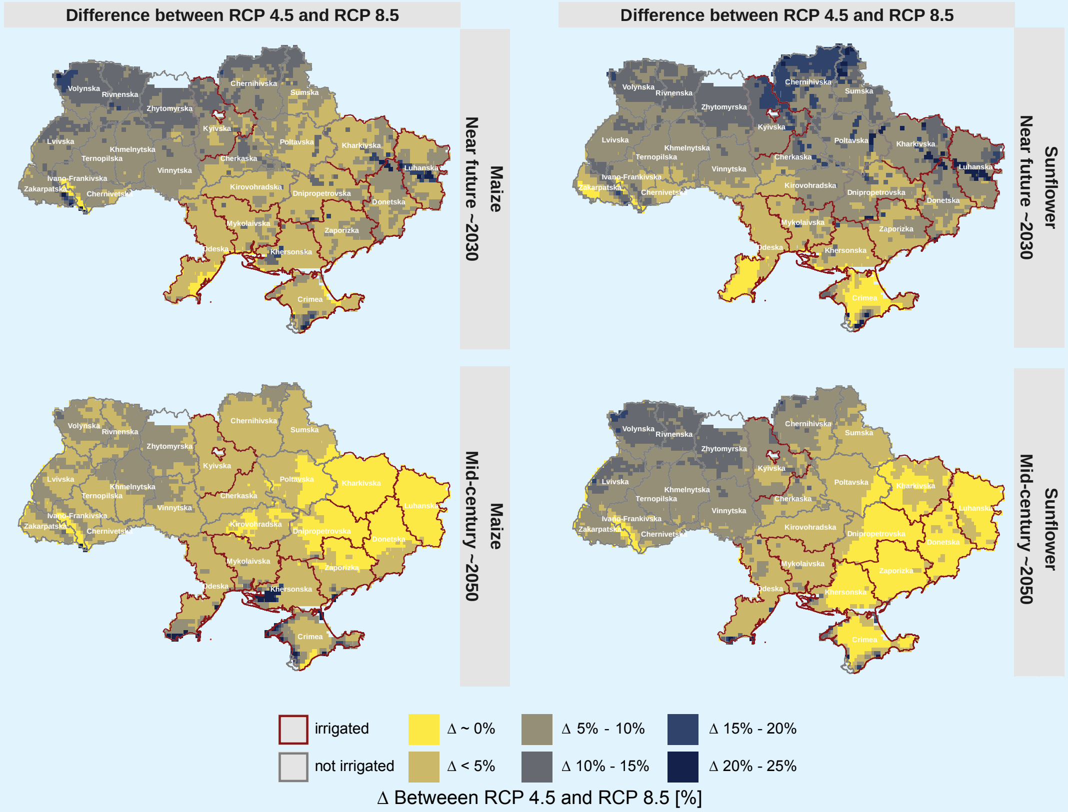

Table 3: Change in Total Production (Millions of Tons) for Major Crops as Compared to the Baseline (with Change in Land Area Allocation for Each Crop)[12]

	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%

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[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.

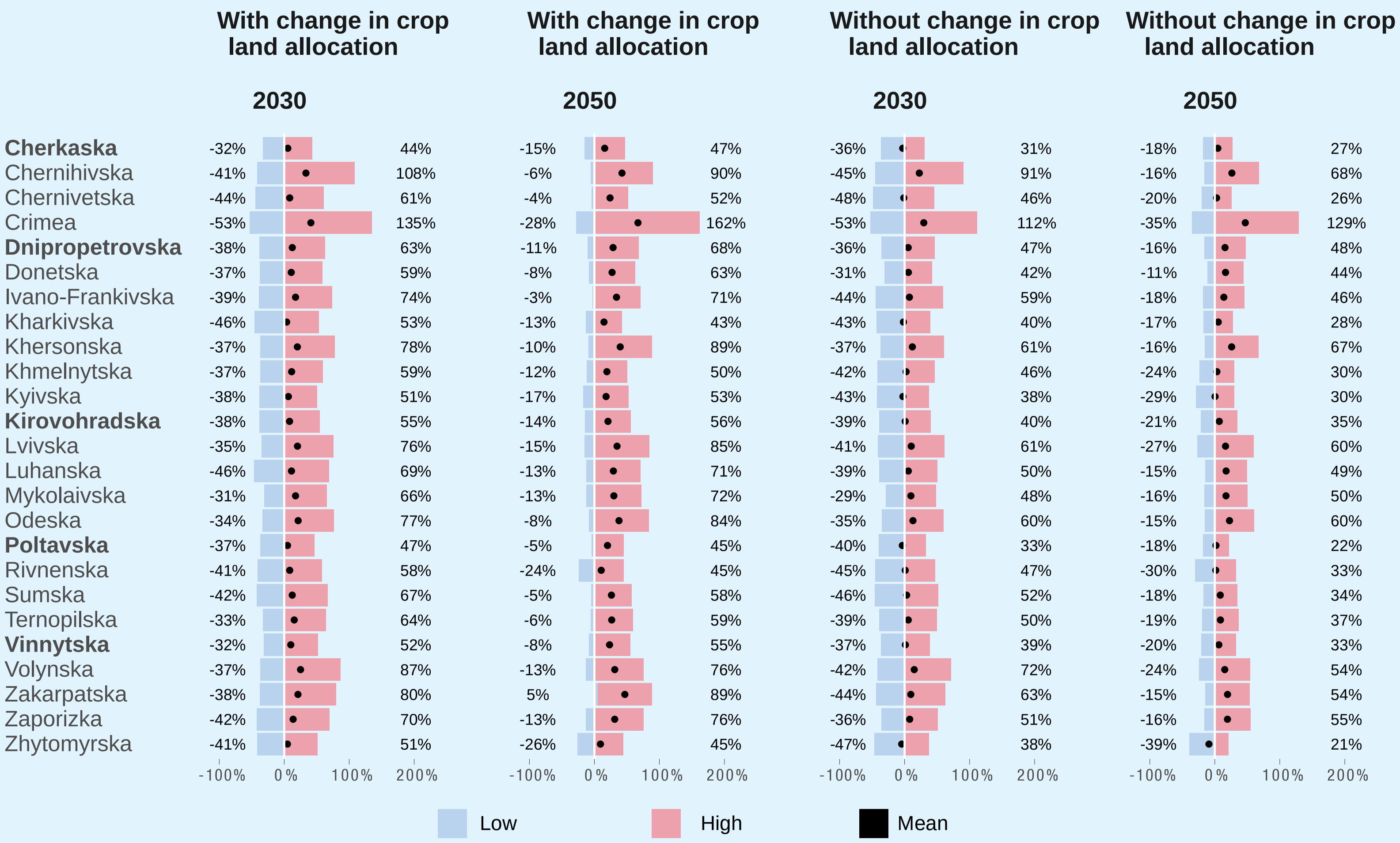
3.6 Effects of Changes in the Growing Season

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]



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[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

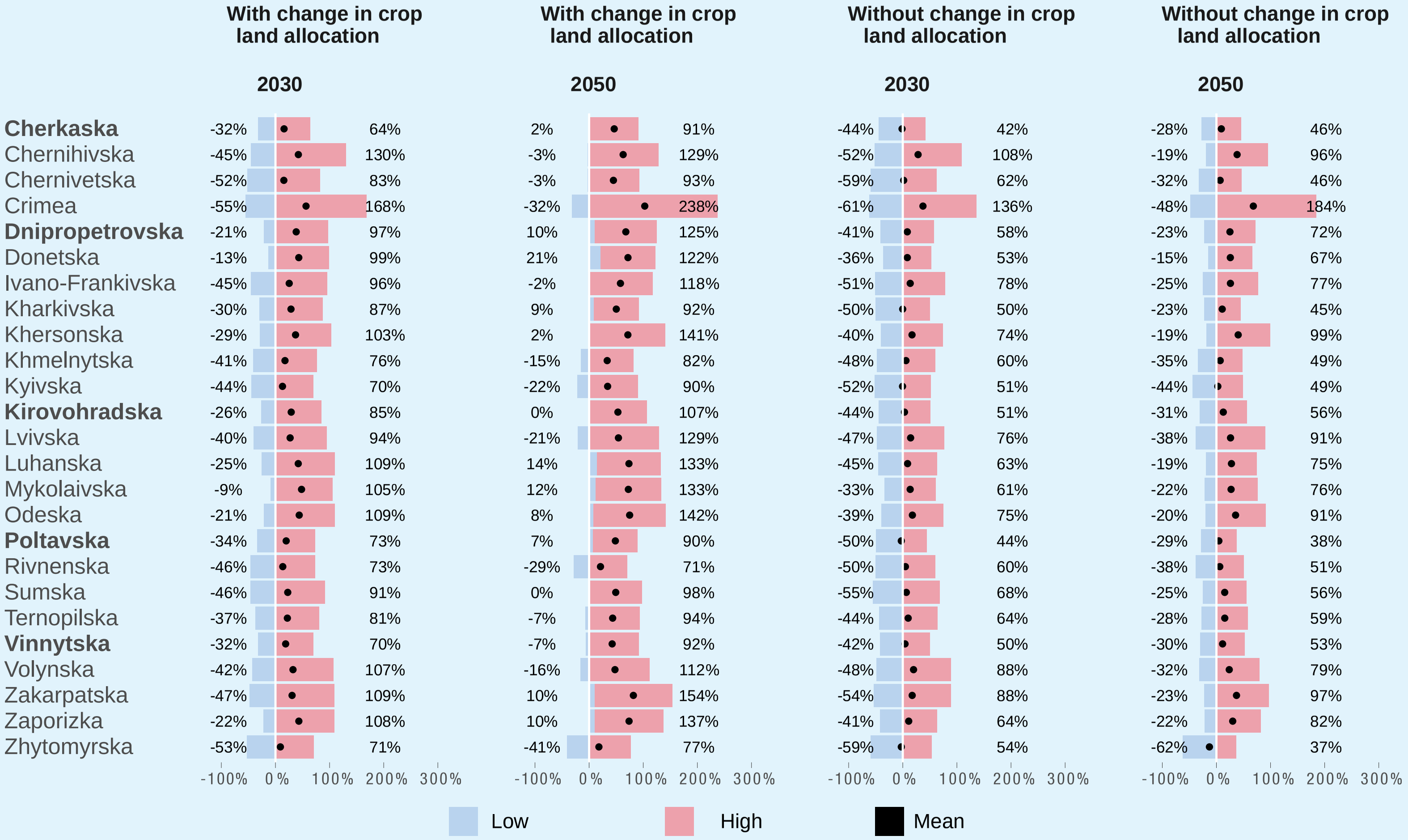

Table 4. Characteristics of Climatic Seasons in Ukraine in Two Past Periods (E-OBS data) and Three Future Periods Under the RCP4.5 Scenario (Ensemble of 34 RCMs from Euro-CORDEX Data)

	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.

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[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.

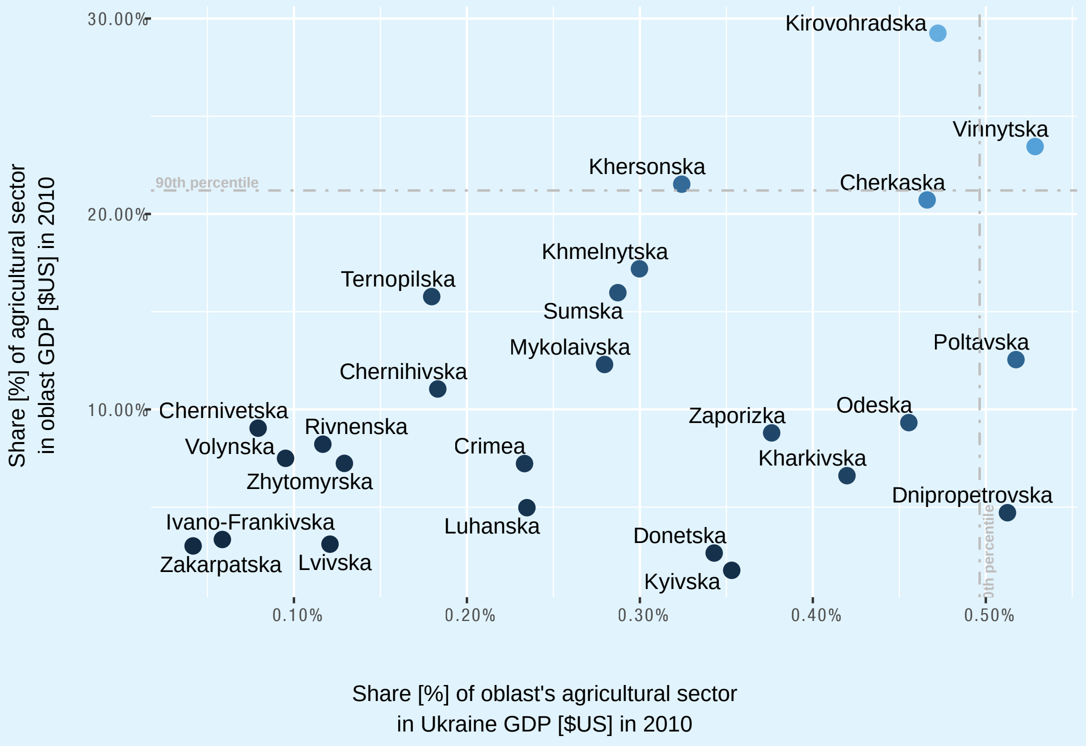
Both the increase in food prices and changes in farm outputs will impact poverty headcounts, however the impact is not significant under any of the projections (low, mean, and high). The poverty gap, however, does not increase in all cases: in seven oblasts, it decreases slightly while in the others, 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



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[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.

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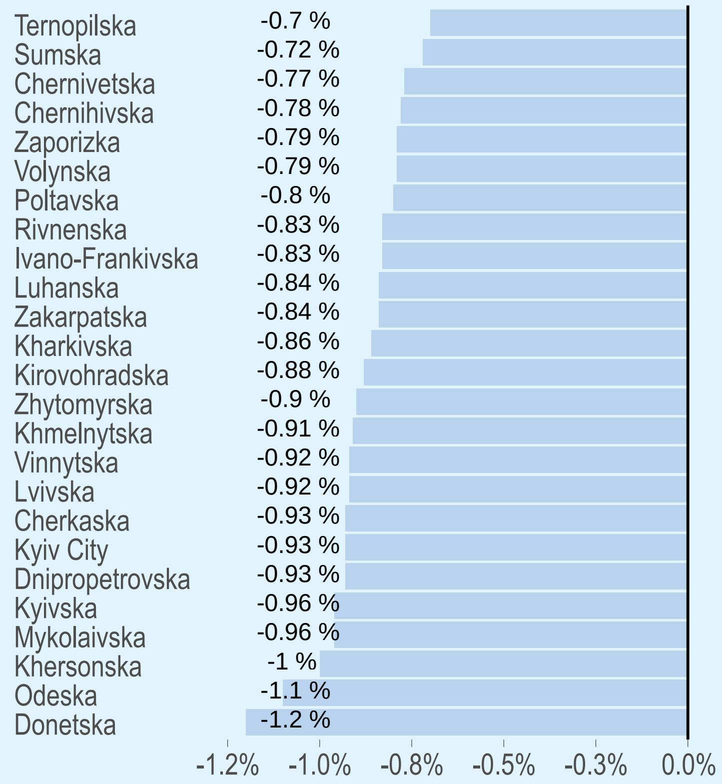
[16] The distributional effects required price projections, which were taken from IFPRI. These were only made for RCP8.5. Additional information is available in Chapter 2.

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)

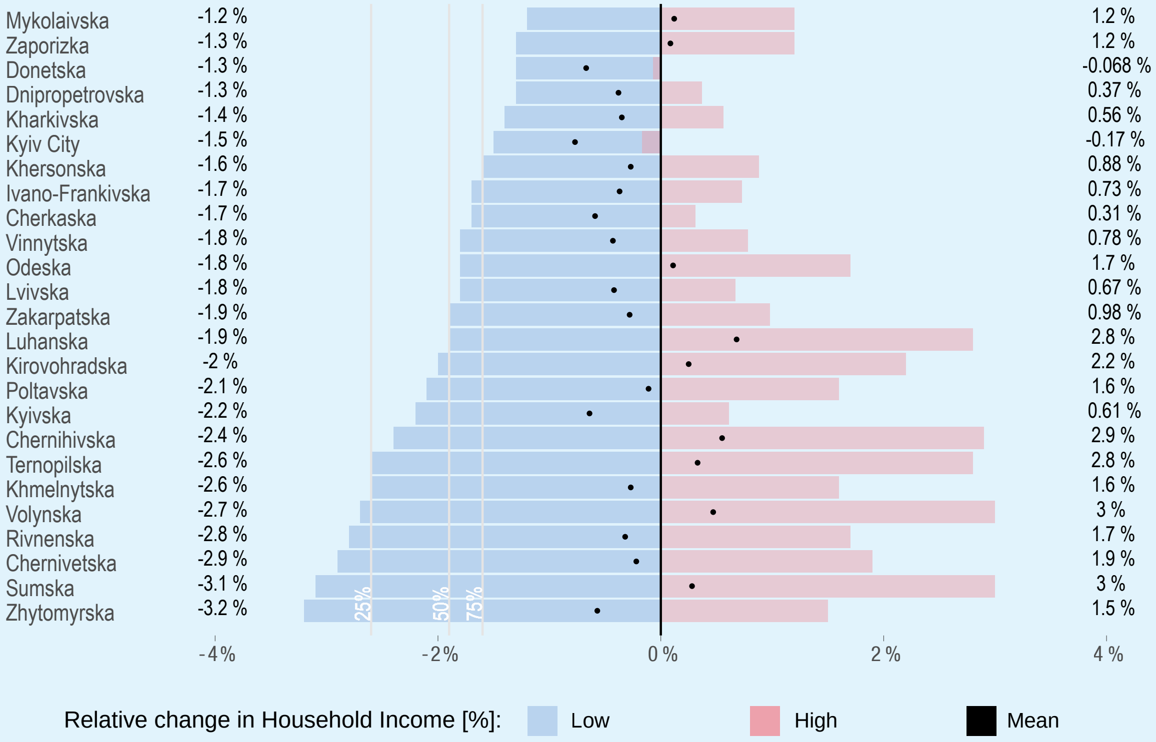
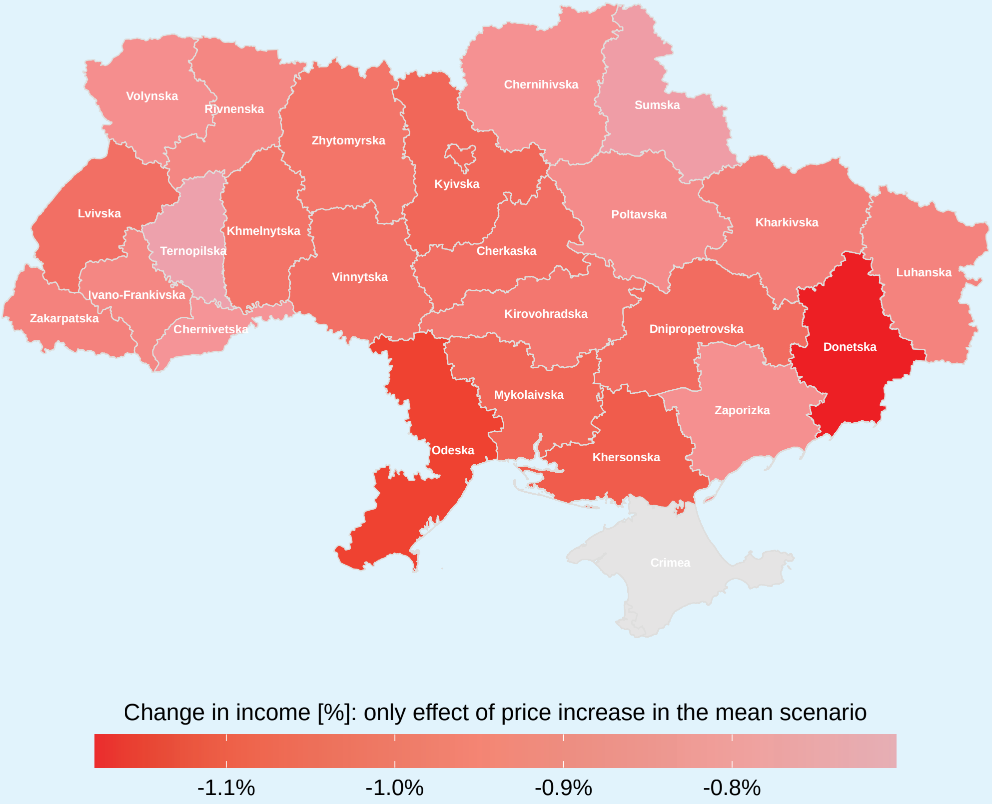


Figure 26: Changes in Expenditure by Oblast for 2030 (Effect of Price Increases only) in the Mean Scenario



4.4 Impact of Climate Change on Agriculture and Poverty

Both the increase in food prices and changes in farm outputs will impact poverty headcounts. 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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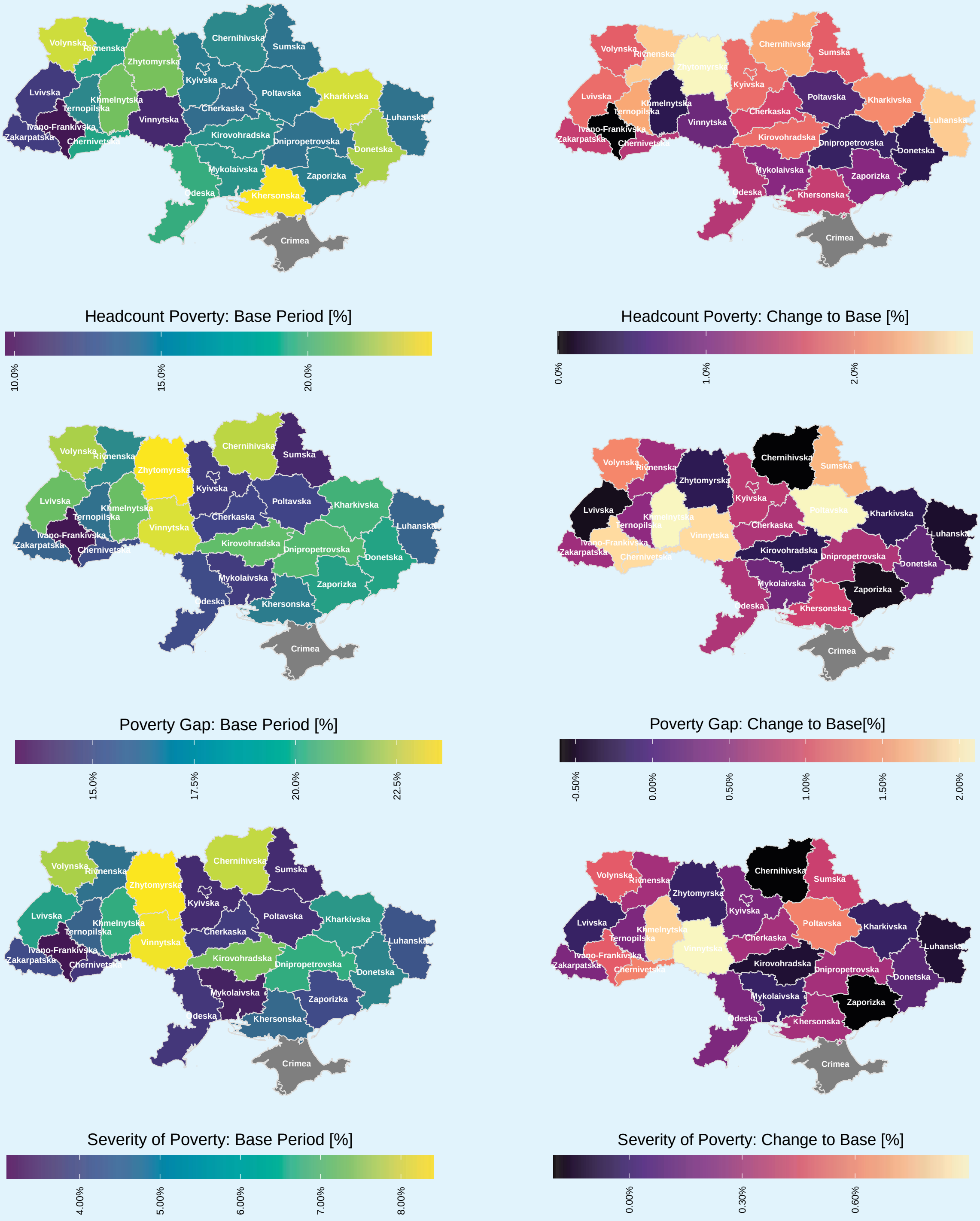
[17] The poverty gap is an estimate of the amount by which income must increase across all poor households to take them above the poverty line. It is the sum of the difference between the income level of each household below the poverty line and the poverty line, reported as a percent of the poverty 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).

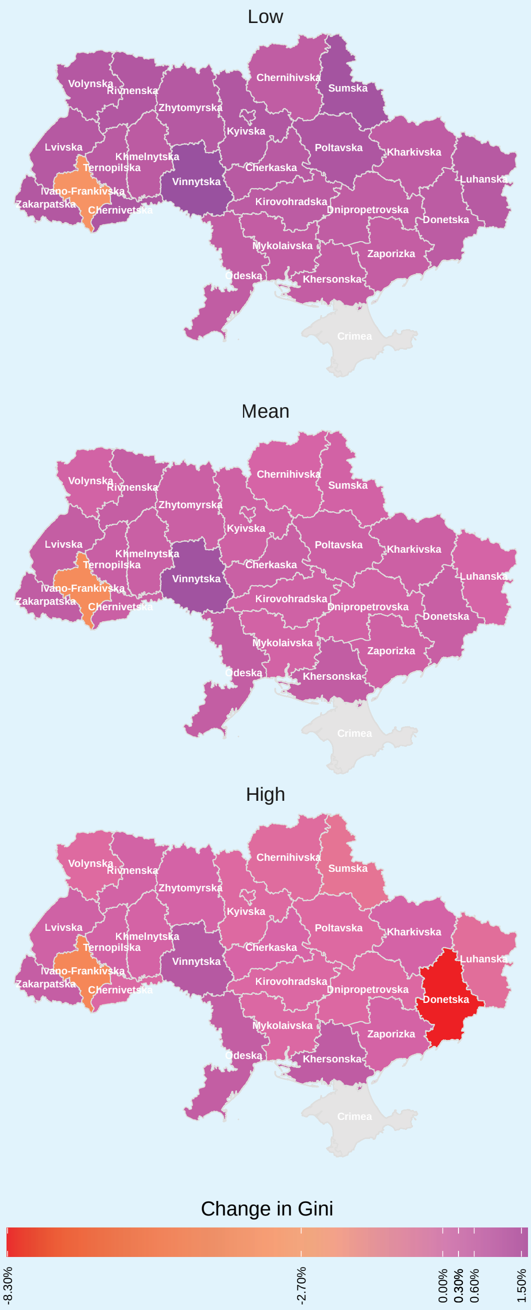
Figure 27: Headcount Poverty, Poverty Gap and Severity of Poverty: Values for the Baseline Period [%] and Changes in 2030 Relative to the Baseline [%], Low Projection



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 [%]



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[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.

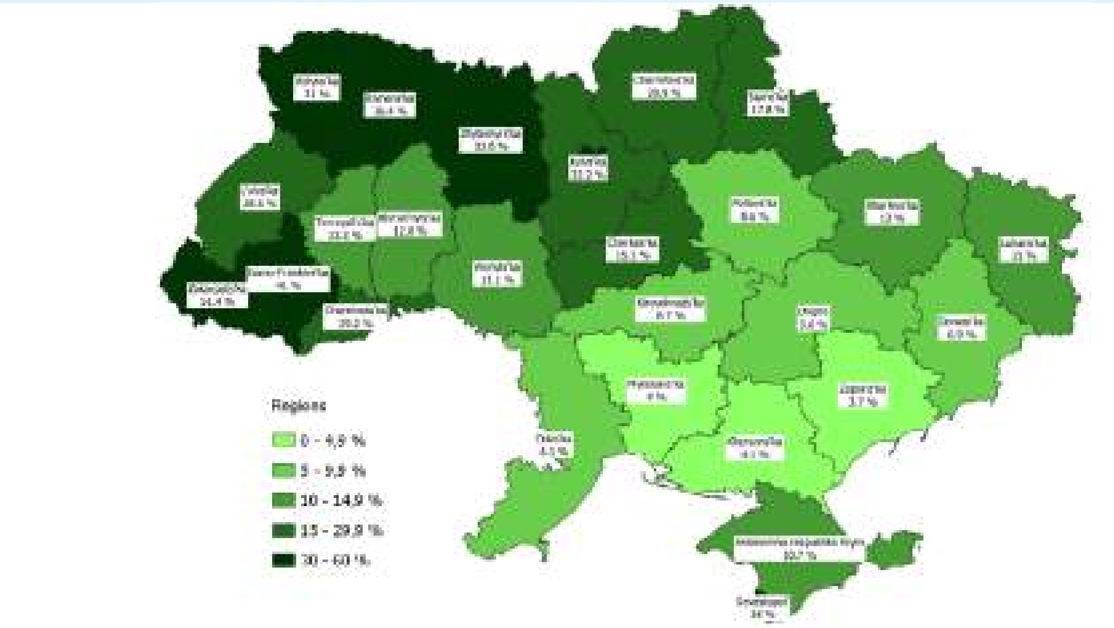
5.2 Climate Vulnerability Indices for Forests

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

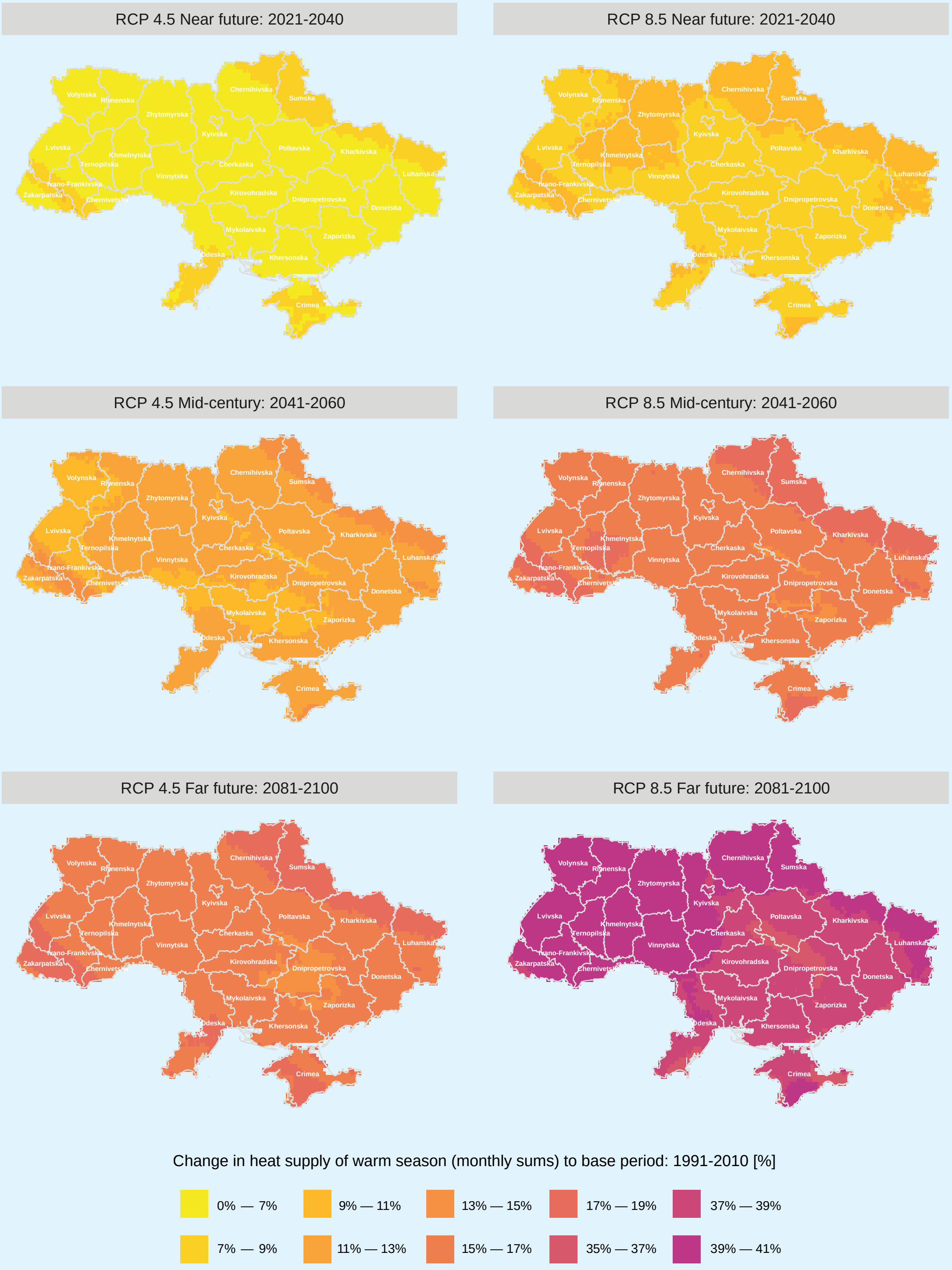
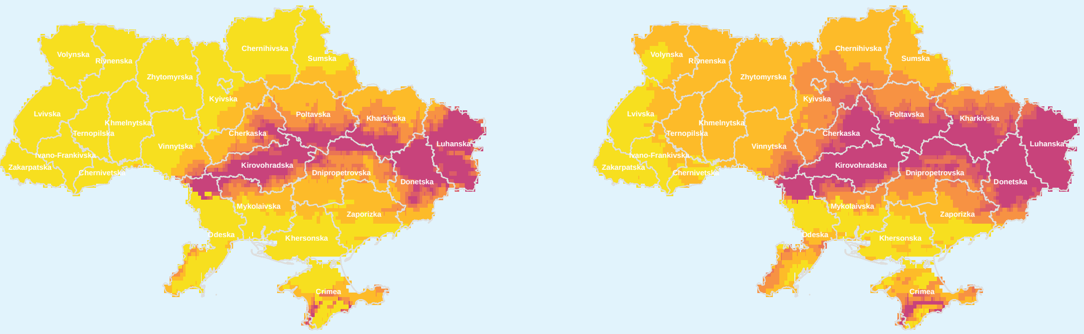


Figure 31: Relative Changes of Vorobjov's Moisture Availability Index to Climate, 1991-2010

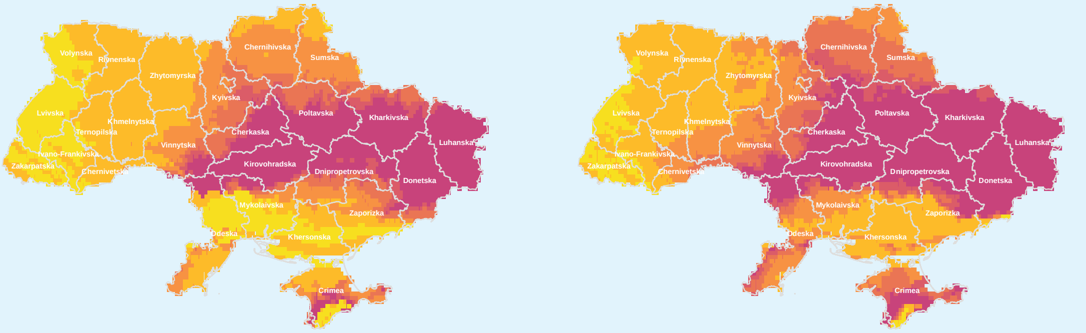
RCP 4.5 Near future: 2021-2040

RCP 8.5 Near future: 2021-2040



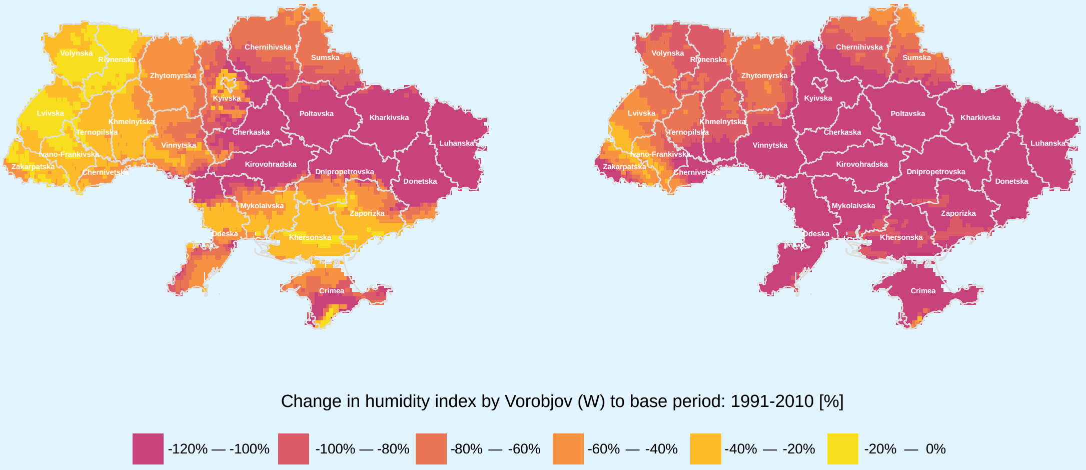
RCP 4.5 Mid-century: 2041-2060

RCP 8.5 Mid-century: 2041-2060



RCP 4.5 Far future: 2081-2100

RCP 8.5 Far future: 2081-2100



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).

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[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

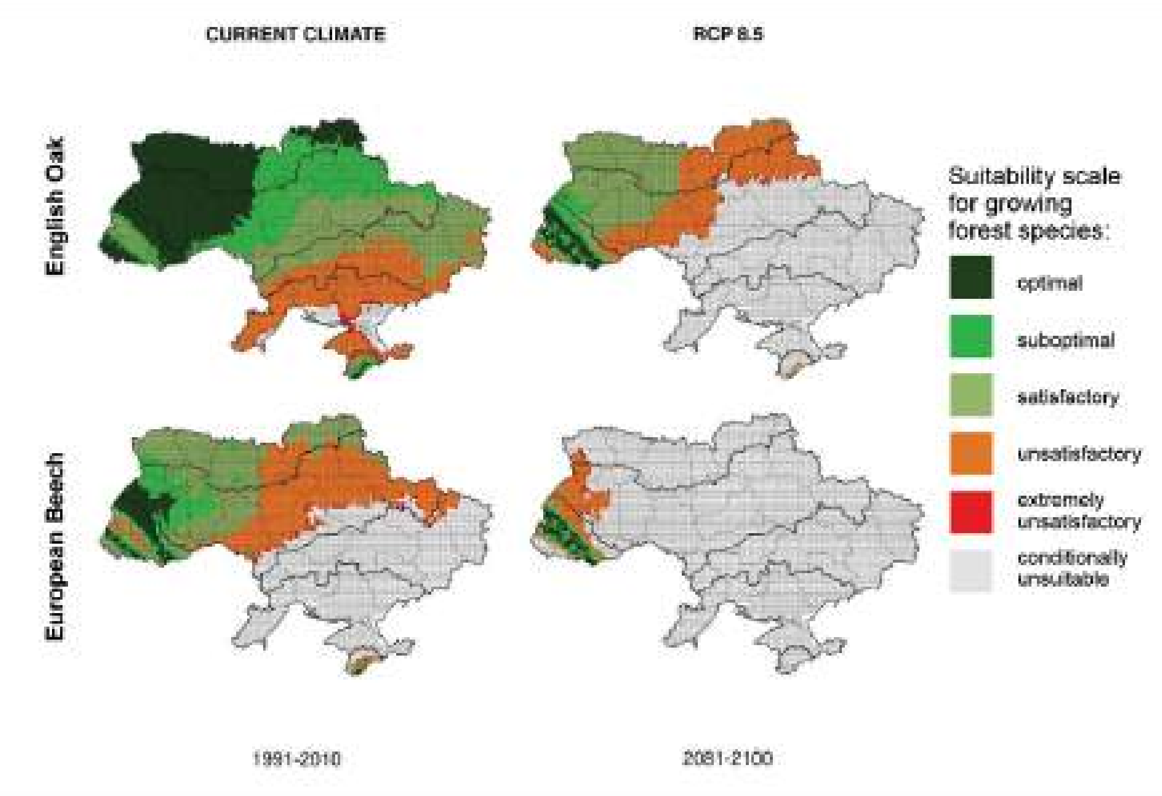
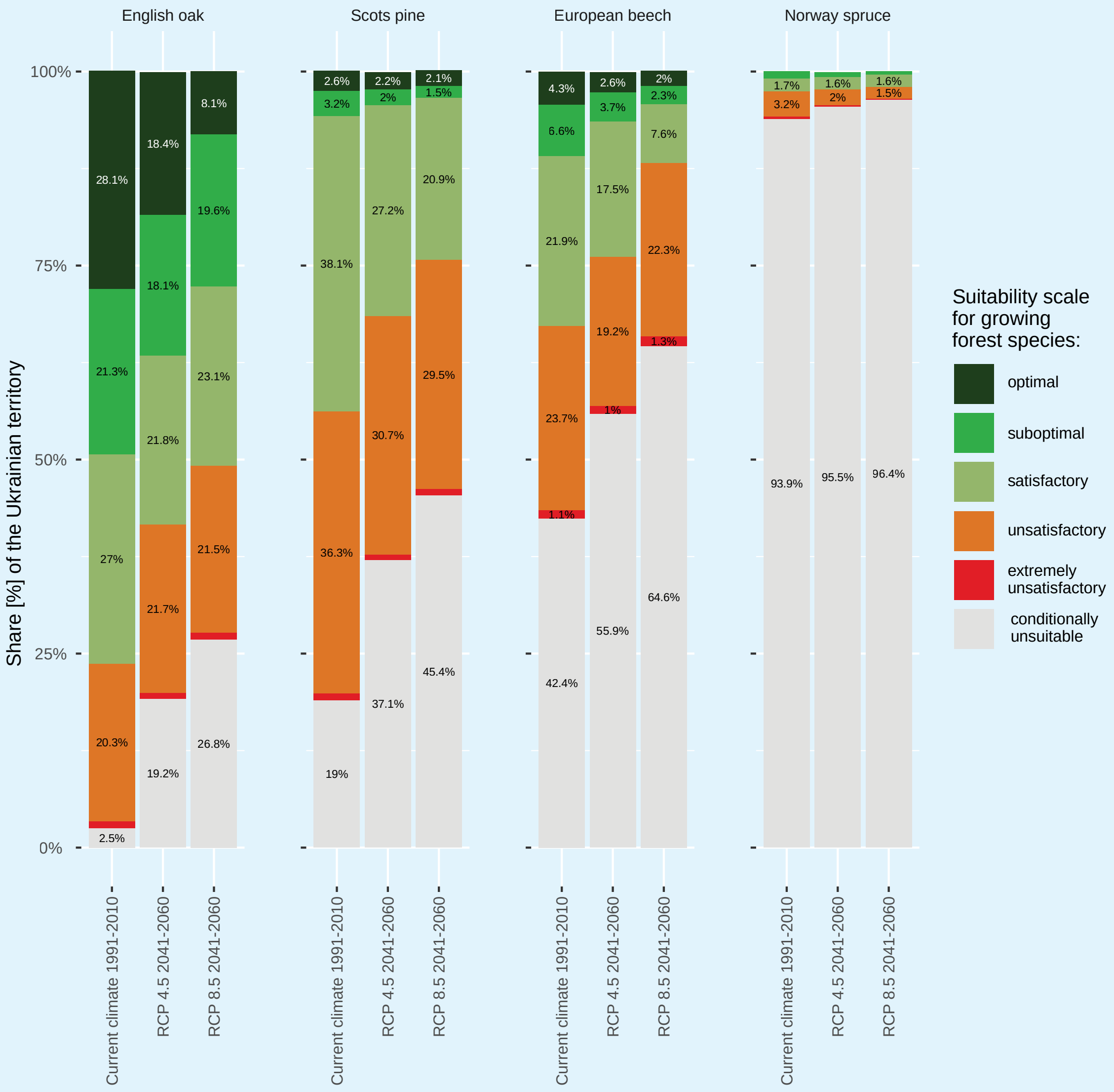


Figure 33: Impact of Climate Change on Areas with Growing Potential for Selected Forest Species, in 2050



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).

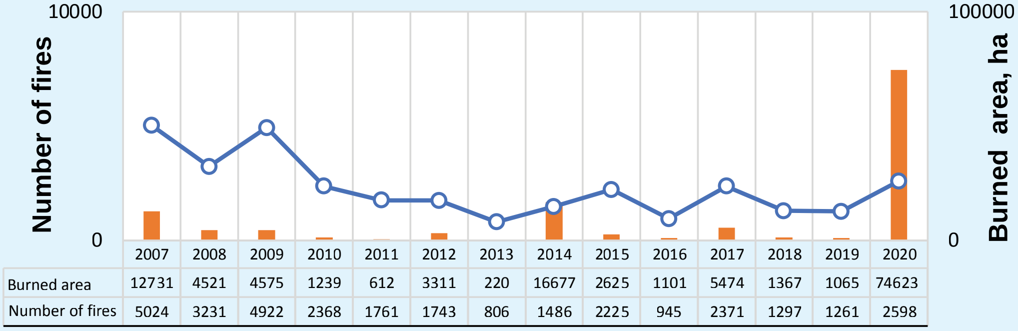
Impact on natural habitats and preservation of biodiversity. The loss of forest species (see Figure 32), which is itself a loss of biodiversity, promotes the ongoing losses (including extinctions) of dependent species and ecosystems. Biodiversity loss reduces the ecosystem's resilience to shocks and 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.

CHAPTER 6:
THE SPATIAL DISTRIBUTION OF AGRICULTURAL IMPACTS: OBLAST-LEVEL ANALYSIS

6.1. Spatial Distribution of Potential Benefits for Agriculture

The analysis of climate change from the preceding sections presents two important findings for the agriculture and land use sector in Ukraine:

(i) Ukraine could benefit from increased productivity of winter wheat, if cropping areas shift to the north-west (Figure 35).

(ii) other export crops (maize, sunflower and soybean) could benefit if measures are taken to maintain optimal water balance.

Figure 35: Relative Changes in Wheat Productivity, Through 2030

Key: Darker shades of green indicate a higher increase in wheat productivity in the oblast, relative to the baseline. Productivity is measured in millions of tons. Red borders show oblasts with the highest yield increases through 2030 in the high projection with most beneficial climate conditions for agriculture.

The northwest oblasts will experience warmer winters with more precipitation, creating conditions favorable for winter crops. Increase in wheat yield [tons/ha] (see Figure 18) and change in crop land allocation will allow for high wheat productivity [millions of tons] in these oblasts. Change in climate periods induced by new climate conditions (see Table 4 and 5) will have a positive effect on sowing and harvesting of winter wheat. These favorable conditions are distributed regionally, with the northwest oblasts Zhytomyrska, Chernihivska, Zakarpatska, Ivano-Frankivska, and Volynska benefiting most.

Measures to maintain optimal water balance under climate change could result in an increase in agricultural production. These potential benefits are estimated by comparing the WOFOST modelled values in 2030 under RCP8.5 of water-limited production and with the production under optimal water availability.[22] The WOFOST model delivers yield projections under optimum water availability for three selected crops: **maize, soybean,** and **sunflower**. The change in value is estimated by multiplying the change in total production by the change in real crop prices. The analysis then proceeds to determine the potential benefits if certain measures are taken to maintain optimal water balance in the agricultural sector to address the projected climate change.

Under the optimal water availability scenario, compared to the no changes to water management scenario for the three selected crops, benefits could reach US$112 million per year until 2030 in the mean projection. This amounts to about 0.8% of 2019 GDP in agriculture, forests and fishery. According to the latest data (WDI 2021), the sector's GDP comprises US$13.8 billion and contributes 9% to Ukraine's GDP. Over the 10-year period from 2026- 2035, the benefits from maintaining an optimal water availability measure calculated by the WOFOST model amount to as much as US$550.7 million, with a range of US$354- 780 million (Table 6 and Annex 5).

In other simulations of yield (both low and high projections), the economic impact of maintaining optimal water availability can amount to US$264-504 million or 2-4% of Ukraine's GDP for agriculture in 2019 (Annex 5). The extent of the benefits of these water balance measures depends on the type of crop. The highest benefit in relative terms (39.6%) is expected for soybean. Suitable measure for maintaining optimal water availability can lead to an increase of 26% to 40% in the values of agricultural output (Table 6). The largest absolute benefit (difference between the optimal water availability vs. the loss under water stress scenarios) is expected for maize, estimated at a US$92.7 million loss.

The benefits of maintaining optimal water availability also have strong regional differences. These differences are illustrated in Figure 36. In the figure, the oblasts are ordered by the change in value of agricultural output in each projection relative to the base year 2010 values. The changes in values of agricultural output under optimal water availability are presented in blue. Generally, the benefits are distributed unevenly among oblasts and crops. As indicated by the yellow and blue bars, for maize, Kyivska, Cherkaska and Poltavska oblasts would enjoy the largest benefits from maintaining optimal water availability. Figure 36 shows the change in value in US$ million. However, for sunflower, Khersonska, Mykolaivska and Odeska would benefit the most from implementing adaptation measures. Zakarpatska oblast also shows a significant benefit; however, the initial value of sunflower production is low. For soybean, Chernivetska, Ternopilska and Khemelnytska show the largest gain. Adaptation measures

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[22] Price changes for the RCP 4.5 scenario are not available, therefore the analysis focused on the RCP 8.5 scenario.

would likely have the most notable benefits in Khersonska oblast (see Figure 36). For some oblasts, these measures may not produce significant benefits, specifically: Rivnenska, Lvivska, Zakarpatska, Ivano-Frankivska and Volynska oblasts for soybean; Lvivska and Volynska for sunflower; and Chernihivska for maize.

Table 6: Effect of Measures to Maintain Optimal Water Balance on Change in the Value of Agricultural Output for Selected Crops (for the mean yield projection)

	Value of Agricultural Output	Change* in the Value of Agricultural Output		Adjusted Change† in the Value of Agricultural Output		Impacts of maintaining optimal water availability	
						(per year)	(10-year total) ‡
	US$ million	%	US$ million	%	US$ million	US$ million	US$ million
	2010	2030	2030	2030	2030	2030	2026-2035
Maize	1700.8	18.7%	317.8	13.2%	225.1	92.7	453.8
Soybean	34.6	26.5%	9.2	39.6%	13.7	4.6	22.3
Sunflower	809.1	3.8%	30.8	5.7%	46.1	15.2	74.6
Total	2544.5	10.9%	277.8	6.5%	165.3	112.5	550.7

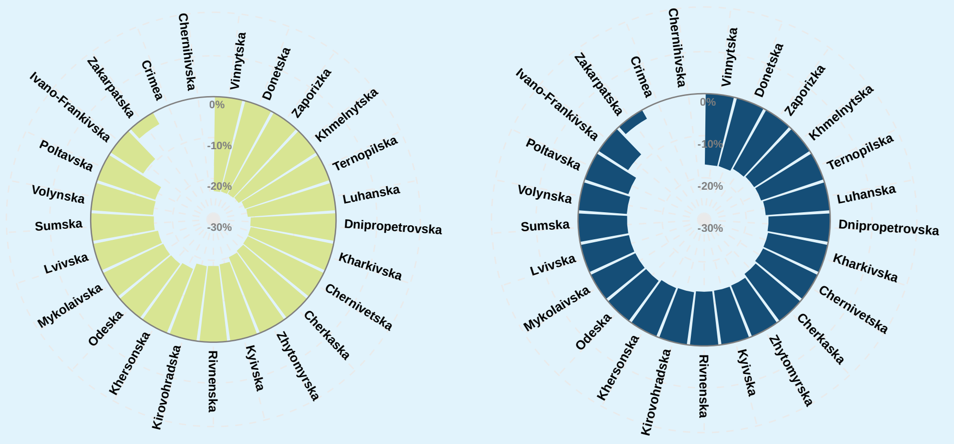
* Change [%] in the value of agricultural production as a percent of 2010 value of agricultural production. Value in Million US$ is given for real prices.

† The estimated adjusted change in the value of water scarce agricultural production as a percentage of the value in 2010 of agricultural production by oblast in 2030 with maintaining water availability measures in the agricultural sector.

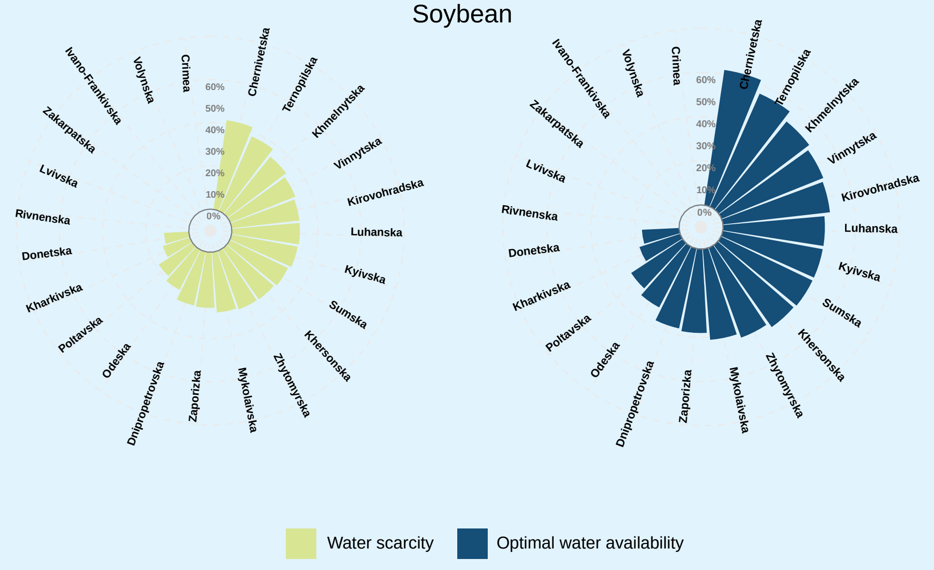
‡ The net present value (to base year 2019) of cost of inaction over the period of climate projections for the agricultural outputs 2026-2035, with 6% interest rate. An assessment with 3% and 10% interest rates is provided in Annex 5.

Figure 36: Change in Value of Agricultural Output in 2030 Relative to 2010 for the Mean Projection Scenario: Optimal Water Availability vs. Water Scarcity Projection Scenario[23]

Maize



Soybean



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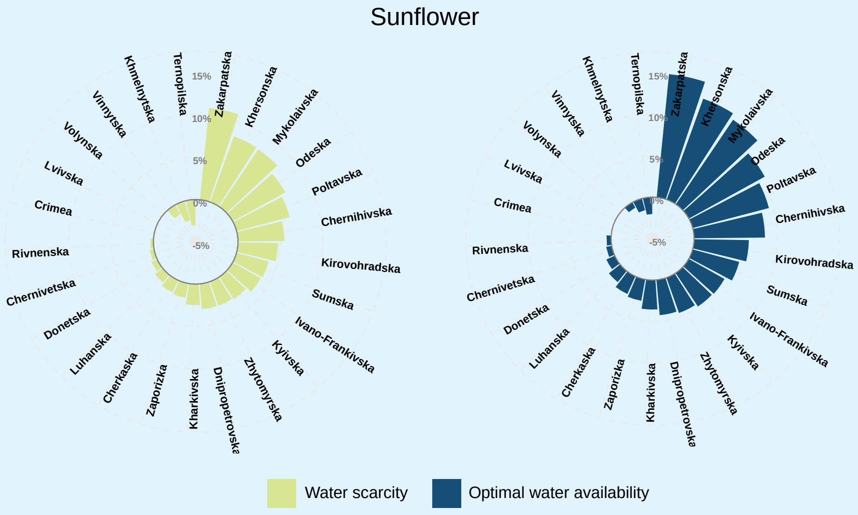
[23] For each projection, oblasts are ordered by the change (%) in value of agricultural output relative to the value of agricultural production in 2010. The circle defines a baseline - 0%. For maize, negative percentage changes signal losses in the value of agricultural output. Implementing adaptation measures can be expected to reduce the losses to the value of maize production as an effect of climate change. For sunflower, implementation of adaptation measures results in greater gains in the value of agricultural output – the case in all but three oblasts that show losses: Ternopilska, Khemelnytska and Vinnytska. For soybean, all oblasts experience a positive change in the value of agricultural production that increases if adaptation measures are introduced.



Source: Authors' estimates using IFPRI data and Ukrainian statistics on agricultural croplands in 2019.

6.2 Spatial Distribution of Potential Risks from Climate Change for Agriculture

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 (Table 7). As discussed in the preceding chapters, the south and the east of Ukraine are expected to experience these changes more than the north and west of the country. All oblasts are grouped and ranked by the magnitude of the impacts on these parameters. The detailed tables for this analysis are provided in Annex 5. This analysis is intended to provide information on climate "hotspots" where potential risks from climate change are the highest based on the impact on agriculture (yield and value of production) and the resultant impact on household income and inequality. This analysis does not account for other factors which could affect agricultural production such as availability of skilled labor, supply chains, or access to finance.

The assessment results until the mid-21st century[24] under RCP 8.5 were selected to identify the potentially most impacted oblasts. This RCP was chosen following recent international studies of climate impact, e.g., PESETA IV in the EU and IFPRI IMPACT (EU Science Hub 2021, IFPRI 2015), which consider RCP8.5 as a core scenario for climate risk analysis.

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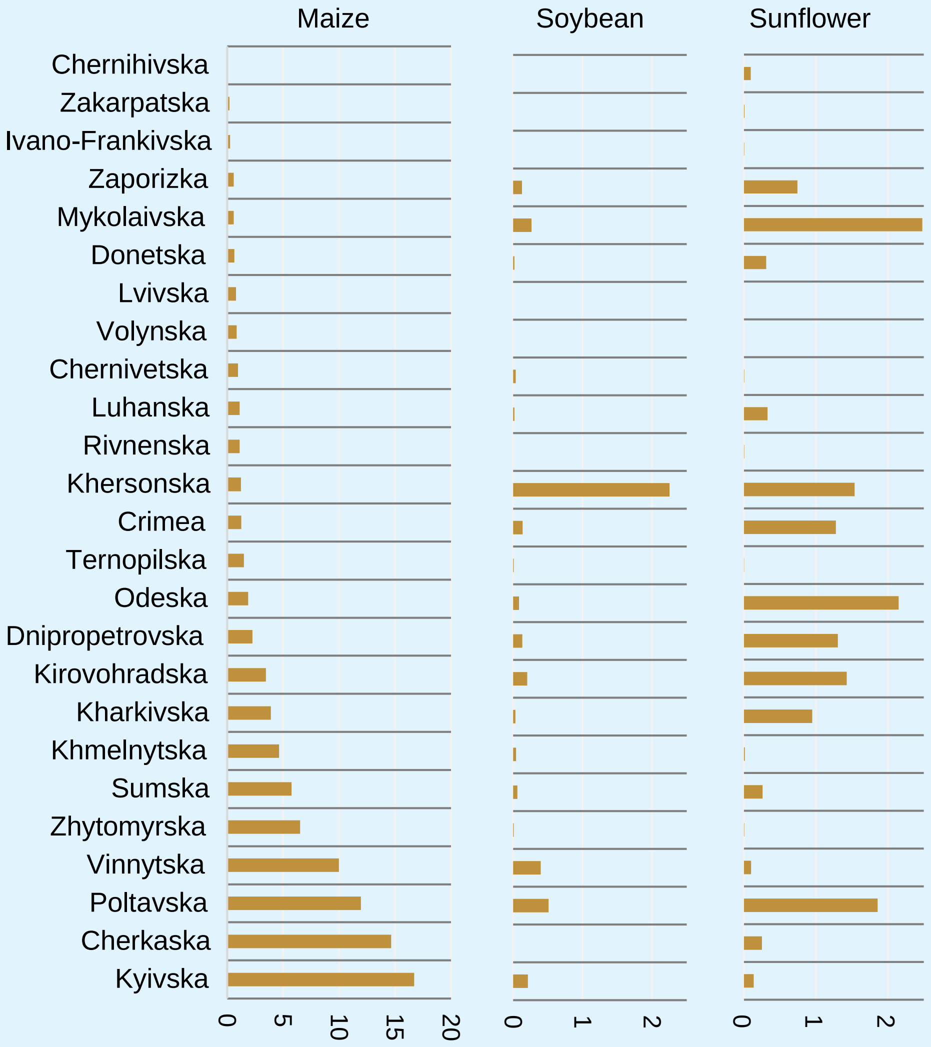
[24] There are many challenges to extending the agricultural impact assessment beyond 2050 and distributional analysis beyond 2030. The uncertainty becomes too high to permit sensible statistical estimations. This challenge is well recognized in the scientific literature and described by the IPCC (2007) as "…scientifically controversial to assign a precise probability distribution to a variable in the far distant future determined by social choices such as the global temperature in 2100…"

Figure 37: Difference in the Value of Agricultural Production Between Optimal Water Availability and Water Scarcity Projections in US$ million/year[1]



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[1] Changes in Figure 36 are given in relative values (%). Therefore, when estimating the effect of adaptation changes for each crop and oblast, it is helpful to consider absolute changes – differences in the value of agricultural production between optimal water availability and water scarcity projections in million US$ per year, e.g., although Chernivetska oblast shows a positive relative change of 42% in the value of agricultural output of sunflower relative to 2010, sunflower has a minor change in the absolute value of the agricultural output, especially in comparison with Mykolaivska and Odeska oblasts (Figure 37).

According to Jafino et al., (2021), a strong synergy between development policies and climate change adaptation, i.e., practical inseparability of development and adaptation strategy, may make benefits of adaptation less noticeable. The observable impact of adaptation reflects only residual impact of climate change after autonomous adaptation is implemented on a national, sectoral or sub-national level. Most of the initial climate damage that may accrue in a counterfactual “no adaptation” scenario is not present in development scenarios built to consider changing climatic conditions. The RCP8.5 emissions pathway, coupled with the low agricultural yield projections scenario, could be considered a stress test that reveals residual damage and highlights the vulnerability of different sectors and oblasts. This approach addresses the uncertainty of climate projections and climate impact assessments.

The effects of climate change on agriculture will have a greater impact on some oblasts than on others. Table 7 shows the top five oblasts across three selected ranking lists: (1) highest share of agriculture GDP at oblast and at national level; (2) biggest decrease in agriculture production; and (3) largest change in combined poverty indicators. Kirovohradska, Zhytomyrska and Lvivska appear in more than one of these three top-five groups, indicating higher overall vulnerability of their agricultural sectors to climate change impacts. Kirovohradska oblast has the highest agricultural GDP in Ukraine (see Annex 5) and the value of its agricultural production will also be considerably impacted by changing climatic conditions. Lvivska and Zhytomyrska will be most exposed to the adverse impacts of climate change, with potential losses of agricultural production value amounting to 34% and 48%, respectively, in the near future period. The substantial losses in agricultural value will have implications for individual household incomes and poverty. Kirovohradska oblast is ranked highest in Group 1 and appears again in Group 3, indicating high impacts on household income. In Group 2, Zhytomyrska and Lvivska will experience the largest reductions in their agricultural production and value due to the changes in local climatic conditions. They are also ranked the highest in Group 3, which indicates significant potential impacts on household incomes.

The top five oblasts with the highest share of agricultural GDP are Khersonska, Kirovohradska, Poltavska, Vinnytska and Cherkaska (Figure 38; see Annex 3 for complete data). In the near future (2021-2040), these oblasts are likely to experience significant losses in household incomes and negative changes in poverty and inequality indicators due to the projected changes in the value of agricultural production. Although the relative reductions in the values of agricultural production in these oblasts are not among the highest in Ukraine, the climate change impacts on the respective oblasts’ GDPs in absolute values will be the strongest due to the high shares of the agricultural sector in their local economies.

The top five oblasts that will experience the largest decreases in agricultural production values attributed to climate change until the mid-21st century are Zhytomyrska, Kyivska, Chernivetska, Rivnenska and Lvivska (Figure 39).[25] The agricultural production values under consideration are from the low projection, which reflects the lowest production potential of the selected crops. These values describe the worst-case scenario, in which the potential reduction in the agricultural production values will be the greatest for the selected oblasts. The decline in the value of agricultural production can be up to 48%, in the case of Zhytomyrska oblast.

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[25] All oblasts are ranked by the reductions in the value of agriculture production in both the near future and mid-century. Annex 7 provides the details on the integrated index for ranking all oblasts by the magnitude of the impact in in both near future and the mid- century.

Table 7: Oblasts Most Affected by the Impacts of Climate Change on Agriculture, by Category

Oblasts ranked by highest share of agriculture GDP at oblast and at national level* Group 1	Oblasts ranked by biggest decrease in agriculture production† Group 2	Oblasts ranked by biggest change in combined poverty indicators‡ Group 3
Khersonska	Zhytomyrska	Lvivska
Kirovohradska	Kyivska	Zhytomyrska
Poltavska	Chernivetska	Kharkivska
Vinnytska	Rivnenska	Luhanska
Cherkasska	Lvivska	Kirovohradska

* Based on the data represented in Annex 3 that describes the share of agricultural sector in the national and local GDP.

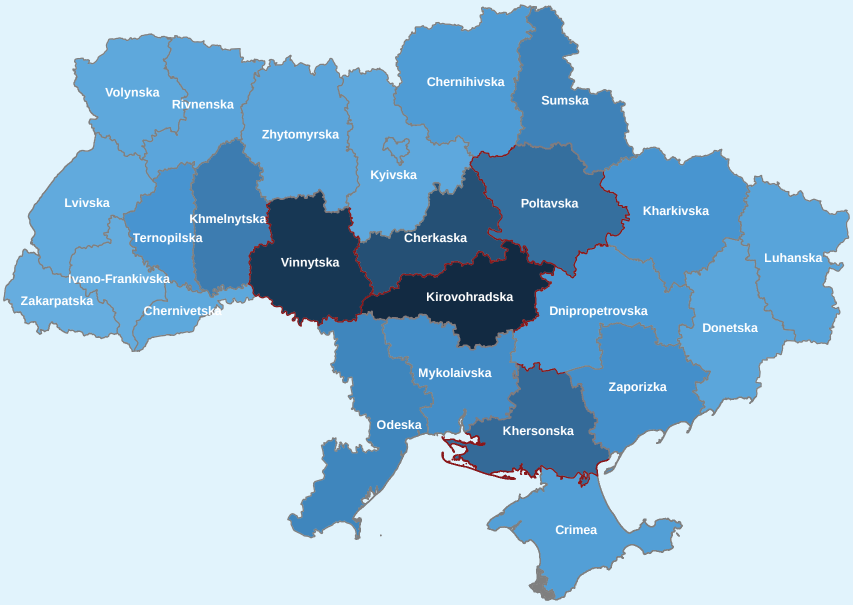
† Based on the findings of the analysis of changes in agricultural production due to climate change. These oblasts show consistent reductions in the value of the agricultural production in 2030 and 2050 under RCP 8.5, assuming no endogenous adaptation measures.

‡ Based on the results of the distributional analysis. These oblasts will undergo the biggest changes in poverty indicators, including poverty headcount, poverty gap, and severity of poverty.

In the near-future period, Zhytomyrska, Kyivska, and Lvivska oblasts will undergo significant changes in climatic conditions, with Kyivska oblast facing a new and drier climate type. Although the agricultural sector in these oblasts accounts for relatively minor shares in either the local or national GDP, the projected changes in agricultural production values will have significant implications for inequality measures. The anticipated loss in household incomes and rise in poverty headcount in Zhytomyrska and Kyivska will be substantial. 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.

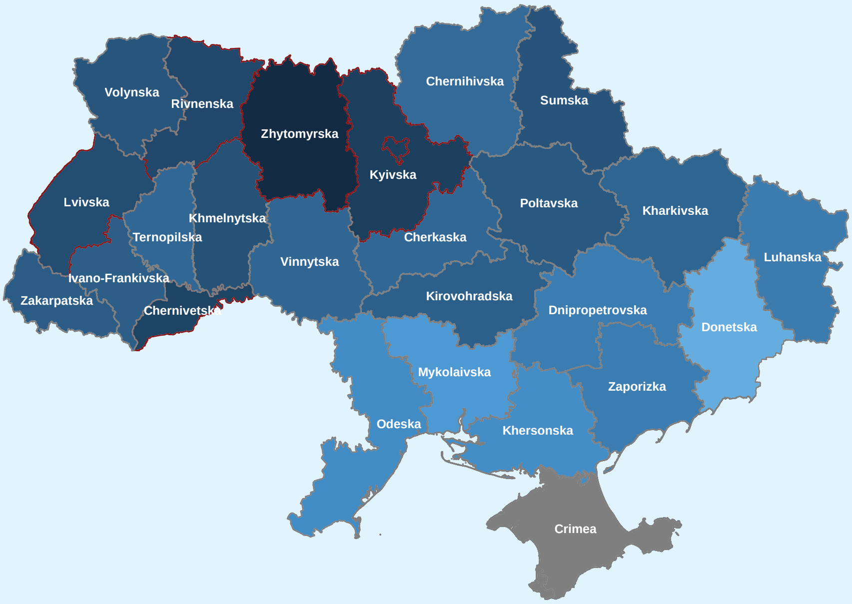
The top five oblasts with the most significant loss in household incomes and the highest increase in poverty and inequality are Lvivska, Zhytomyrska, Kharkivska, Luhanska, and Kirovohradska (Figure 40). Agriculture accounts for less than 5% of GDP in these oblasts and the oblasts are ranked highest in term of potential household income loss due to rising food prices caused by adverse climate change impacts on agricultural production. The ranking reflects the combined impacts of climate change and induced changes in the agricultural sector on the key poverty indicators, including poverty headcount, poverty gap, and severity of poverty. Annex 3 presents the detailed ranking of all oblasts in Ukraine based on these indicators. In the near future, all oblasts in this group will be exposed to warmer and drier climates. These changes in climatic conditions will be most pronounced in southern Ukraine.

Figure 38: Share of Agriculture in National and Local GDP, by Oblast



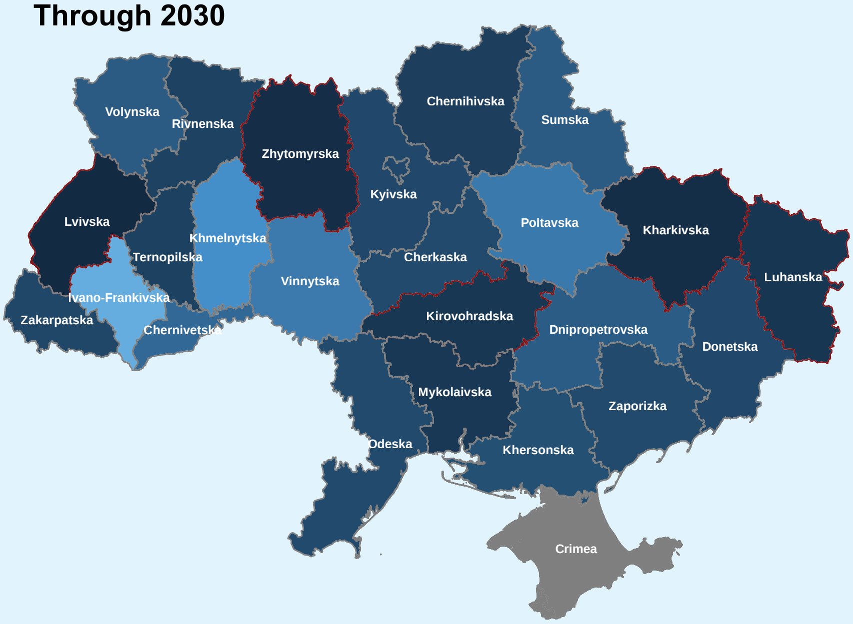
Key: Darker shades of blue denote a higher share of agricultural sector in GDP of Ukraine and oblast. Red borders show the oblasts analyzed in detail in the integrated criteria assessment tables.

Figure 39: Reduction in Agriculture Production Values, by Oblast, Through 2030



Key: Darker shades of blue denote a higher negative impact on agricultural production and its value in the oblast. Red borders show the oblasts analyzed in detail in the integrated criteria assessment tables.

Figure 40: Combined Changes in Household Income, Poverty, and Inequality, Through 2030



Key: Darker shades of blue denote a higher impact on poverty headcount, poverty gap, and severity of poverty in the oblast. Red borders show the oblasts analyzed in detail in the integrated criteria assessment tables.

CHAPTER 7:

ACTIONS TO BUILD CLIMATE RESILIENCE IN AGRICULTURE AND FORESTRY

This report details many of the projected changes in climate Ukraine will experience over the course of the 21st century. It provides a detailed assessment of the potential impacts these changes could have on the country, with a focus on agriculture, a key driver of the economy and jobs. Empowered with highly granular data on a range of climate indicators across 7,400 geographic points generated for this study using the latest available global and regional climate models, and analysis for three time periods and three climate scenarios, Ukraine can adapt to meet the projected risks of temperature increase, shifts in seasons, and changes in precipitation patterns. With proactive planning, the country may even be able to benefit from the long-term impacts of climate change on agriculture and forestry. Recommended adaptation actions for Ukraine, based on the country context and international good practice are outlined below.

Recommendations are grouped into three sections:

1. **Strengthen institutions, policy, and planning:**
    - Establish a national level institutional mechanism for climate policy
    - Establish a mechanism to integrate climate change action within the Ministry of Agriculture Policy and Food
    - Include climate risk assessment in oblast development planning
2. **Increase scientific capacity and research:**
    - Enhance capacity of national scientific institutions on climate change
3. **Promote transition to climate-smart agriculture and forestry:**
    - Promote climate-smart agriculture
    - Promote farmer information systems and precision agriculture technologies
    - Improve targeting of subsidy programs and develop insurance products for climate risks
    - Include agroforestry and forest management in adaptation planning

7.1 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 in order to prepare critical sectors such as energy, infrastructure, health, and agriculture for climate impacts.

Establish a mechanism to incorporate climate change action within the Ministry of Agriculture 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-level development planning. It will be important to carry out more comprehensive impact assessment reviews at the oblast level to identify specific climate risk considerations for development planning, tailoring action to the sectors that face highest risk in the oblast. While this study is not an in-depth assessment of vulnerability, the analysis has identified oblasts with varying levels of vulnerability, based on the share of agriculture in their respective GDPs and resulting household income inequalities:

- **Khersonska, Kirovohradska, Poltavska, Vinnytska, and Cherkasska:** could face greater negative impacts. Adopting climate-smart agricultural practices for maintaining optimal water balance should be among the focus areas for development planning.
- **Zhytomyrska, Kyivska, Chernivetska, Rivnenska, and Lvivska:** economic impacts could be less profound due to a lower share of agriculture in their respective GDP*.* However, climate change could still cause significant changes to agricultural production, entailing the need for diversification of their production structure.
- **Kirovohradska, Zhytomyrska, and Lvivska:** would need to focus on developing overall adaptation capacity based on their vulnerability to climate change.

More comprehensive impact assessment reviews should be carried out at the oblast level to identify specific climate risk considerations.

7.2 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 are 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. Continuous

Box 5: National Climate Policy and Coordination: A Variety of Approaches

Indonesia. The State Ministry for National Development Planning/National Development Planning Agency (BAPPENAS) is responsible for implementation and monitoring and evaluation of the National Action Plan for Climate Change Adaptation (RAN-API), including dissemination to provincial governments. The BAPPENAS formed a core group with the Ministry of Environment, the Agency for Meteorology, Climatology and Geophysics and the National Council on Climate Change when initiating the RAN-API. It organized meetings with central ministries, provincial governments, universities, and non-governmental organizations (NGOs) (UNFCCC 2014).

Japan. The National Plan for Adaptation to the Impacts of Climate Change was formulated to systematically address the impacts of climate change. The National Institute for Environmental Studies (NIES) and its Center for Climate Change Adaptation are responsible for analyzing and providing information about climate change impacts and adaptation. The NIES also provides technical advice to local governments and Local Climate Change Adaptation Centers to help formulate their climate adaptation plans and support the implementation of adaptation measures by central and local governments and other stakeholders (CCCA 2021).

The Netherlands. The National Climate Adaptation Strategy (NAS 2016) and the Delta Program (DP 2010) are at the center of the Dutch Climate adaptation policies. These documents were prepared through an inclusive participatory process. The implementation of the NAS is governed by a board of directors from all relevant ministries of the Dutch Government, and the Ministry of Infrastructure and the Environment has the coordinator role. Sub-national Provinces and Cities develop and implement their own programs, based on NAS. The DP is jointly planned and implemented by the municipalities, district water boards, provinces, and the central government. Climate change impacts and resilience are integrated into environmental assessment procedures, disaster risks management, and some sectoral planning. (Climate-ADAPT 2021).

Mexico. The National Climate Change Strategy (2007) proposes concrete adaptation and mitigation measures for all sectors. Climate change strategies and action plans have also been developed at the subnational level for some cities and states. The Inter-Ministerial Commission on Climate Change is responsible for formulating and coordinating the implementation of national climate change strategies and incorporating them in sectoral programs; promoting national climate change research; and promoting GHG emission reduction projects. The Commission receives advice from the Consultative Council on Climate Change, composed of scientists and representatives of civil society and the private sector. The CCF has a technical committee chaired by the Ministry of the Environment and Natural Resources, with representatives from many agencies (GoM 2020; UNDP 2021).

analysis and updating of this data will be needed for sub-national adaptation planning, for which significant hardware and software capacity will be required within these institutions. It will also help Ukraine participate in and take advantage of the EURO-CORDEX experiment and develop highly disaggregated climate projections that could be used to estimate climate risks in different sectors of the national economy and on a sub-national level.

7.3 Promote Transition to Climate-Smart Agriculture and Forestry

As a long-term adaptation strategy, Ukraine can increase its agriculture resilience through an integrated approach of natural resource management and sustainable soil management. Ukraine is committed to improving measures to rebuild irrigation infrastructure as one of the main technologies to counter climate change and improve agricultural production efficiency. However, irrigation alone is not sufficient to support resilient agricultural production. Additional measures and technologies to help Ukraine adapt to climate change are proposed below.

Promote climate-smart agriculture (CSA) including agroforestry (planting combinations of trees and crops), drought-resistant varieties of key crops, cover crops, etc., and increase landscape diversity and connectivity to increase the ability of ecosystems to adapt to changing climate conditions and stresses. Maintaining or restoring riparian areas, wetlands, peatlands and floodplains helps maintain water balance and reduce soil erosion. Give incentives to farmers through agrotourism and ecotourism programs to manage non-arable lands for maintaining biodiversity and natural habitats. These approaches have been shown to benefit agriculture from environmental and climate stresses.

Promote farmer information systems and precision agriculture technologies. Provide farmers with reliable and accessible information about, and systems to support, climate-smart agriculture, including crop land allocation, to enhance their capacity for adaptation. Based on the information in this study, changes in crop land allocation, and shifting vegetation periods and growing seasons for major crops should allow farmers to increase resilience to changing climate (See Annex 1.2). Farmers need information so they can make these adaptations. 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 (VRT), remote sensing and drones), would help in moving Ukraine towards more climate-friendly technologies by reducing waste of water and other inputs. Ukraine can leverage its significant capacity and large pool of talent in information technologies to develop and maintain such systems.

Improve targeting of subsidy programs and develop insurance products for climate risks. The Government already provides financial support for the development of agriculture in Ukraine through direct subsidies, low/free-interest loans, and other instruments. However, financial assistance remains difficult to access for most agricultural producers, especially small farmers. A targeted program with banks and agriculture departments could ensure that loans and subsidies are linked to adoption of climate-smart technologies and approaches. This will offset the initial risk for the farmers and the lending institutions.

Residual risk insurance could increase farmers' resilience to climate change via the coverage of residual risks not addressed by adaptation actions. This type of insurance could be considered in oblasts where adverse weather events such as droughts and long-lasting heatwaves are expected, and there is limited capacity to adapt.

Box 6: Examples of Climate-Smart Agriculture

The following groups of adaptation measures have been documented to strengthen the resilience of agricultural systems in many locations around the world.

Soil Management: Interventions should aim at enhancing soil fertility and water availability, reducing runoff and erosion. Well-documented interventions with such benefits include contour ploughing or contour tillage on sloping land, contour bunding, conservation tillage, surface mulching, and revegetation and reforestation of areas around farmland (i.e., shelter belts), among others.

Water Management:

- Bio mulching (covering fields with biodegradable mulch films and other biomaterials)
- Conservation farming practices (a combination of direct seeding and covering crops with different tillage systems: no-till, mini-till, strip-till, etc.)
- Precision agricultural practices that minimize water and material inputs
- Planting drought-tolerant species and varieties with long growing periods

Forestry and Agroforestry: Incorporating trees in farming systems has been shown to improve soil quality, which leads to higher and more stable crop yields. Agroforestry practices also increase the moisture absorptive capacity of soil and reduce evapotranspiration, while tree canopy covers help reduce soil temperature for crops planted underneath and decrease runoff velocity and soil erosion from heavy rainfall.

Source: Adapted from CGIAR Research Program on Climate Change (2021).

Include agroforestry and forest management in adaptation planning. The country can also engage in agroforestry, a win-win measure for both climate change adaptation and mitigation of negative impacts on agricultural and forest productivity due to higher temperatures, increased aridity, and soil erosion. Agroforestry includes planting orchards with cultivation of perennial grasses, plantations of bioenergy crops, developing agroforestry practices on the agricultural land occupied by self-planted forests and other solutions. Planting orchards will diversify production, reduce risks of climate change and increase food security. However, the greatest potential to develop agroforestry is generated by the restoration of protective shelterbelts. Shelterbelts are important for improving soil quality and thermal regulation, retaining or increasing soil moisture content, increasing crop production, generating additional incomes from forest and non-timber products, and protecting biodiversity.

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

REFERENCES

Balabukh V., Lavrynenko O., Bilaniuk V., Mykhnovych A. & Pylypovych O. (2018). Extreme Weather Events in Ukraine: Occurrence and Changes. In: Extreme Weather. InTech. https://doi.org/10.5772/intechopen.77306

Balabukh V. O., Malitskaya L. V. 2017 Assessment of the current changes in the thermal regime of Ukraine. Geoinformatika, 64(4), 34–49 (in Ukrainian).

Balabukh V., Malytska L. (2017). Impact of climate change on natural fire danger in Ukraine. IDŐJÁRÁS –Quarterly Journal of the Hungarian Meteorological Service. V121, N 4, P. 453—477. https://www.met.hu/en/ismeret-tar/kiadvanyok/idojaras/index.php?id=583.

Beck, H.E., N.E. Zimmermann, T.R. McVicar, N. Vergopolan, A. Berg, E.F. (2018). Wood: Present and future Köppen-Geiger climate classification maps at 1-km resolution, Nature Scientific Data.

Bondaruk, M.A., Tselischev, O.G. (2015). Evaluation of satisfiability of ecotypes environmental conditions and predictive modeling of populations of species of forest flora rarities. In Forestry and Agromelioration: Kharkiv. Volume 126, 188–201 (in Ukrainian).

Buksha I.F. (2010). Study of climate change impact on forest ecosystems, and the development of adaptation strategies in forestry of Ukraine in I.F. Buksha, Climate Change Impacts on Forest Management in Eastern Europe and Central Asia: Dimensions, impacts, mitigation and adaptation policies. Forests and Climate Change Working Paper 8. Csaba Matyas, Editor. Food and Agriculture Organization of the United Nations. 157–179.

Buksha I.F., Pasternak V.P. (2020). Strategic directions of mitigation and adaptation to climate change in forestry of Ukraine. Proceedings of the 1st All-Ukrainian Scientific and Practical Conference: Climate Adaptation in Ukraine: Status, Challenges and Prospects (dedicated to World Climate Protection Day). Kherson: KhSAU. 2020, 11-16 (in Ukrainian).

Cabinet of Ministers of Ukraine. (2019). Irrigation and drainage strategies in Ukraine for the period up to 2030. https://zakon.rada.gov.ua/laws/show/688-2019-%D1%80#Text.

Cabinet of Ministers of Ukraine. (2020). Order “On Approval of the Rules of Maintenance and Conservation of Forest Smoothies Located on Agricultural Land.” #650. July 22, 2020. https://zakon.rada.gov.ua/laws/show/650-2020-%D0%BF#Text.

Cabinet of Ministers of Ukraine. (2021). Order “Approval of the National Economic Strategy for the period up to 2030.” #179. March 3, 2021. https://www.kmu.gov.ua/npas/pro-zatverdzhennya-nacionalnoyi-eko-a179.

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). (2021). At https://csa.guide/csa/practices.

Center for Climate Change Adaptation (CCCA). (2021). About Us. https://ccca.nies.go.jp/en/about/index.html.

Climate Action Tracker. (2021). Ukraine: Current Policy Projections. https://climateactiontracker.org/countries/ukraine/current-policy-projections/.

Council of National Security and Defense of Ukraine. (2021). Decision: On Challenges and Threats to Ukraine's National Security in the Environmental Sphere and Priority Measures to Neutralize Them. https://zakon.rada.gov.ua/laws/show/n0018525-21/print (accessed on May 25, 2021).

Damania, R., Desbureaux, S., Hyland, M., Islam, A., Rodella, A. S., Russ, J., & Zaveri, E. (2017). Uncharted waters: The new economics of water scarcity and variability. World Bank Publications.

De Rigo, D., Libertà, G., Houston Durrant, T., Artés Vivancos, T., San-Miguel-Ayanz, J. (2017). Forest fire danger extremes in Europe under climate change: variability and uncertainty, EUR 28926 EN, Publications Office of the European Union, Luxembourg, ISBN: 978-92-79-77046-3, doi:10.2760/13180, JRC108974.

De Wit, A., H. Boogaard, D. Fumagalli, S. Janssen, K. van Diepen. (2019). 25 years of the WOFOST cropping systems model. Agricultural Systems, Volume 168, January 2019, Pages 154-167.

Didovets, I. et al. 2017. Assessment of Climate Change Impacts on Water Resources in Three Representative Ukrainian Catchments Using Eco-Hydrological Modelling in Water 9, 204.

Didukh, Y. P. (2011). The Ecological Scales of the Species of Ukrainian Flora and Their Use in Synphytoindication; Phytosociocentre: Kyiv, Ukraine; 176.

Didukh, Y. P. (2012). Backgrounds of Phytoindication; Institute of Botany, National Academy of Sciences of Ukraine: Kyiv, Ukraine; 344. (In Ukrainian).

Didukh, Y. P. (2021). Climate Change Assessment Based on Synphytoindication Method. In: Lackner M., Sajjadi B., Chen WY. (eds) Handbook of Climate Change Mitigation and Adaptation. Springer, New York, NY. https://doi.org/10.1007/978-1-4614-6431-0_137-1.

EURO-CORDEX. (2021). Guidance for EURO-CORDEX climate projections data use. Version1.1. 2021.02 https://www.euro-cordex.net/imperia/md/content/csc/cordex/guidance_for_euro-cordex_climate_projections_data_use__2021-02_1_.pdf.

European Commission. (2019a). Extent and impacts of the heatwaves in Europe. In JRC MARS Bulletin. Crop monitoring in Europe., edited by European Commission and Joint Research Center. Vol 27 No 6.

European Commission. (2019b). Challenging harvesting and sowing conditions. Rapeseed sowing and emergence particularly affected. In JRC MARS Bulletin. Crop monitoring in Europe., edited by European Commission and Joint Research Center. Vol 27 No 10.

Femenia, F. A (2019). Meta-analysis of the price and income elasticities of food demand. [University works] Inconnu, 78 p. https://hal.archives-ouvertes.fr/hal-02103880/document.

European Climate Assessment & Dataset (ECA&D). (2021).
E-OBS gridded dataset. At https://www.ecad.eu/download/ensembles/download.php.

EU Science Hub. (2021). JRC PECETA IV. https://ec.europa.eu/jrc/en/peseta-iv.

Expert Team on Climate Change Detection and Indices (ETCCDI). (2021). http://www.clivar.org/organization/etccdi/etccdi.php).

FAO. (2013). Climate change guidelines for forest managers. FAO Forestry Paper 172., 122.

FAO. (2019). Irrigation and drainage strategy in Ukraine until 2030. http://www.fao.org/faolex/results/details/en/c/LEX-FAOC190984/.

FAO. (2020a). Guideline on effective shelterbelt models management. http://www.fao.org/3/ca9554uk/CA9554UK.pdf

FAO (2020b). Practical training “Ways to improve the economic efficiency of shelterbelts”. https://www.ukrinform.ua/rubric-presshall/3150730-skola-fermera-fao-krasi-agrolisomelioracitivni-praktiki.html

FAO. (2021a). AQUASTAT - FAO’s Global Information System on Water and Agriculture. http://www.fao.org/aquastat/en/

FAO. (2021b). FAOSTAT: http://www.fao.org/faostat/en/#data/QC

Femenia, F. (2019). A meta-analysis of the price and income elasticities of food demand. [University works] Inconnu, 78 p. hal-02103880. https://hal.archives-ouvertes.fr/hal-02103880/document.

Feyen L. et al. (2020). Climate change impacts and adaptation in Europe. JRC PESETA IV final report. EUR 30180EN, Publications Office of the European Union, Luxembourg.

Forest Ecology Laboratory of URIFFM. 2020.

FOREST EUROPE. (2020). Adaptation to Climate Change in Sustainable Forest Management in Europe. Liaison Unit Bratislava, Zvolen, 52.

Forzieri G., Girardello M., Ceccherini G., Mauri A., Spinoni J., Beck P., Feyen L. and Cescatti A. (2020). Vulnerability of European forests to natural disturbances, EUR 29992 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-13884-6, doi:10.2760/736558, JRC118512.

Gensiruk S.A., Shevchenko S.V., Bondar V.S. et. al. (1981). Complex forest zoning of Ukraine and Moldova (edited by S.A. Gensiruk), Kyiv. – Naukova Dumka. – 360 p. (In Russian).

Government of Mexico (GoM). (2020). Ministry of Environment & Natural Resources Actions and Program. Trust: Climate Change Fund (SEMARNAT). https://www.gob.mx/semarnat/acciones-y-programas/fideicomiso-fondo-para-el-cambio-climatico-semarnat.

Hellerstein, D., Vilorio, D., and Ribaudo, M. (editors). (2019). Agricultural Resources and Environmental Indicators. EIB-208, U.S. Department of Agriculture, Economic Research Service, May 2019.

Herger, N., Sanderson, B. M., and Knutti, R. (2015). Improved pattern scaling approaches for the use in climate impact studies. In Geophys. Res. Lett., 42, doi:10.1002/2015GL063569.

International Food Policy Research Institute (IFPRI). (2015). The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). Model Description for Version 3. IFPRI Discussion Paper Nº01483. IFPRI, Washington DC.

International Food Policy Research Institute (IFPRI). (2019). IMPACT Projections of Food Production, and Prices to 2050, With and Without Climate Change. 2019 GFPR Annex Table 5.

IPCC. (2000). Summary for Policymakers. IPCC Special Report Emissions Scenarios. Summary for policymakers. A Special Report of IPCC Working Group III. Geneva: Intergovernmental Panel on Climate Change.

IPCC. (2001). Climate change 2001: IPCC third assessment report. Geneva: Intergovernmental Panel on Climate Change Secretariat.

IPCC. (2007a). Fourth Assessment Report: Climate Change 2007: The AR4 Synthesis Report. Geneva: Intergovernmental Panel on Climate Change.

IPCC. (2007b). Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. edited by B. Metz, O.R. Davidson, P.R. Bosch, R. Dave and L.A. Meyer. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K.

Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535.

IPCC. (2014). Fifth Assessment Report: Climate Change 2014: Impacts, Adaptation, and Vulnerability (AR5). Geneva: Intergovernmental Panel on Climate Change. URL: https://www.ipcc.ch/site/assets/uploads/2018/03/sres-en.pdf

IPCC. (2014). Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117-130.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

Jacob, D., Petersen, J., Eggert, B., Alias, A., Christensen, O. B., Bouwer, L. M. et al. (2014). EURO-CORDEX: New high-resolution climate change projections for European impact research. Regional environmental change, 14(2), 563-578. https://doi.org/10.1007/s10113-013-0499-2.

Jacob, D., Teichmann, C., Sobolowski, S., Katragkou, E., Anders, I., Belda, M., et al. (2020). Regional climate downscaling over Europe: perspectives from the EURO-CORDEX community. In Regional Environmental Change, 20(2), 1-20.

Jafino, B.A., Hallegatte, S. and Rozenberg, J. (2021). Focusing on differences across scenarios could lead to bad adaptation policy advice. In Nature Climate Change, pp.1-3.

Janowiak, M. K. et. al. (2016). Adaptation Resources for Agriculture: Responding to Climate Variability and Change in the Midwest and Northeast. US Department of Agriculture. Washington D.C.

Johnson, J. A., Ruta, G., Baldos, U., Cervigni, R., Chonabayashi, S., Corong, E., Gavryliuk, O., Gerber, J., Hertel, T., & Nootenboom, C. (2021). The Economic Case for Nature. International Bank for Reconstruction and Development / The World Bank, Washington.

Knutti, R. and Sedláček, J. (2013). Robustness and uncertainties in the new CMIP5 climate model projections. Nature Climate Change, 3(4), pp.369-373.

Kolomyts E.G. (2010). Local humidification coefficients and their values for ecological forecasts. Bulletin of the Russian Academy of Sciences. - No 5. – 61-72 p. (in Russian).

Krakovska S.V., Gnatiuk N.V., Shpytal T.M., Palamarchuk L.V., (2016). Projections of surface air temperature changes based on data of regional climate models' ensemble in the regions of Ukraine in the 21st century, Naukovi pratsi Ukrainskoho hidrometeorolohichnoho instytutu. N 268. P. 33—44 [in Ukrainian]

Krakovska S.V., Palamarchuk L.V., Gnatiuk N.V., Shpytal T.M., Shedemenko I.P. (2017). Changes in precipitation distribution in Ukraine for the 21st century based on data of regional climate model ensemble. Geoinformatica. N 4(64), 62—74 (in Ukrainian).

Krakovska S.V. & Shpytal T.M., (2018). Dates of air temperature transition over 0, 5, 10 and 15 °C and corresponding lengths of climatic seasons from the second part of the 20th to the middle of the 21st century in Ukraine. Geoinformatica. N 4(68), 74—92 (in Ukrainian).

Kropff, M.J., and H.H. Van Laar. (1993). MODELING crop–weed accurately be simulated. Application of a descriptive interactions CAB Int., Wallingford, Oxon, UK.

Kruhlov, I., Thom, D., Chaskovskyy, O. et al. (2018). Future forest landscapes of the Carpathians: vegetation and carbon dynamics under climate change. Reg Environ Change 18, 1555–156. URL: https://doi.org/10.1007/s10113-018-1296-8.

Kryvobok O.A. (2015). Calibration for the mars crop yield forecasting system over Ukraine, report under the contract CCR.IES.C390895 European Commission JRC "Improved input data and calibration for the MARS crop yield forecasting system over Ukraine", p.18, European Commission JRC.

Kryvobok O.A., Kryvoshein O.O., Adamenko T.I. (2018). Peculiarities of technological adaptation of the CGMS system for agricultural crops monitoring in Ukraine. Ukraïns'kij gìdrometeorologìčnij žurnal, Issue 22. Available at http://nbuv.gov.ua/UJRN/Uggj_2018_22_9.

Kunreuther, H., Gupta, S., Bosetti, V., Cooke, R., Dutt, V., Ha-Duong, M. & Weber, E. (2014). Integrated risk and uncertainty assessment of climate change response policies. In Climate Change 2014: Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 151-206). Cambridge University Press.

Law of Ukraine # 985-IX "On Amendments to the Law of Ukraine on State Support of the Agricultural Sector of Ukraine". O5.11.2020. https://zakon.rada.gov.ua/laws/show/985-20#Text. Lawrence Livermore National Laboratory. Earth System Grid Federation (ESGF). https://esgf-node.llnl.gov/search/esgf-llnl/.

Lopushnyak, G.S. and Shandar, A. M. (2017). The poverty problem of rural population of Ukraine as complex social and economic phenomenon. Institutional Repository of the State Higher Educational Institution Kyiv National Economic University named after Vadim Hetman. Issue https://ir.kneu.edu.ua/bitstream/handle/2010/22595/151-160.pdf?sequence=3&isAllowed=y.

Ministry for Development of Trade, Economy and Agriculture (MDTEA). (2020). “State support of Agriculture sector in 2021”. Presented on-line by the Deputy Minister of Agriculture. December 25, 2020.

Ministry of Environmental Protection and Natural Resources of Ukraine (MEPNR). (2020a). Priorities of the Ministry for the period 2020-2024. https://mepr.gov.ua/content/prioriteti.html.

Ministry of Environmental Protection and Natural Resources of Ukraine (MEPNR). (2020b). The Second National Determined Contribution. https://mepr.gov.ua/news/36563.html.

Navarro-Racines, C., Tarapues J., Thornton, P., Jarvis, A., and Ramirez-Villegas, J. (2020). High-resolution and bias-corrected CMIP5 projections for climate change impact assessments. In Scientific Data. 7:7. https://doi.org/10.1038/s41597-019-0343-8.

Naumann, G., Russo, S., Formetta, G., Ibarreta, D., Forzieri, G., Girardello, M., & Feyen, L. (2020). Global warming and human impacts of heat and cold extremes in the EU. JRC PESETA IV Project, Task, 11.

NIR. (2020). Annual National Inventory Report (NIR) for Submission under the United Nations Framework. Convention on Climate Change and the Kyoto Protocol. Ministry of Energy and Environmental Protection of Ukraine, National Center for GHG Emission Inventory, Kyiv, Ukraine. (For sector-specific uncertainty, see Table A7.1 in the Annexes of NIR).

OECD. (2008). Growing Unequal? Income Distribution and Poverty in OECD Countries, Paris.

OECD. (2011). Divided We Stand – Why Inequality Keeps Rising, Paris. URL: www.oecd.org/social/inequality.htm / www.oecd.org/fr/social/inegalite.htm.

Palamarchuk L. V. & Shedemenko I. P., (2020). Statistical evaluation of temporal changes in annual precipitation in the plain territory of Ukraine. Physical Geography and Geomorphology, 101–102(3–4), 7–18 (in Ukrainian). https://doi.org/10.17721/phgg.2020.3-4.0X.

Platts. (2018). European Power Daily. S&P Global 20 (151).

President of Ukraine. (2021). Order on Decision of the Ukrainian National Security and Defense Council of March 23, 2021. About the Challenges and Threats to the National Security of Ukraine in the Ecological Sphere and the First Steps for their Neutralization. 23.03.2021. https://www.rnbo.gov.ua/ua/Ukazy/4856.html.

Rybchenko, L.S. and Savchuk, S.V. (2015). Potential of the Climatic Solar Radiation Energy Resources in Ukraine // Ukr. geogr. z. 2015, N4:16-23 https://doi.org/10.15407/ugz2015.04.016.

Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, (2012). Changes in climate extremes and their impacts on the natural physical environment. In Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, 109-230.

Shevchenko, O., Vlasiuk, O., Stavchuk, I., Vakoliuk, M., Illiash, O., & Rozhkova, A. (2014a). National climate vulnerability assessment: Ukraine. In Climate Forum East (CFE) and NGO Working Group on Climate Change.

Shevchenko, O., Lee, H., Snizhko, S., & Mayer, H. (2014b). Long term analysis of heat waves in Ukraine. International Journal of Climatology, 34(5), 1642-1650.

Shvidenko, A., Buksha, I., Krakovska, S., Lakyda, P. (2017). Vulnerability of Ukrainian Forests to Climate Change. Sustainability, 9, 1152. https://doi.org/10.3390/su9071152.

Schvidenko, A., Buksha I., Krakovska S. (2018). Vulnerability of Ukraine’s forests to climate change. Monography. Kyiv, Nika-Centre, 184.

Shvidenko, A., Buksha, I., Krakovska, S., & Lakyda, P. 2017. Vulnerability of Ukrainian forests to climate change. Sustainability, 9(7), 1152.

Schvidenko, A., Lakyda, P., Shepashenko, D., Vasylishin R., Marchuk I. (2014). Carbon, Climate and Land Management in Ukraine: The Forestry Sector. Korsun-Shevchenkivskii NUBIP i MIPSA.

Shvidenko, A., Kraxner, F., & Shchepashchenko, D. (2018b). Ensuring a sustainable future for forests: The case of Ukraine. IIASA Policy Brief No18.

Soil Capital. (2019). Case study on regenerative agriculture. https://www.soilcapital.com/capture-carbon.

Spittlehouse, D., & Stewart, R. (2004). Adaptation to climate change in forest management. Journal of Ecosystems and Management, 4(1), pp. 1-11. URL: https://jem-nline.org/index.php/jem/article/view/254.

Teichmann, C., Jacob, D., Remedio, A. R., Remke, T., Buntemeyer, L., Hoffmann, P., et al. (2020). Assessing mean climate change signals in the global CORDEX-CORE ensemble. Climate Dynamics, 1-24.

The European Climate Adaptation Platform Climate-ADAPT. (2021). The Netherlands. https://climate-adapt.eea.europa.eu/countries-regions/countries/netherlands.

The European Climate Adaptation Platform Climate-ADAPT. (2021). Spain. https://climate-adapt.eea.europa.eu/countries-regions/countries/netherlands.

Ukrainian Hydrometeorological Center. (2021). https://meteo.gov.ua/ua/33345/services/#2.

Ukrainian State Forest Agency. (2019).

Ukrainian Statistics. (2021).Statistical Committee of Ukraine. http://ukrstat.org.

United Nations (UN). (2021). UN Comtrade Database. At https://comtrade.un.org/.

United Nations Development Program (UNDP). (2021). Climate Change Adaptation. Mexico. https://www.adaptation-undp.org/explore/mexico.

United Nations Framework Convention on Climate Change (UNFCCC). Adaptation Committee. (2014). Institutional arrangements for national adaptation planning and implementation. 2014 Thematic Report. https://unfccc.int/files/adaptation/application/pdf/adaption_commitee_publication_-_web_high.pdf.

Van Diepen, C.A., J. Wolf, H. van Keulen, C. Rappoldt. (1989). WOFOST: a simulation model of crop production, Soil use and Management, V.5, Number 1, 1989, 16-24.

Williams, A., Jordan, N.R., Smith, R.G. et al., (2018). A regionally adapted implementation of conservation agriculture delivers rapid improvements to soil properties associated with crop yield stability. In Scientific Reports, 8(1), 1-8.

The World Bank. 2019. Ukraine Economic Update: May (2019). https://pubdocs.worldbank.org/en/677701558601578072/Ukraine-Economic-Update-Spring-2019-en.pdf.

World Bank. (2020). Ukraine Country Forest Note. http://hdl.handle.net/10986/34097.

The World Bank. (2021a). The World Bank in Ukraine. https://www.worldbank.org/en/country/ukraine/overview#3.

The World Bank. (2021b). World Development Indicators. https://databank.worldbank.org/source/world-development-indicators#.

The World Bank. (2021c). Data Bank. Metadata Glossary. https://databank.worldbank.org/metadataglossary/gender-statistics/series/SI.POV.GINI.
The World Bank. (2021d). Ukraine Systematic Country Diagnostic: 2021 Update. https://www.worldbank.org/en/news/infographic/2021/09/06/ukraine-scd-2021.

World Food Program (IFAD) (2011). Weather Index-based Insurance in Agricultural Development. A Technical Guide. https://documents.wfp.org/stellent/groups/public/documents/communications/wfp242409.pF

Yang, W. et al. (2010). Distribution-based scaling to improve usability of regional climate model projections for hydrological climate change impacts studies, Hydrology Research, 41 (3-4): 211–229.

ANNEX 1.
METHODOLOGY

A 1.1 Climate Projection

As projections of climate change depend heavily on future human activities, climate models are run against scenarios that make certain assumptions about how these activities will evolve. Climate models rely on several different scenarios, each making a number of assumptions for future greenhouse gas emissions, land-use, technological development, population, economic development, and other driving forces. Such scenarios form the basis for future atmospheric GHG concentration projections. The scenarios from the Special Report on Emissions Scenarios (SRES) were used in the IPCC Third Assessment Report (TAR), published in 2001, and in the IPCC Fourth Assessment Report (AR4), published in 2007. For the Fifth Assessment Report (AR5), a new set of scenarios was developed, the so-called Representative Concentration Pathways (RCPs) that consisted of: i) the RCP 2.6 scenario, which assumes a strongly declining emissions trend, compatible with a 2°C global warming limit by 2100; ii) the RCP 4.5 scenario, which assumes a slowly declining emissions trend, compatible with 2.4 °C global warming limit by 2100; iii) the RCP 6.0 scenario, which assumes a stabilizing emissions trend, compatible with a global 2.8°C warming limit by 2100; and iv) the RCP 8.5 scenario, which assumes a rising emissions trend, compatible with a global 4.3°C warming limit by 2100.

Climate data is processed on a daily basis for a base period and three future time horizons. These include 1991-2010 (base period), 2021-2040 (to allow a range value for the year 2030 to be calculated), 2041-2060 (to allow a range value for the year 2050 to be calculated), and 2081-2100 (to allow a range value for the year 2090 to be calculated). Key climate variables (i.e., temperature and precipitation) in future periods are measured against the base period 1991-2010 to determine the extent of changes. The historical period 1961-1990 is also used to compare the results with older studies and assess the projected future changes against the changes that have already happened between this period[26] and the base period. Such comparison is significant, considering the climate in Ukraine has been changing considerably since late 1980s. It should be noted that for several reasons, the base period used for the forestry and agricultural assessment are different. Specifically, the base period for forestry analysis is 1961-1990, as many field data were obtained and methodologies developed during this time. For agricultural analysis, the base period is 2006-2015, since 10-year periods are sufficient for significant changes to take place in the sector, and thus, it also makes the most sense to compare the projected changes against the most recent period with available data.

Climate projections are obtained by running numerical models of the Earth’s climate, which may cover either the entire globe or a specific region. These models are referred to as: i) Global Climate Models (GCMs), also known as Atmosphere-Ocean General Circulation Models (AOGCMs) and Earth System Models (ESMs), which provide projections with resolution

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[26] The World Meteorological Organization (WMO) advocates using a historical base period (1961-1990) for assessing climate change, as well as the most recent 30-year period, in order to standardize and harmonize across institutions.

of around 100km^2 covering a variety of landscapes; and ii) Regional Climate Models (RCMs), which are applied over a limited area, taking into account the large-scale climate information from GCMs as initial and boundary conditions, and provide projections at much higher resolutions. Presently, modelling is conducted through a series of Coupled Model Intercomparison Projects (CMIP), of which the latest is CMIP6.

The climate projections in this study are based on the European Coordinated Regional Downscaling Experiment (Euro-CORDEX) time series[27] with the most advanced RCMs covering Ukraine. GCMs can only simulate earth processes in coarse grid-cells, which are not suitable for local impact assessment studies. Dynamical downscaling, using RCMs with boundary and initial conditions from GCMs as inputs, increases the resolution of climate projections. RCMs provide information on much finer scales, including more detailed specifications of land and water bodies and simulation of mesoscale processes (Navarro-Racines et al. 2020), to support more detailed impact assessment and adaptation planning. RCM outputs have been made available recently through the Coordinated Regional Downscaling Experiment (CORDEX), a program sponsored by the World Climate Research Program (WCRP) to produce improved regional climate change projections for all land regions worldwide. Euro-CORDEX is one of the 14 domains of the international CORDEX initiative with the most advanced RCMs providing the highest resolution, at 0.11 (~12.5km), and covering the entire territory of Ukraine. The Coordinated Regional Downscaling Experiment (CORDEX) framework provides a basis for selecting the combined ensembles of various RCMs and overarching GCMs and assessing the level of associated certainty.

Simplifications, assumptions, and choices of parametrizations have to be made when constructing climate models, resulting in model and forecast errors. Climate models are numerical models that parameterize the relevant physical processes and their interplay and feedback to project weather and climate from time scales of days to centuries. The uncertainties in constructing and running these models are inherent and manifold and originate from different initial and boundary conditions, as well as structural uncertainties (IPCC 2007b; EURO-CORDEX 2021). Initial condition uncertainty is related to the value of observations used to initialize numerical climate models. This type of uncertainty is most relevant for forecasts over the shortest time scales, but not significant for long-term climate projections, which are often averaged over decades and therefore are largely insensitive to variations in initial conditions. Uncertainty in boundary condition is introduced when datasets are used to replace an interactive part of the system. Parameter uncertainty stems from the parameterization of small-scale processes in all components of the climate system using bulk formulas when these processes cannot be explicitly resolved due to computational constraints. Structural uncertainty refers to any uncertainty originating from the choices in the model design. As a true climate system is highly complex, it is impossible to describe all the system processes in a climate model. Thus, choices must be made on what processes to include and how to parameterize them (Kunreuther et al. 2014).

Multi-model ensembles are used in climate projections to improve the skill, reliability, and consistency of model forecasts. A multi-model ensemble is a set of model simulations from structurally different models (i.e., different initial and boundary conditions and parameterization).

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[27] The high-resolution and bias-adjusted CORDEX data only became available in late 2019. This study takes advantage of this new data for the analysis and provides significantly more insights compared to previous studies, where limited availability and the complexity of dealing with large datasets have hindered the broader use of this source.

Combining models to enhance climate projections rests on the assumption that errors tend to cancel if the choices are made independently for constructing each model, and uncertainty should decrease with an increasing number of models. Experiences from weather- and climate-related applications also show that seasonal forecasts and El Ninõ Southern Oscillation (ENSO) predictions from multi-model ensemble are generally better than those from single models. Studies indicate that multi-model ensemble performs dramatically better when considering an aggregated performance measure over many diagnostics, as illustrated in Figure 1.

Multi-model ensembles also help quantify model uncertainty. Uncertainty in projected climate variables (i.e., temperature and precipitation) can be estimated using quantitative metrics such as (inter-model) standard deviation and range. In this study, we estimate the range or spread in the projections for each climate variable from the different RCM-GCM combinations in the ensemble to quantify the degree of uncertainty. This range is herein referred to as the “ensemble range.” The ensemble range represents all possible realizations of the simulated climate variables under each RCP in each time horizon under study, while the means of the ensemble represent the most probable values of the average changes for the modeled variables.

We have evaluated the performance of five driving GCMs from the CMIP5 ensemble, using the R-based GCMeval tool. These five GCMs were initially selected by the scientist community for a high-resolution regional climate change ensemble established for Europe within the EURO-CORDEX initiative. In general, the GCMeval tool is used to assess and choose a subset of GCMs from the CMIP5 based on their relative performance (in terms of the spread of the projected temperature and precipitation changes), compared to the entire ensemble. This tool is opensource and available online at https://gcmeval.met.no. The GCMeval tool is currently under further improvements, so not all CMIP5 models are included, and the results are aggregated over just SREX IPCC regions[28] for prescribed periods and seasons. In this study, we utilize the outputs for the Central Europe region, which is much larger but covers the entire territory of Ukraine. Another caution is that estimations of the GCMeval tool are available for two slightly different time periods, specifically 2021-2050 and 2071-2100 over the present period 1981-2010. However, it is currently one of the best tools for selecting and assessing a subset of CMIP5 GCM ensemble for Ukraine. Overall, the subset of five GCMs corresponds reasonably well with the entire CMIP5 ensemble and shows consistency and balance in their representation of temperature and precipitation changes. The ensemble ranges of the subset are slightly lower (38-55% for temperature) and higher (35-63% for precipitation), compared to those of the entire CMIP5. In term of mean values, the precipitation values of the 5 GCM subset are also similar to those of the CMIP5 ensemble, with slightly higher values (wetter conditions) in winter and annual estimates. For temperature, both summer and annual means of the subset and the entire CMIP5 ensembles are very close under both RCP 4.5 and RCP 8.5 in both periods.

To form RCM ensembles, this study employs a so-called “fitness-for-purpose” method. This means when we want to project changes in only one independent in climate variable (i.e., air temperature or precipitation), all available RCMs are included in the ensemble – up to 43

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[28] The 26 SREX regions include Alaska/NW Canada (ALA), Eastern Canada/Greenland/Iceland (CGI), Western North America (WNA), Central North America (CNA), Eastern North America (ENA), Central America/Mexico (CAM), Amazon (AMZ), NE Brazil (NEB), West Coast South America (WSA), South- Eastern South America (SSA), Northern Europe (NEU), Central Europe (CEU), Southern Europe/the Mediterranean (MED), Sahara (SAH), Western Africa (WAF), Eastern Africa (EAF), Southern Africa (SAF), Northern Asia (NAS), Western Asia (WAS), Central Asia (CAS), Tibetan Plateau (TIB), Eastern Asia (EAS), Southern Asia (SAS), Southeast Asia (SEA), Northern Australia (NAS) and Southern Australia/New Zealand (SAU).

RCM runs for RCP 4.5 with bias-adjusted data. When the projected results are intended to be used as inputs for further modeling (i.e., crop productivity), all meteorological variables from the same RCM runs are utilized. Even when a less sophisticated model is used (i.e., for forestry), where there is no need to directly use daily data (since multi-year monthly values give enough temporal resolution to estimate the differences among scenarios), we still use the same number of RCM runs in ensembles for air temperature and precipitation for both RCP4.5 and RCP8.5.

Two types of EuroCORDEX datasets for seven climate variables were obtained from the Earth System Grid Federation (ESGF) website (https://esgf-node.llnl.gov/search/esgf-llnl/). These include: i) the bias-adjusted outputs for daily precipitation and daily mean, maximum, and minimum temperatures; and ii) the raw outputs (without bias adjustments) for daily surface wind speed, relative humidity (RH), and downward shortwave solar radiation (RSDS). CORDEX-adjusted outputs covering Ukraine were available for five GCMs and seven RCMs. The different combinations of these models produce 96 datasets for RCP 8.5, 132 for RCP 4.5, and only 12 for RCP 2.6. As only three RCM datasets were available for RCP 2.6, only daily precipitation and daily mean, maximum, and minimum temperatures are calculated for this scenario (see Table 8). The CORDEX raw outputs were available for five GCMs and three RCMs. There are 33 datasets for RCP 4.5 and 56 for RCP 8.5 from the combinations of these models.

Table 8: Number of CORDEX Datasets Processed by Combination of RCMs and Overarching GCMs

	Number of CORDEX bias- adjusted datasets			Number of CORDEX datasets without bias adjustment	
	RCP 2.6	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Mean temperature	3	43	34	-	-
Maximum temperature	3	23	14	-	-
Minimum temperature	3	23	14	-	-
Precipitation	3	43	34	-	-
Surface wind speed	-	-	-	11	22
Relative humidity	-	-	-	11	12
Downward shortwave solar radiation	-	-	-	11	22

For historical and baseline data, we used the E-OBS v20.0e (EC&D 2021) gridded dataset with the same spatial resolution (0.11°) as the RCM data from EuroCORDEX. There was no data in grid cells for some climate variables from RCMs in these past periods. For example, data for relative humidity (RH) and sunshine duration (SD) during 1961-1990 are absent from the RCM datasets, but are needed for forestry assessment. In this case, the most suitable data available are used based on a physical consistency approach. In particular, since RH does not have a significant inter-annual variability, we use multi-year means over just 5 years (2006-2010) from 11 available RCMs in RCP 4.5 runs for both past periods. For SD, we interpolate in grid cells the data of 38 Ukrainian stations for the period 1991-2013 (Rybchenko and Savchuk 2015).

Bias-correction is necessary to make the climate projections more realistic, as RCM outputs are also subject to errors due to uncertainties associated with both the structure of the RCMs and the boundary conditions of the driving GCMs. Bias-correction improves the realism and sometimes, resolution of climate model outputs (i.e., when projections are made at coarser spatial resolution), using different types of statistical techniques, assuming that those outputs are already plausible representation of future climate characteristics. Existing bias correction methods cannot fundamentally correct future climate change trends (Navarro-Racines et al. 2020).

The data for air temperature and precipitation has been bias-adjusted by the data provider EuroCORDEX using the Distribution-Based Scaling (DBS) method.[29] The DBS approach reproduces the variations generated from RCMs and preserve their adjustments to the key hydro-meteorological variables, precipitation and temperature, to obtain more realistic inputs for hydrological modeling (Yang et al. 2010). These bias-adjusted data are inputted in to the WOFOST model for crop yield simulations. The DBS method clearly improves the representation of temperature and precipitation distribution, as shown in Figure 41. Column (a) represents the raw data received directly from the RCM model developed by Centre National de Recherches Météorologiques (CNRM). Column (b) represents the CNRM model data that was bias adjusted with the DBS method. Columns (c) and (d) show ensembles of 8 and 34 bias-adjusted RCMs (including the CNRM model) for RCP 8.5. Column (e) shows the reanalysis ERA5 data[30] that approximate observational data for the 2006-2015 period. Comparing temperature and precipitation maps, we notice that RCMs usually have more difficulties in representing precipitation, not only extremes, but also seasonality and even annual averages.[31] It is evident from Figure 1 that the bias-adjusted precipitation distribution map of the individual

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[29] General information on bias-adjustment is provided at https://cordex.org/data-access/bias-adjusted-rcm-data/. A summary of bias adjustment methods applied to CORDEX simulations can be found at http://is-enes-data.github.io/CORDEX_adjust_summary.html.

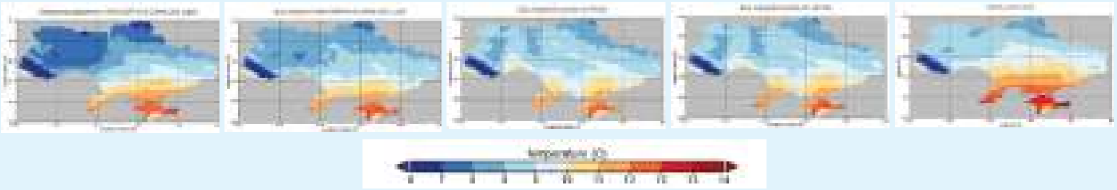
[30] Climate reanalyses combine past observations with model simulations to generate a consistent time series of multiple climate variables. Reanalyses are among the most-used datasets in the geophysical sciences since they provide a comprehensive description of the observed climate as it has evolved during recent decades, on 3D grids at sub-daily intervals. ERA5 is the latest climate reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), providing hourly data on many atmospheric, land-surface and sea-state parameters together with estimates of uncertainty (https://www.ecmwf.int/en/research/climate-reanalysis).

[31] In previous assessments of projected precipitation distribution based on the FP6 project ENSEMBLES data only four out of 14 RCMs were able to represent the annual cycle of precipitation in Ukraine (http://www.geology.com.ua/en/7195-2/).

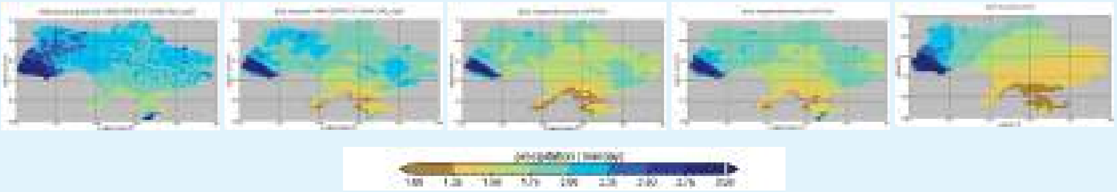
RCM (b) is visually closer to that of the ERA5,[32] indicating the benefits of the DBS method in markedly improving RCM outputs with cold and wet biases for hydrological modeling (Yang et al. 2010). Moreover, the level of similarity to the maps by ERA5 increases with the larger number of RCMs, as shown in column (d), compared to column (c). However, the maps of the 8 RCM ensemble (c) are sufficiently similar to those of the ERA5. This shows that the subset of 8 RCMs is a reasonable representation of the full 34 (43) RCMs ensemble and can be used to assess agricultural impact. Finally, even bias-adjusted outputs in the full ensemble of 34 RCMs are still colder and wetter than the ERA5 reanalysis data, showing that warming and drying in this period in Ukraine were higher than simulated.

Figure 41: Effect of Use of Multi Model Ensembles for Temperature and Precipitation

Temperature



Precipitation



(a) Raw data from **CNRM'** model

(b) **CNRM'** model bias adjusted **by DBS45**

(c) Ensemble 8 RCMs, including **CNRM's** model

(d) Ensemble of 34 RCMs, including **CNRM's** model

(e) Approximated observation data (ERA5)

Further bias-correction by the delta method was conducted within the framework of this study. The delta-method involves deriving a change factor, or a "delta" from the GCM and then adding it to the observation dataset. The change factor is defined as the difference between the long-term mean of a climate variable in the future and the base period. In this study, the observational data for Ukraine for the base period 1991-2010 is obtained from the E-OBS v20.0e gridded dataset with the same spatial resolution (https://www.ecad.eu/download/ensembles/download.php). Subsequently, the differences in temperatures (in degrees Celsius) and precipitation ratios (mm per month or year) in the future periods from the RCMs were added to (for temperature) and multiplied by (for precipitation) values in the base period. This procedure

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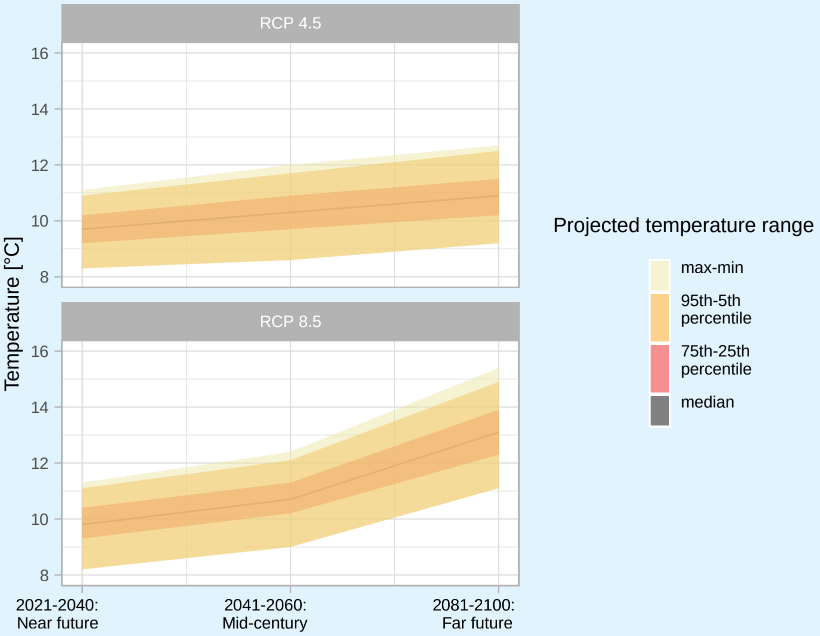
[32] For the periods after 2010, E-OBS climatological data clearly diverges from the reanalysis ERA5 data that heavily relies on modern satellite data (see https://climate.copernicus.eu/climate-reanalysis). One of the reasons could be an absence of up-to-date meteorological data for Ukraine in the European Database E-OBS after 2010. That is why we used E-OBS only till 2010, and ERA5 for subsequent years.

has resulted in some reduction in number of grid points mainly due to the differences in coastline masks of the Black and Azov Seas in E-OBS and RCMs.

The use of both bias-adjusted (temperature and precipitation) and non-adjusted variables (wind speed, RH, and RSDS) in this study is justified. The combination of bias-adjusted and raw data can be an issue when impact models are to provide outputs on a daily basis. In this study, multi-year means of most climate variables are used for forestry analysis. For agriculture, where daily data were inputs for the impact model and many processes were parameterized based on thresholds, it was more crucial to have proper distributions of precipitation and temperature rather than consistency across variables, some of which are less influential on agricultural model outputs.

The ensemble ranges of annual mean temperature and precipitation totals under RCP 4.5 and 8.5 in three periods are presented in Figure 2 and Figure 3. The ensemble range of warming levels in Ukraine slightly grows under RCP 4.5 and substantially increases under RCP 8.5 by the end of the century (see Figure 42). The ensemble range of annual precipitation totals under RCP 4.5 show a rather stabilizing trend from the middle to the end of the century. In contrast, the ensemble range under RCP 8.5 widens significantly toward the far future period, indicating that half of the RCMs in the ensemble project up to 56 percent higher precipitation levels (see Figure 3), and annual precipitation totals are likely higher under under RCP 8.5 than RCP 4.5.

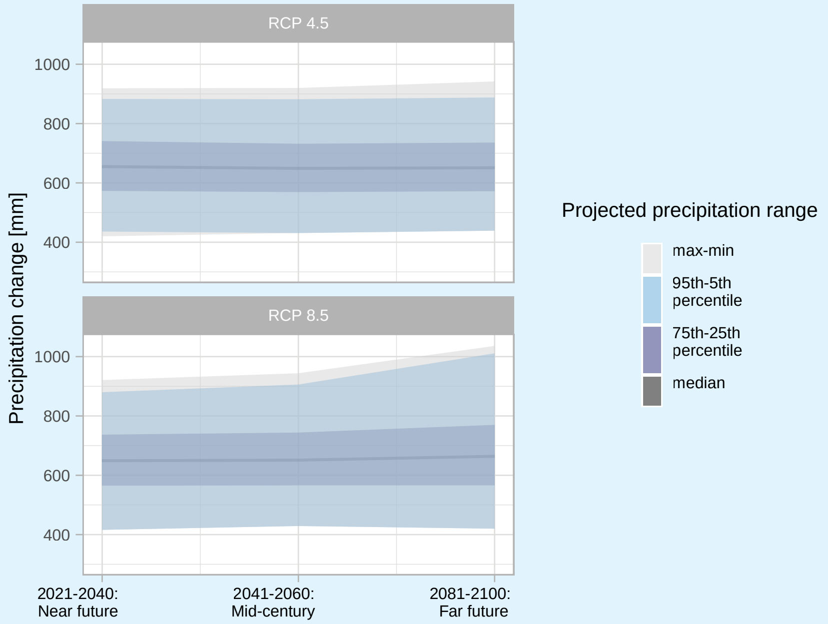
Figure 42: Mean Annual Air Temperature Change (left) and Values for Percentiles over the RCM Ensembles (right) for Three Periods and Two RCPs



	RCP4.5			RCP8.5		
percentile	2021-2040	2041-2060	2081-2100	2021-2040	2041-2060	2081-2100
max	11.1	12.0	12.7	11.3	12.4	15.4
95pctl	10.9	11.7	12.5	11.1	12.1	14.9
75pctl	10.2	10.9	11.5	10.4	11.3	13.9
50pctl	9.7	10.3	10.9	9.8	10.7	13.1
25pctl	9.2	9.7	10.2	9.3	10.2	12.3
5pctl	8.3	8.6	9.2	8.2	9.0	11.1
min	8.3	8.6	9.2	8.2	9.0	11.1
range	2.8	3.4	3.5	3.0	3.4	4.2

Note: The plot displays the distribution of data based on 5-95th percentile range in orange and a five-number statistic summary: minimum, first quartile (25th percentile), median (50th percentile), third quartile (75th percentile), and maximum. The plot directly compares three time periods under each RCP scenario.

Figure 43: Mean Annual Precipitation Change (left) and Values for Percentiles over the RCM Ensembles (right) for Three Periods and Two RCPs



percentile	RCP4.5			RCP8.5		
	2021-2040	2041-2060	2081-2100	2021-2040	2041-2060	2081-2100
max	919	920	942	921	944	1036
95pctl	883	882	888	880	906	1011
75pctl	741	732	736	737	744	770
50pctl	655	649	651	649	651	664
25pctl	573	569	572	565	566	566
5pctl	436	431	439	416	429	420
min	420	431	439	416	429	420
range	498	489	503	505	515	616

Note: The plot displays the distribution of data based on 5-95th percentile range in blue and a five-number statistic summary: minimum, first quartile (25th percentile), median (50th percentile), third quartile (75th percentile), and maximum. The plot directly compares three time periods under each RCP scenario.

Table 9: List of CORDEX-Adjusted Outputs Based on Combinations of GCM-RCM-Ensemble-Adjustment[33]

	CORDEX-Adjust output				RCP 4.5				RCP 8.5				RCP 2.6			
Id	GCM	Ensemble	RCM	Adjustment	tas	t max	t min	pr	tas	t max	t min	pr	tas	t max	t min	pr
1	CNRM-CM5	r1i1p1	CLMcom-CCLM4-8-17	v1-METNO-QMAP-MESAN-1989-2010	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
2	CNRM-CM5	r1i1p1	CLMcom-CCLM4-8-17	v1-SMHI-DBS45-MESAN-1989-2010	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜
3	CNRM-CM5	r1i1p1	CNRM-ARPEGE51	v1-IPSL-CDFT21-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
4	CNRM-CM5	r1i1p1	CNRM-ARPEGE51	v1-IPSL-CDFT22-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
5	CNRM-CM5	r1i1p1	SMHI-RCA4	v1-IPSL-CDFT21-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
6	CNRM-CM5	r1i1p1	SMHI-RCA4	v1-IPSL-CDFT22-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
7	CNRM-CM5	r1i1p1	SMHI-RCA4	v1-METNO-QMAP-MESAN-1989-2010	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
8	CNRM-CM5	r1i1p1	SMHI-RCA4	v1-SMHI-DBS45-MESAN-1989-2010	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜
9	EC-EARTH	r1i1p1	KNMI-RACMO22E	v1-IPSL-CDFT21-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
10	EC-EARTH	r1i1p1	KNMI-RACMO22E	v1-IPSL-CDFT22-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜

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[33] Simulations chosen for the agriculture research are highlighted in gold. Mean (tas), maximum (t max) and minimum (t min) temperature and precipitation (pr) highlighted in green for three scenarios were available and used.

	CORDEX-Adjust output				RCP 4.5				RCP 8.5				RCP 2.6			
Id	**GCM**	**Ensemble**	**RCM**	**Adjustment**	tas	t max	t min	pr	tas	t max	t min	pr	tas	t max	t min	pr
11	EC-EARTH	r1i1p1	KNMI-RACMO22E	v1-METNO-QMAP-MESAN-1989-2010	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
12	EC-EARTH	r1i1p1	KNMI-RACMO22E	v1-SMHI-DBS45-MESAN-1989-2010	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜
13	EC-EARTH	r3i1p1	DMI-HIRHAM5	v1-IPSL-CDFT21-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
14	EC-EARTH	r3i1p1	DMI-HIRHAM5	v1-IPSL-CDFT22-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
15	EC-EARTH	r3i1p1	DMI-HIRHAM5	v1-METNO-QMAP-MESAN-1989-2010	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
16	EC-EARTH	r3i1p1	DMI-HIRHAM5	v1-SMHI-DBS45-MESAN-1989-2010	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜
17	EC-EARTH	r12i1p1	CLMcom-CCLM4-8-17	v1-METNO-QMAP-MESAN-1989-2010	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
18	EC-EARTH	r12i1p1	CLMcom-CCLM4-8-17	v1-SMHI-DBS45-MESAN-1989-2010	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
19	EC-EARTH	r12i1p1	SMHI-RCA4	v1-IPSL-CDFT21-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜
20	EC-EARTH	r12i1p1	SMHI-RCA4	v1-IPSL-CDFT22-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
21	EC-EARTH	r12i1p1	SMHI-RCA4	v1-METNO-QMAP-MESAN-1989-2010	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
22	EC-EARTH	r12i1p1	SMHI-RCA4	v1-SMHI-DBS45-MESAN-1989-2010	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜
23	IPSL-CM5A-MR	r1i1p1	IPSL-INERIS-WRF331F	v1-IPSL-CDFT21-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
24	IPSL-CM5A-MR	r1i1p1	IPSL-INERIS-WRF331F	v1-IPSL-CDFT22-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
25	IPSL-CM5A-MR	r1i1p1	SMHI-RCA4	v1-IPSL-CDFT21-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
26	IPSL-CM5A-MR	r1i1p1	SMHI-RCA4	v1-IPSL-CDFT22-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
27	IPSL-CM5A-MR	r1i1p1	SMHI-RCA4	v1-METNO-QMAP-MESAN-1989-2010	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜
28	IPSL-CM5A-MR	r1i1p1	SMHI-RCA4	v1-SMHI-DBS45-MESAN-1989-2010	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
29	HadGEM2-ES	r1i1p1	CLMcom-CCLM4-8-17	v1-SMHI-DBS45-MESAN-1989-2010	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜
30	HadGEM2-ES	r1i1p1	KNMI-RACMO22E	v1-IPSL-CDFT22-WFDEI-1979-2005	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
31	HadGEM2-ES	r1i1p1	KNMI-RACMO22E	v2-SMHI-DBS45-MESAN-1989-2010	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜
32	HadGEM2-ES	r1i1p1	SMHI-RCA4	v1-IPSL-CDFT21-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
33	HadGEM2-ES	r1i1p1	SMHI-RCA4	v1-IPSL-CDFT22-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
34	HadGEM2-ES	r1i1p1	SMHI-RCA4	v1-METNO-QMAP-MESAN-1989-2010	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
35	HadGEM2-ES	r1i1p1	SMHI-RCA4	v1-SMHI-DBS45-MESAN-1989-2010	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
36	MPI-ESM-LR	r1i1p1	CLMcom-CCLM4-8-17	v1-METNO-QMAP-MESAN-1989-2010	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜
37	MPI-ESM-LR	r1i1p1	CLMcom-CCLM4-8-17	v1-SMHI-DBS45-MESAN-1989-2010	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜
38	MPI-ESM-LR	r1i1p1	MPI-CSC-REMO2009	v1-IPSL-CDFT21-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
39	MPI-ESM-LR	r1i1p1	MPI-CSC-REMO2009	v1-IPSL-CDFT22-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
40	MPI-ESM-LR	r1i1p1	MPI-CSC-REMO2009	v1-SMHI-DBS45-MESAN-1989-2010	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
41	MPI-ESM-LR	r1i1p1	SMHI-RCA4	v1-SMHI-DBS45-MESAN-1989-2010	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	⬜	⬜	⬜	⬜
42	MPI-ESM-LR	r1i1p1	SMHI-RCA4	v1-IPSL-CDFT22-WFDEI-1979-2005	🟩	⬜	⬜	🟩	🟩	⬜	⬜	🟩	⬜	⬜	⬜	⬜
43	MPI-ESM-LR	r2i1p1	MPI-CSC-REMO2009	v1-SMHI-DBS45-MESAN-1989-2010	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

Figure 44: Simulations Prepared for RCP 4.5 for CORDEX-Adjust Output (left) and for Euro-CORDEX Output (right)

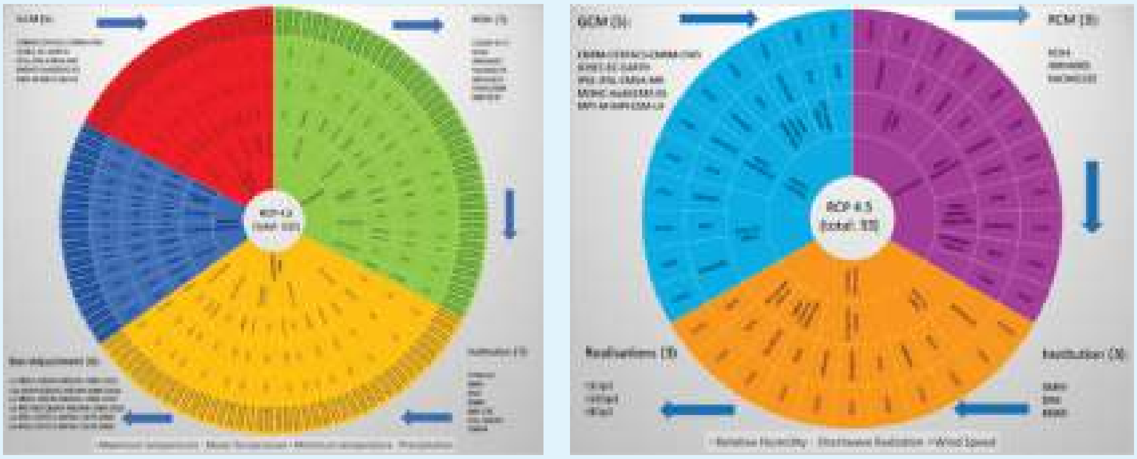
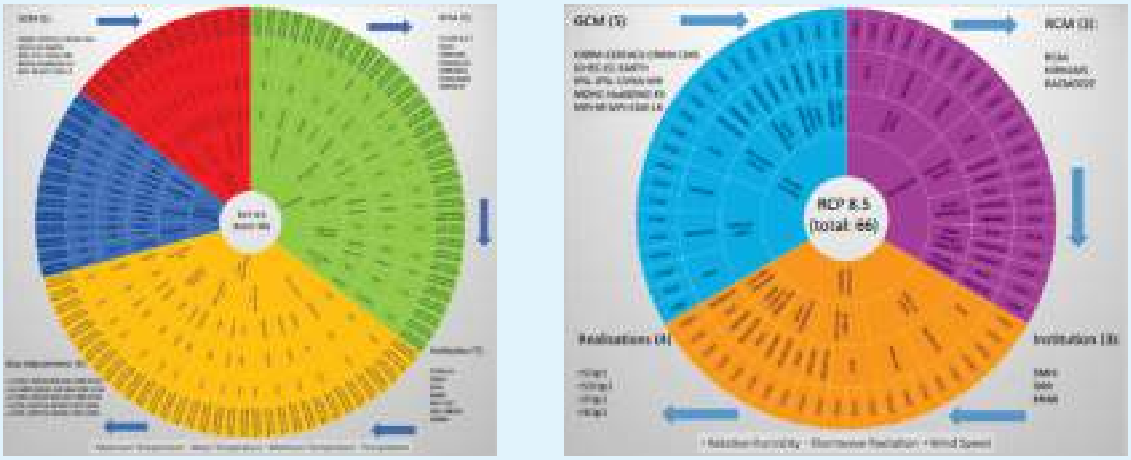


Figure 45: Simulations Prepared for RCP 8.5 for CORDEX-Adjust Output (left) and for Euro-CORDEX Output (right)



Additional climate and vulnerability indicators were estimated from temperature and precipitation variables from the model ensembles: continental climate Ivanov index (especially for the impact assessment on forestry) and the De Martonne aridity index (especially for the impact assessment on agriculture).

To assess the impacts on forests, climate continentality must be taken into account as an additional limiting factor for the growth of this tree species. Climate has been getting less continental, as revealed by comparing the two past climatic periods of 1961-1990 and 1991-2010 (Figure 46). The estimated values of the Ivanov Continentality Index on the territory of

Ukraine, which is calculated as a combination of annual (ATR) and daily (DTR) temperature ranges, varies from 100 to 168. The indicator generally grows in the direction from the northwest to southeast. The lowest values are observed in the Carpathian Mountains area, as well as in the northwest (Volynska oblast, partially adjacent areas), where the values are in the range of 100-120. The highest values of the Continentality index, up to 160-168, are in eastern and southern Ukraine. In some parts of the coast, the values of this index are lower due to the influence of the Black and Azov Seas on ATR and DTR.

Climate continentality[34] will exhibit a more a contrasting pattern in Ukraine in the future especially under the RCP 8.5 scenario. The zone with low values of 120-130 observed in the past only in the northwest is projected to expand towards southeast and cover not only Volynska, but Rivnenska and Lvivska oblasts. At the same time, the continentality index is expected to increase significantly in the south (Khersonska and Zaporizka oblasts, Crimea) and east (Donetska and Luhanska oblasts) of Ukraine, mostly due to rising DTR, especially under the RCP 8.5 scenario.

To assess the impacts on agriculture and forests the De Martonne aridity index (Figure 47) along with additional indicators has been used. The De Martonne aridity index combines annual precipitation total and mean temperature has shown drier conditions in the past for the south, north and some west oblasts and is projected to stay at the same level for all areas and over all projections in Ukraine. It reflects a combination of predicted increasing temperature combined with increased precipitation. This combination explains the impact of climate change on the sectors of the economy, dependent on temperature and water regimes, like agriculture and forestry. For agriculture, the analysis used daily temperature, precipitation, and humidity indicators, as well as solar radiation and surface wind, which have been elaborated under this study. For forestry, climatic indicators based on monthly air temperature and precipitation as well as relative humidity and sunshine duration during certain periods of the year are required including highly important growing season length and its start (end) date for different temperature thresholds. A set of around 70 indicators has been generated.

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[34] Climate continentality is characterized by the average daily temperature range, as well as the annual temperature range. Ivanov Continentality Index is calculated using the following equation:

$$\text{Kn ivanov}= \frac{(R_y + R_d + 0.25D_0)\ *100\%}{0.36\,\varphi + 14}$$

where R_y is the annual air temperature range (°C), that is, the difference between the warmest and coldest months; R_d – mean daily air temperature range (°C), which is the difference between the average maximum and minimum air temperatures for each month that were then averaged for the year; D_0 – average annual deficit of relative humidity, %; 0.36φ– linear dependence of the three aforementioned components on geographical latitude φ,°; 14 – the sum of the components of the numerator at the equator.

Figure 46: The Continental Climate Ivanov Index for Historic Periods (E-OBS) and Ensembles of the RCMs by Periods of the 21st Century

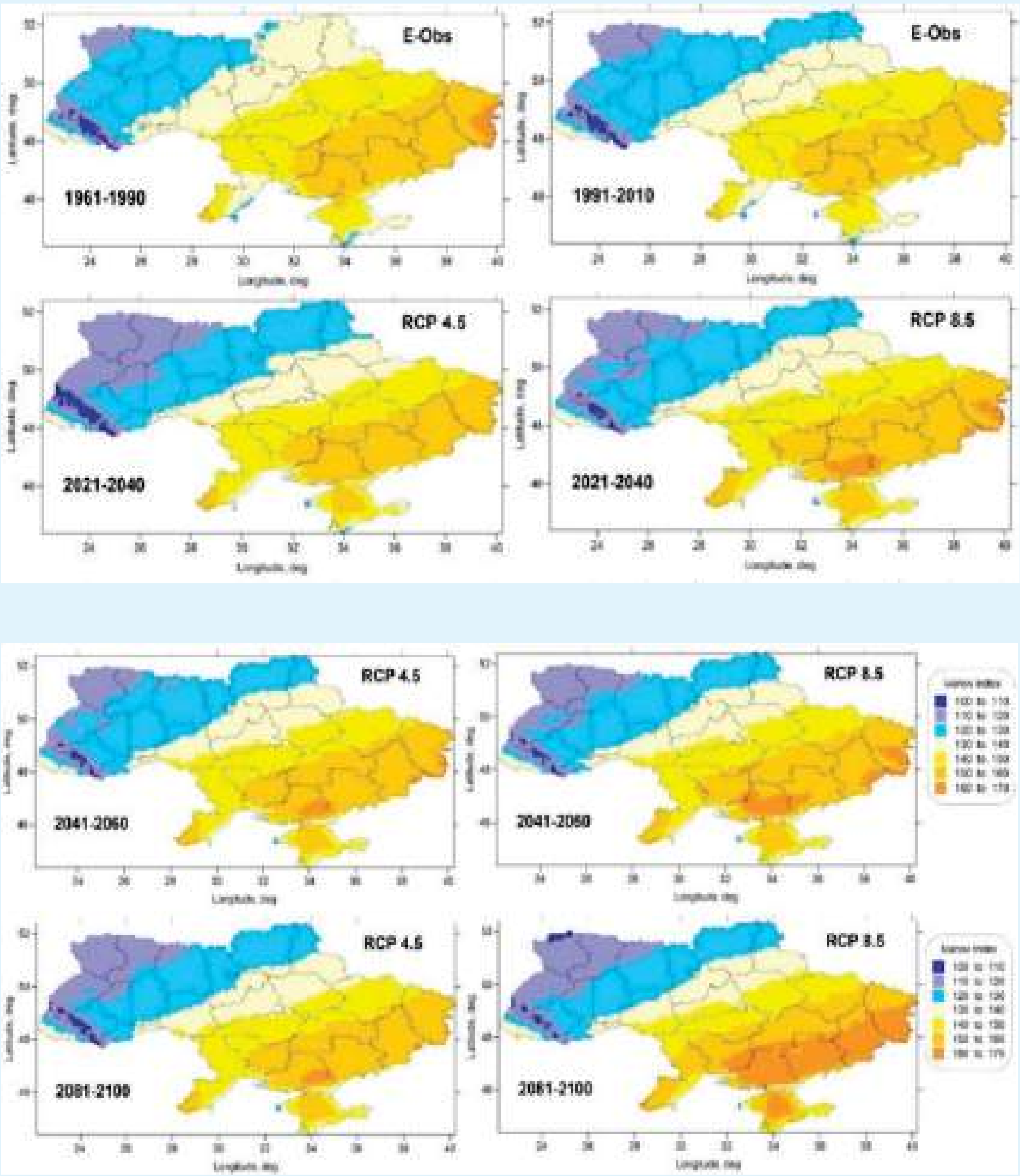
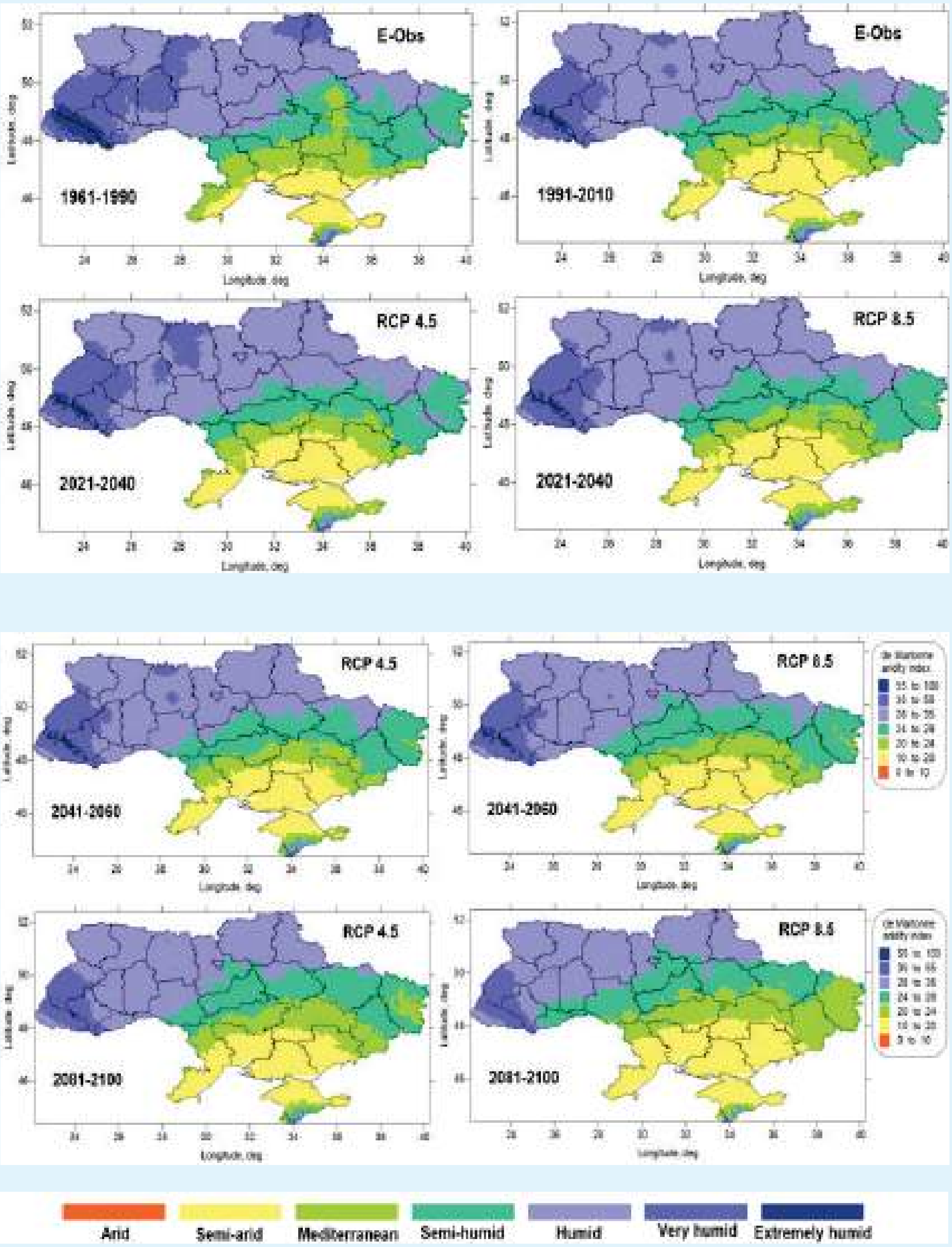


Figure 47: De Martonne Aridity Index



A 1.2 Agricultural Impact Assessment

The agricultural impact assessment provides a comprehensive and granular regional analysis of the future production potential for five crops that collectively accounted for 61%of Ukraine's agricultural production volume in 2018. The objective of the assessment is to estimate the losses and gains in crop yield, production, and production values by Ukrainian oblasts under the RCP 4.5 and RCP 8.5 scenarios in the near future (2030), and the middle of the century (2050), using 2010[35] as the base year. The analysis is conducted in three steps: i) estimation of the changes in yield (tons/ha) for each crop, including uncertainty ranges; ii) estimation of the changes in agricultural production (tons) for each oblast by combining yield simulation results with expected changes in the areas for each crop; and iii) estimation of the changes in the values of production by applying price projections for the crops in 2030 and 2050. The models employed for the analysis include the WOrld FOod STudies (WOFOST) model, which was adapted and calibrated by the Ukrainian Hydro Metrological Institute UHMI, and the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) by the International Food Policy Research Institute (IFPRI). The five crops analyzed are barley, maize, soybean, sunflower, and winter wheat, which in total accounted for 61 percent of production volume in 2018 (FAO 2021b). The analysis was carried out within the 10-year time periods that drive agricultural practices and at a highly granular level, covering more than 7,400 grid cells. Such granular analysis requires an enormous amount of climate data and extensive modelling with a deep understanding of soil conditions and requirements of specific crops.

The simulations built in simplified endogenous adaptation measures to show the benefits of appropriate adaptation actions. By integrating simplified endogenous adaptation measures, such as changes in the allocation of land compared to 2010 in response to changes in relative yields, the simulations allow for a comparison between adaptation and no adaptation. The estimated changes in the agricultural production and production values help show the benefits of adaptation measures in each oblast. The results of this assessment indicate the importance of forming effective adaptation strategies in the agriculture sector of Ukraine.

The assessment of climate change impact on yield and production is conducted using the WOrld FOod STudies (WOFOST) model, which was adapted and calibrated for Ukraine by the Ukrainian Hydro Metrological Institute UHMI. The WOFOST crop simulation model has been one of the key components for monitoring crops and predicting yield in Europe. It is implemented in the Monitoring Agricultural Resources (MARS) system. Originally, WOFOST was developed to simulate crop production potentials in the tropics. However, the biophysical core of the model is generally applicable, and the model can be easily used to estimate annual crops in Europe (De Wit et al. 2019). WOFOST is a mechanistic model with a solid biophysical basis and is widely used to simulate the effects of climate change on the growth, development, and yield of major crops like wheat, maize, barley, soybean, sunflower, and others. It simulates crop growth on the basis of various eco-physiological processes, including phenological development, carbon (CO_2) assimilation (or photosynthesis), transpiration, respiration, assimilate partitioning, and dry matter production with a time step of one day (Van Diepen et al. 1987; de Wit et al. 2019). The model simulates the phenological development from sowing to maturity based on crop genetic properties and environmental conditions. The inputs

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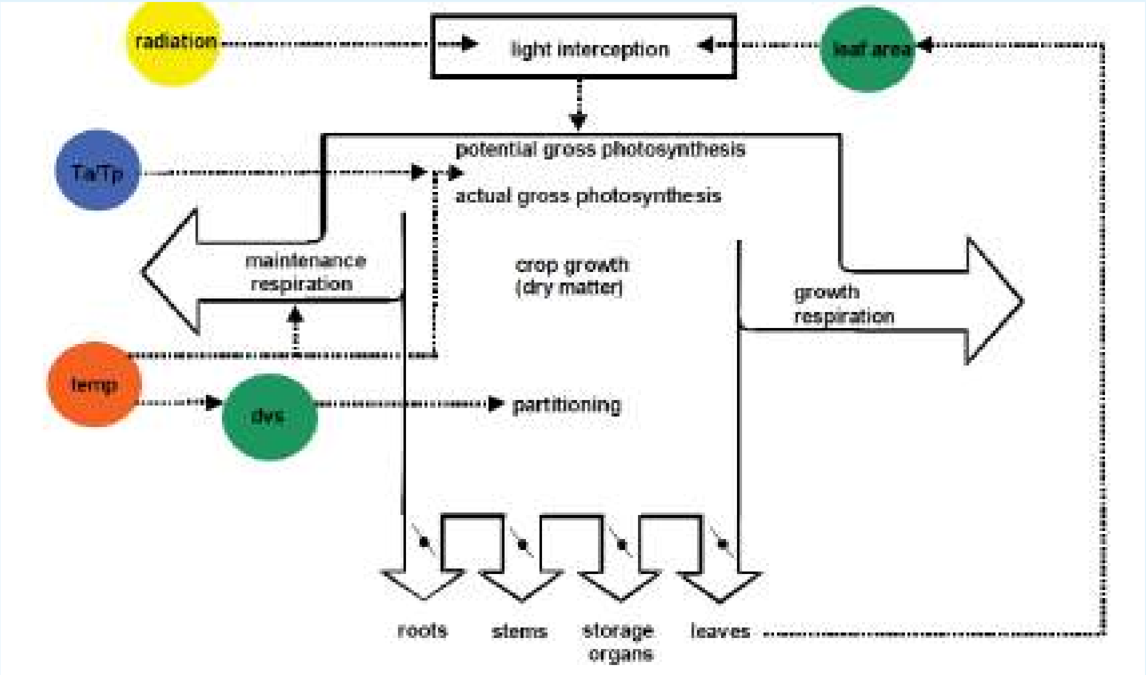
[35] Data is processed for the periods of 2006 – 2015, 2026 – 2035, and 2045 – 2055 with reported central values for 2010, 2030, and 2050, respectively.

required for WOFOST include weather, crop, phenology, and agro-management data. Table 9 gives minimum input weather data required for WOFOST. The adaptation and calibration were conducted through: (i) the generation of a new soil database based on a soil map of Ukraine 1:2,500,000 with spatial resolution 10×10 kilometers (km); the data obtained for 40 soil types were correlated with WRB (World Reference Base for Soil Resources) soil classification and correspondent soil physical characteristics; and (ii) the calibration of phenological coefficients for crops (i.e., sowing date, sum of temperature from sowing to emergence, emergency to anthesis, and anthesis to maturity) based on phenological observations at local agrometeorological stations (Kryvobok 2015, Kryvobok et al. 2018).

Figure 48: Crop Growth Processes in the WOFOST Model



Source: Kropff and van Laar, 1993.

Projected changes in climatic conditions are included in the WOFOST simulations to show the combined effects of changes in atmospheric CO_2 concentration, temperature, precipitation, and other meteorological variables on biomass production. Higher levels of CO_2 significantly increase photosynthesis for wheat, barley, sunflower, and soybean crops (all C3 plant species), but less so for maize crop (C4 plant species), and thus, lead to increases in the generation of total biomasses and yields. This is referred to as the carbon fertilization effect. Temperature can influence biomass production in different ways. Higher temperature has a positive effect on winter crops during cold periods of vegetation and reduces risks of frost damages for spring crops, but shortens crop maturity time (or vegetation stages), which

Table 10: Minimum Input Weather Data Required for WOFOST

Input	Description
Minimum temperature	Minimum temperature
Maximum temperature	Maximum temperature
Sunshine hours	Bright sunshine duration
Calculated radiation	Daily global radiation
Wind speed	Daily mean wind speed at 10 m
Rainfall	Daily rainfall
Vapor pressure	Daily mean vapor pressure

leads to decrease in yields. Higher temperature shifts the sowing, emergence, anthesis, and maturity dates, which can have different effects on biomass and yield production, depending on each crop. An increase or decrease in the annual precipitation totals has different effects on yield production for most parts of Ukraine, but it is more important to estimate its effect in combination with temperature and other meteorological data. For example, the differences between precipitation and evapo-transpiration indicate the arid conditions (low values of soil moisture), which will reduce biomass and yield production. Optimal values of soil moisture depend on crop development stage (DVS); most crops need high values of soil moisture on earlier DVS up to anthesis and low values on later DVS.

Daily meteorological input data for the base year 2010 and 2030 and 2050 projections are generated by 8 RCMs for 7,344 grids. Sowing date, as required phenological information to start the simulation, is estimated as optimal sowing date assuming optimal temperature, precipitation and evapotranspiration conditions for each grid which continued during last 10 days. The simulations are finished when crops reach maturity stage. It should be noted that the assessment methodology cannot directly incorporate climate extremes such as heat and cold waves, drought, windstorms, and river and coastal flooding.

In this study, the WOFOST model simulates two production levels: potential and water-limited. The simulation for potential production is only limited by temperature, day length, solar radiation, atmospheric CO2 concentration, and crop features. This simulation assumes that the soil moisture level is optimal or that water is fully available for crop growth. In the water-limited simulation, water shortage also plays a role in determining the production outcome. Therefore, a soil-water balance is calculated that applies to a freely draining soil, where groundwater is so deep that it does not influence the soil moisture content in the rooting zone. In both the potential and water-limited simulations, an optimal supply of nutrients is assumed, and the damages caused by pests, diseases, weeds and/or extreme severe weather events (i.e., flooding, hail, strong wind, etc.) are not considered. So, to make the simulations as realistic as possible, we define special coefficients between the actual yields, obtained from official statistics, and simulated yields at the oblast level for base year, and then use them for the 2030 and 2050 two projections. The outputs of WOFOST simulations include crop indicators (i.e., biomass-potential productivity level, storage organs biomass-potential productivity level, total biomass-water limited productivity level, and storage organs biomass-water limited productivity level), potential leaf area index, water-limited leaf area index, soil moisture, development stage, main phrenological dates (i.e., sowing, emergence, anthesis and maturity), and total water requirement.

The yield projections from the WOFOST model have been aggregated to provide estimates at the oblast level. The modeled yields for each grid point on the map of Ukraine show an overall potential based on the conditions projected by the climate model. The final yield level for each oblast is estimated as mean value of all grids within the corresponding oblast. Such aggregation of data, while reducing detailed spatial variability, allows policymakers to examine the significant differences among the administrative regions in Ukraine regarding climate change impacts on agriculture, and facilitate decision-making and planning accordingly.

These confidence intervals have been estimated as follows:

$$\text{Confidence interval} = \bar{y} \pm z * \frac{\sigma}{\sqrt{n}}$$

where $\bar{\mathbf{y}}$ is the mean simulated yield for each region for time periods: 2006 – 2015, 2026 – 2035, and 2045 – 2055, with reported central values for 2010, 2030, and 2050); **z** is the confidence (95%); **σ** is the standard deviation between actual and simulated yield for 2006-2015. Assuming relative error for 2026-2035 and 2045-2055 periods is the same as for 2006-2015, we can estimate **σ** for each period; and **n** is the sample size| (10 years).

Variability and uncertainty in the projections of the future yields and production levels in the face of expected climate changes is reflected in the low, mean, and high projections for each RCP scenario. Like the climate models, the agricultural model also undergoes an intensive process of “bias correction”, where it is trained to simulate observational processes. However, uncertainties in the agricultural analysis persists. This is due to the fact that the projected climate variables from the 8 GCM-RCM ensemble are used as meteorological inputs for the WOFOST model. As such, crop yield projections also have an uncertain range stemming from the uncertainties associated with climate projections. The uncertainty range (+/- values) in agricultural modeling results in three sets of projections: low, mean, and high under each RCP. Thus, the results should not be interpreted as forecasts. Considering all three sets of projections is a justified and recommended approach (Herger at al. 2015). The mean projection represents the mean value of the modeled yield potential (or crop productivity) within each oblast. Low and high projections are the lower (5th percentile) and upper (95th percentile) limits[36] of the modeled yield potential, as determined by the confidence interval. The larger is

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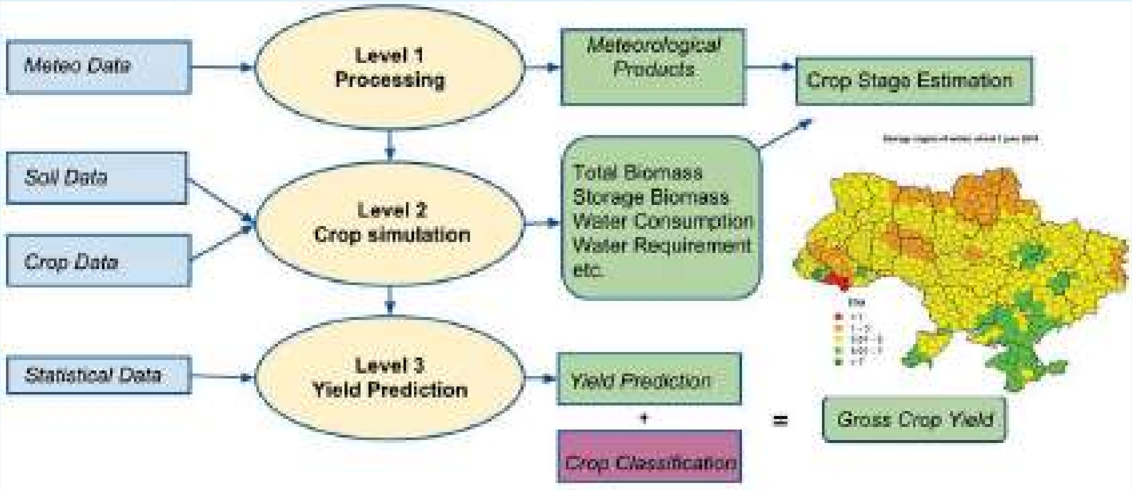
[36] 0-5th and 95-100th percentile ranges are defined as “low likelihood, high impact” outcomes.

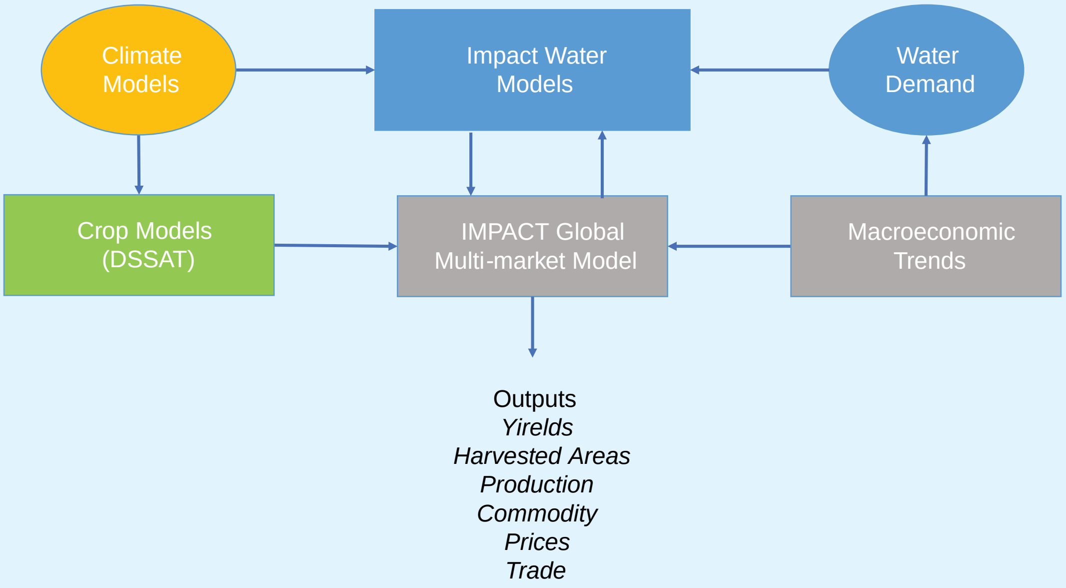
Figure 49: Simulation Model (WOFOST) for Crop Yield Assessment



the difference between the low and high projections, the larger is the uncertainty range. Such range highlights the uncertainty associated with the variations in local soil and climatic conditions, which could influence yield potentials and production outputs, within an oblast territory.

The projected changes in production and production values are calculated using the estimated changes in land areas under each crop and crop prices in 2030 and 2050 from the IFPRI IMPACT model. Changes in production are estimated by multiplying the changes in the land area under each crop (ha) by the projected yields (tons/ha). The change in land areas are calculated from the IMPACT model, based on the Shared Socioeconomic Pathways 2 (SSP2) GDP and Population Trends. Data on cropland areas in 2010 (both irrigated and rainfed) by oblast and by type of grain was used as the base. Finally, the changes in production values are estimated by multiplying the change in total production by the changes in crop prices. The IMPACT model uses IPSL Climate Models and Global Environmental Multiscale Models to estimate the future changes in crop prices. The IMPACT model gives prices of four grains (maize, barley, wheat, and soybean) for 2010, 2030 and 2050 under two sets of scenarios: SSP2 RCP 8.5 IPSL and SSP2 RCP 8.5 HGEM. The mean value of these two scenarios has been used to obtain a single projection under RCP 8.5. Price changes for the RCP 4.5 scenario are not available. For sunflower, the 2010 price was taken from the FAO Producer Prices Stats , as the IMPACT model data does not include sunflower seed prices. The ratio of price changes for maize in 2030 and 2050 from IMPACT is then used to get the 2030 and 2050 prices of sunflower.

Figure 50: The IMPACT Model System by IFPRI



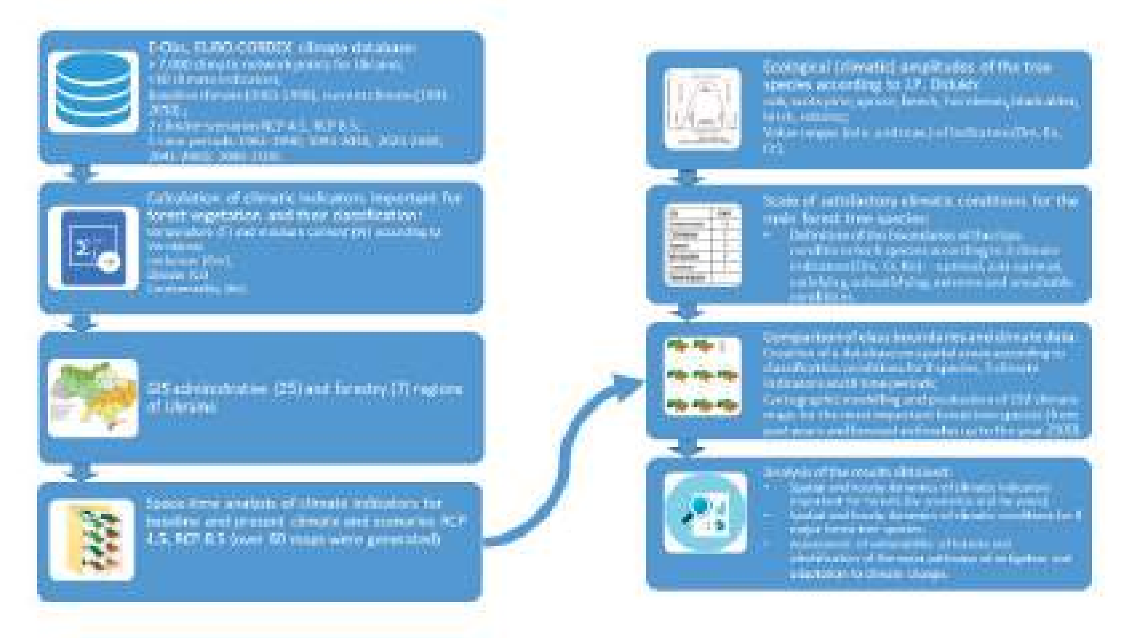
IMPACT is a network of linked economic, climate, water, and crop models. The core of IMPACT is a partial equilibrium multi-market economic model that simulates national and global markets for agricultural commodities and includes 159 countries. The core model is linked to modular models (i.e., climate, water, crop simulation, land use change, value chain, and others) in a consistent equilibrium framework that supports longer-term scenario analysis. Some of the model communication is linear while some captures feedback loops. Agricultural production is specified by models of land supply, allocation of land to irrigated and rain-fed crops, and determination of yields. Production is modelled at a sub-national level, including 320 regions called food production units (FPUs). FPUs are linked to the water models and correspond to 154 water basins. Figure 10 shows the links between the various models. The links to water and crop models support the integrated analysis of changing environmental, biophysical, and socioeconomic trends, allowing for in-depth analysis on a variety of critical issues of interest to policymakers at national, regional, and global levels.

The core model of IMPACT simulates the production, trade, demand, and pricing for 62 agricultural commodities across the globe, representing the bulk of food and cash crops. The model specifies supply and demand behavior in all markets. Currently in IMPACT, there are three main types of commodities (i.e., crops, livestock, and processed goods). Crop production in IMPACT is simulated through area and yield response functions and is specified sub-nationally at the level of FPUs. This regional disaggregation permits linking with water models and provides the added benefit of smaller geographical units for aggregating climate change impacts, which can vary significantly from one location to another. Land used for crop production is divided into irrigated and rain-fed systems, capturing the significant differences in yields observed across these cultivation systems and linking directly with the water models, which treat irrigated and rain-fed water supplies separately. The system solves for prices, allocations of land, and outputs of different agricultural outputs simultaneously, with changes in the allocations of land depending on changes in yields of crops and the prices of the crops.

A 1.3 Forestry Impact Assessment

The assessment of climate change impacts on Ukrainian forests is conducted for the main forest-species, using Vorobjov's climate-related forestry typology model and Didukh's model of suitable environmental condition for plants. Assessing the potential impacts of climate change on forests needs to consider general trends in climate variables, short-term climate variability, and the interactions with biotic and abiotic disturbances (Lindner M. et al. 2010). The analysis is carried out at two levels: i) assessment of changes in core climatic indexes that are important for forests based on Prof. D. Vorobjov's climate-related *forestry typology classification model*; and ii) assessment of the favorable climatic conditions for eight main forest-forming tree species based on the scales of *ecological amplitudes* for natural flora of Ukraine by Prof. Ya. Didukh. The main tree species that form most of the forest stands in Ukraine include Scots pine (*Pinus sylvestris L.*), common oak (*Quercus robur L.*), beech (*Fagus sylvatica L.*), spruce (*Picea abies (L.) H.Karst.*), birch (*Betula pendula Roth.*), black alder (*Alnus glutinosa (L.) Gaertn.*), hornbeam (*Carpinus betulus L.*) and robinia (*Robinia pseudoacacia L.*). These tree species are prominent in more than 86 percent of the forest areas[37] in Ukraine and constitute coniferous forests (43 percent, of which 35 percent is pine) and hardwood plantations (43 percent, of which 37 percent are oak and beech). An illustration of the step-by-step process of assessing forest vulnerability to climate change is shown in Figure 51.

Figure 51: Workflow for Forests Vulnerability Assessment to Climate Change



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[37] Lands covered in forest vegetation.

The climate-related forest typology classification model of Vorobjov's is based on the close connections between forest typologies and climatic conditions (Vorobjov 1961). Specifically, the forest plot types under homogeneous parent materials and landforms are defined by the impacts of humidity and heat. The formation of forest types and boundaries of individual forest plots are tied to climate continentality. Additionally, within the limits of an individual forest type, the productivity of forest stands is directly connected to the level of heat. Thus, three climate indexes with the most significant effects on forest growth, condition, productivity, and biodiversity are employed to assess the suitability of future climatic conditions for Ukrainian forests. These include humidity (Ombro-regime), continentality, and frostiness (Cryo-regime)

The climate humidity index, or Ombro-regime (Om) is one of the most important environmental factors, reflecting the aridity / humidity of climate. This index characterizes air humidity associated with precipitation, evaporation and transpiration, soil moisture, and groundwater level, etc. The Om index integrates the effects of precipitation and thermal resources of a given area and is defined as the difference between annual precipitation (W) and evaporation (E_0):

$$O_m = W - E_0 \text{ (mm)}$$

Evaporation is the potential evaporation from the surface, which has unlimited reserves of moisture. Among the methods suggested for calculating E_0, the method developed by Kolomyts (2010) seems most reasonable for the parts of the country where forests are concentrated–specifically, mixed forests, forest steppe, and Carpathian zones:

$$E_0 = 1384 - 161{,}6 * t_{max} + 6{,}245 * t^2_{max} ,$$

where $\mathbf{t_{max}}$ is the long-term average air temperature of the warmest month of the year. The method by Kolomyts reflects well the impacts of extreme events (i.e., droughts) on forest species.

The Continentality of climate (Kn) is among several indexes of climate continentality. The formula suggested by Ivanov (1959) seems most appropriate for territories of Ukraine:

$$Kn = \frac{(Ap + Ad + 0.25D0) * 100\%}{0.36\ \varphi + 14}$$

where $\mathbf{A_p}$ is the yearly amplitude of air temperature (the difference between the warmest and coldest months) in ^{0}C; $\mathbf{A_d}$ is daily air temperature (annual average), defined as difference between average maximal and minimal temperature in ^{0}C; $\mathbf{D_0}$ is the average annual deficit of relative air humidity in %; $\mathbf{0.36\varphi}$ is the linear dependence of all three components of geographical latitude φ in degrees; and **14** is the sum of components of the numerator at the equator.

Based on the three indexes Ombro-regime (Om), Continentality (Kn) and Cryo-regime (Cr), 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 (2011, 2012). The critical limits refer to the thresholds, above or below which the organisms cannot survive (Didukh 2012). The ecological amplitude are the boundaries of the environmental conditions within which an organism can live and function. Understanding such amplitudes of the eight main forest-forming tree species is essential in diagnosing the conditions of their ecotopes and forecasting the development of their populations and phytocoenoses. The amplitudes of forest species in terms of both edaphic and climatic factors are significantly narrower compared to those of other ecological communities (i.e., meadows, steppe, wetlands). The state of tree species under study and characteristics of forest stands, the ability to form stable forest cenosis, and the ability to provide ecosystem services vary with the gradients of the ecological amplitude. The center of the ecological amplitude is where the conditions for growth are optimal. The conditions become less optimal further from the center. The ecological optimum can be assessed using plant parameters such as vitality, productivity, yield, biomass, height, diameter, density, abundance, leaf area index, canopy close, or projective cover for grasses, etc.

Based on the Om, Kn and Cr indexes, the degree to which the projected climatic conditions support healthy and productive growth of the main forest-forming species in Ukraine is determined using the scale of optimal environmental conditions developed by Bondaruk and Tselischev (2015):

- **Optimal** (combined index scores of 91-100/100): conditions are optimal for the species (i.e., high viability of the species population with maximum productivity values with class I forest land fertility index (*bonitet*) and others).
- **Suboptimal** (71-90/100):conditions are close to optimal for the species (i.e., a certain decrease in productivity to class I-II *bonitet* with a sufficiently high viability).
- **Satisfactory** (51-70/100): conditions are satisfactory for the species (i.e., decrease in productivity (i.e., phyto-mass, stock, growth, etc.) of the species to class II-III *bonitet*).
- **Unsatisfactory** (21-50/100): conditions are not satisfactory for the species (i.e., reduction of productivity to class III and sometimes class III-IV *bonitet*, deterioration of stand sanitary conditions, and reduced competitiveness).
- **Extremely unsatisfactory** (1-20/100): conditions are extremely for the species unsatisfactory (i.e., significant decrease in productivity to class III-IV and sometimes class IV-V *bonitet*, further deterioration of stand sanitation conditions, disruptions to the cycle of phenological development, gradual decrease of natural recovery, weak resistance to pests and diseases, and reduced competitiveness).
- **Conditionally unsuitable** (up to 1%): conditions are disruptive for the species (i.e., population regression, loss of productivity (class IV-V *bonitet*), unsatisfactory stand sanitary conditions, damages due to pests and diseases, loss of reproductive capacity, disruptions to the cycle of ontogenesis, and loss of cenosis-forming function).

Key climate variables and the average values for Vorobjov’s indexes under RCP 4.5 and RCP 8.5 were calculated for each of the approximately 7,400 grid cells for the base period 1961-1990, the recent period 1991-2010, 2021-2040 (to allow a range value for the year 2030), 2041-2060 (to allow a range value for the year 2050), and 2061-2100 (to allow a range value for the year 2080). As the life cycle of forest development extends over very long periods of time, we use 1961-1990 as the base period. Additionally, a significant part of the existing forests in Ukraine was formed during the recent period 1991-2010, thus we include this period in the analysis to allow for sufficient comparisons. The analysis examined areas of suitable climatic conditions for eight main forest-forming species based on Vorobjov's indexes (Om, Kn, and Cr) for all administrative and forestry regions of Ukraine. The open-source Geographic Information System (Q-GIS) was used to perform spatial analysis and visualize the results.

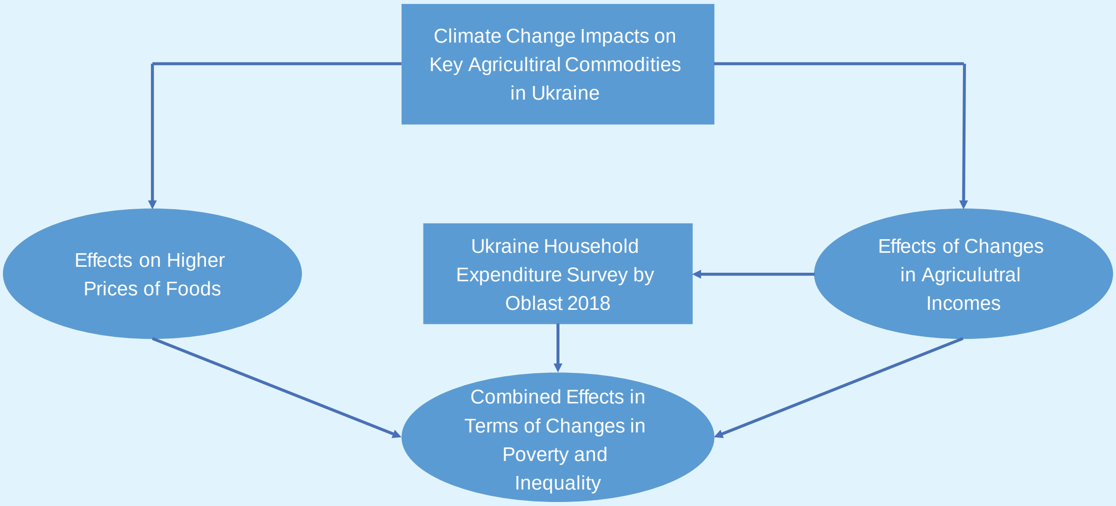
A 1.4 Distributional Analysis

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 provides two key outputs: i) increases in the prices of key food products due to climate change and estimates of price increases for 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.

Like the agricultural impact assessment, the analysis of income considers three sets of projections: low, mean, and high. They reflect the uncertainty range in the results of the WOFOST model simulations for changes in yields, production, and production values for the selected crops (i.e., barley, wheat, maize, sunflower and soybean) under RCP 4.5 and 8.5 in 2030 and 2050, relative to 2010. Such a range reflects a distribution of likely outcomes. The low and high projections 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. The analysis is limited to 2030 because by 2050, the baseline expenditure data cannot be considered a reasonable point of comparison.

The analysis is based on comprehensive data collected for 250 to 500 individual households for each oblast, which allows for identification of variations in income distribution due to climate-induced changes in the agricultural sector. The modeled climate impacts data is combined with Ukrainian Household Expenditure Survey (HES) data for the latest available year (2018) to examine the effects on households at different levels of income. The changes in values of different commodities (which may be negative or positive, depending on the scenario) in turn affect the income of households to the extent they derive their incomes from the production of these commodities. The HES provides details of expenditure by commodity and the amount of income from the sale of agricultural products for each household in each oblast. Data are anonymized, with between 250 and 500 individual households for each oblast. This enables an estimation of the real expenditure needed to make up for the increase in prices, as well as the actual changes in real income due to the change in revenues from agricultural products. The two sets of data at the household level can be used to assess how the distribution of income is affected by climate change impacts on the agricultural sector.

Figure 52: Distributional Analysis Workflow



A 1.5 Identification of "hotspot" oblasts

Using the results from climate impacts on agriculture, "hotspot" oblasts are grouped based on several factors. These factors include: 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.

Table 11: Criteria Used in the Integrated Assessment Tables

Criteria	
Change in climate types	Indicates the emergence of new climate types or continuous expansion of arid areas. Reflects the combined effects of changes in annual precipitation and temperatures. The de Martonne aridity index and its classification of climate types is widely used to describe these joint changes. (See Figure 7).
Impact of climate extremes	Reveals the increased likelihood of extreme weather events until the end of the century. This criterion is based on the estimated changes in two climate indicators: number of frost and tropical nights per year for every location in Ukraine. (See Figures 14 and 15 in Chapter 2).

Criteria	
Value of agriculture	Changes in the value of agricultural production stemming from changes in crop yields, which are sensitive to the main climate indicators such as temperature, precipitation, and seasonal shifts. The value of agricultural production explains changes in the incomes of households in the agricultural sector. This parameter is estimated for the selected crops. For 2030, values are given as the cumulative effect of value changes from the low, mean, and high projections, assuming no adaptation measures in place. For 2050, values are given for two estimations: with adaptation and without the adaptation. There are two adaptation measures incorporated in the model-based analysis: an endogenous optimal choice of seeding dates for each crop and optimal adjustments of the land allocated to each crop type in response to the changing climatic conditions.
Availability of irrigation infrastructure	One of the key adaptation measures for reducing adverse climate change impacts on agricultural production. The assessment shows that the availability of water is crucial for minimizing the adverse impacts of climate change, especially in the central and northwestern parts of Ukraine. This factor should be considered for the evaluation of future adaptation measures.
Income loss	Describes changes in household incomes as the results of the changes in food prices and the value of agricultural production. These changes are driven by the variability in the climate indicators. Is based on the comprehensive data collected for 250 to 500 individual households for each oblast. Data is used to identify variations in income distribution among households at different levels of income due to climate change-induced changes in the agricultural sector.
Poverty headcount	Describes the deviation of a household's income from the subsistence level. The percentage of all households below the subsistence income level (household equivalent).
Inequality measure – changes in the Gini coefficient	Describes the deviation of the observed income distribution from the theoretic level of equal distribution of income. The Gini coefficient measures the extent to which the distribution of income (or, in some cases, consumption expenditure) among individuals or households within an economy deviates from a perfectly equal distribution. The Gini index measures the difference between the hypothetical line of absolute equality and the actual distribution of the cumulative income over the cumulative number of households receiving the income. A Gini index of 0 represents perfect equality, while an index of 1 implies perfect inequality.

Table 12: Integrated Criteria Assessment of Oblasts with the Highest Share of Agriculture in Their GDP in the Near Future

	Climate type (temperature and precipitation) 2021-2040 the area under this climate type is rising ▲or decreasing ▼	**Value of agriculture** 2021-2040 change % to base	**Potential risk reduction via irrigation** low or high potential	**Loss in the households' income** 2021-2040 change % to base	**Poverty Headcount** base%+change % to base	**Impact on inequality Gini coefficient** 2021-2040 base % / change % to base	
Kirovohradska	Semi-humid and Mediterranean	-25 %	high	-2.0%	17%+2%	0.31	0.5%
Vinnytska	Humid and semi-humid	-28%	high	-1.8%	11%+0.9%	0.33	1.4%
Cherkasska	Humid and semi-humid ▲	-32 %	high	-1.7%	15%+1.6%	0.31	0.6%
Poltavska	Humid and semi-humid ▲	-32 %	high	-2.1%	16%+0.7%	0.35	0.8%
Khersonska	Semi-arid	-25%	low	-1.6%	24%+15 %	0.31	0.3%

ANNEX 2.
PROJECTED SEASONAL CHANGES

Figure 53: Changes in Warm-Season Length in the Recent Period 1991-2010 (E-Obs), Near-Future (RCP 8.5) and the End of the Century (RCP 4.5 and RCP 8.5)

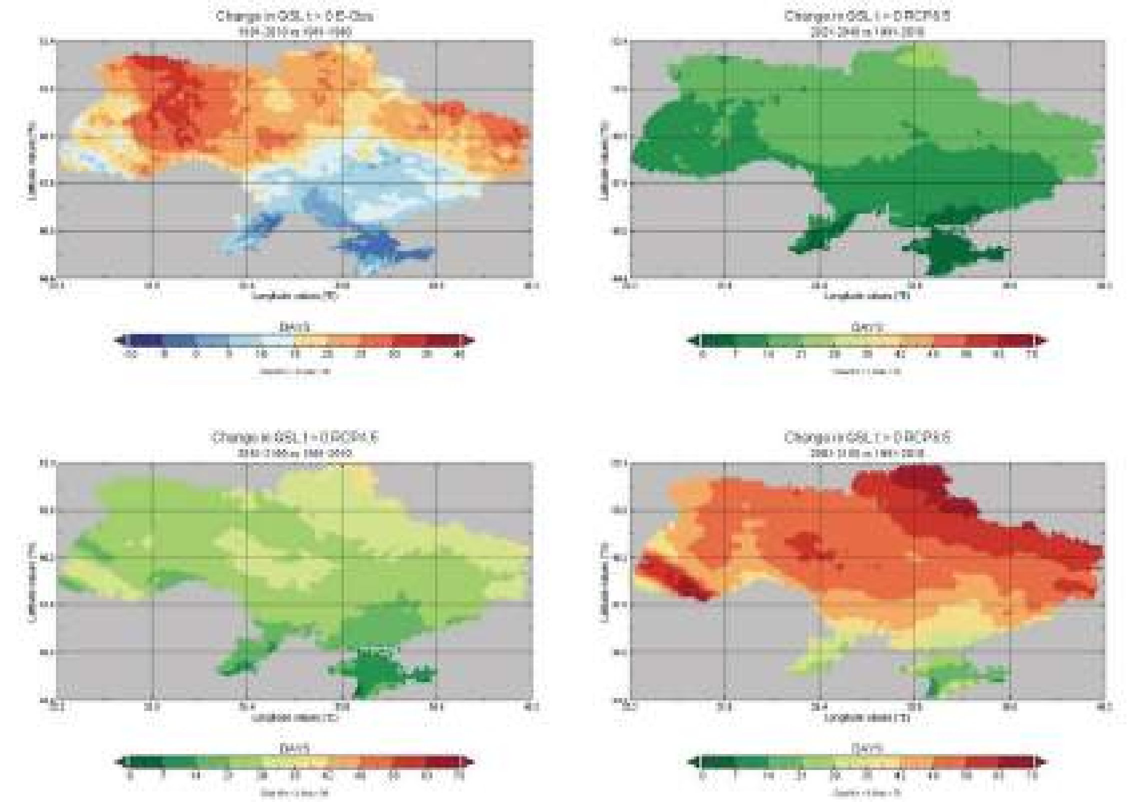


Figure 54: Changes in Growing Season Length in the Recent Period 1991-2010 (E-Obs), Near-Future (RCP 8.5) and the End of the Century (RCP4.5 and RCP 8.5)

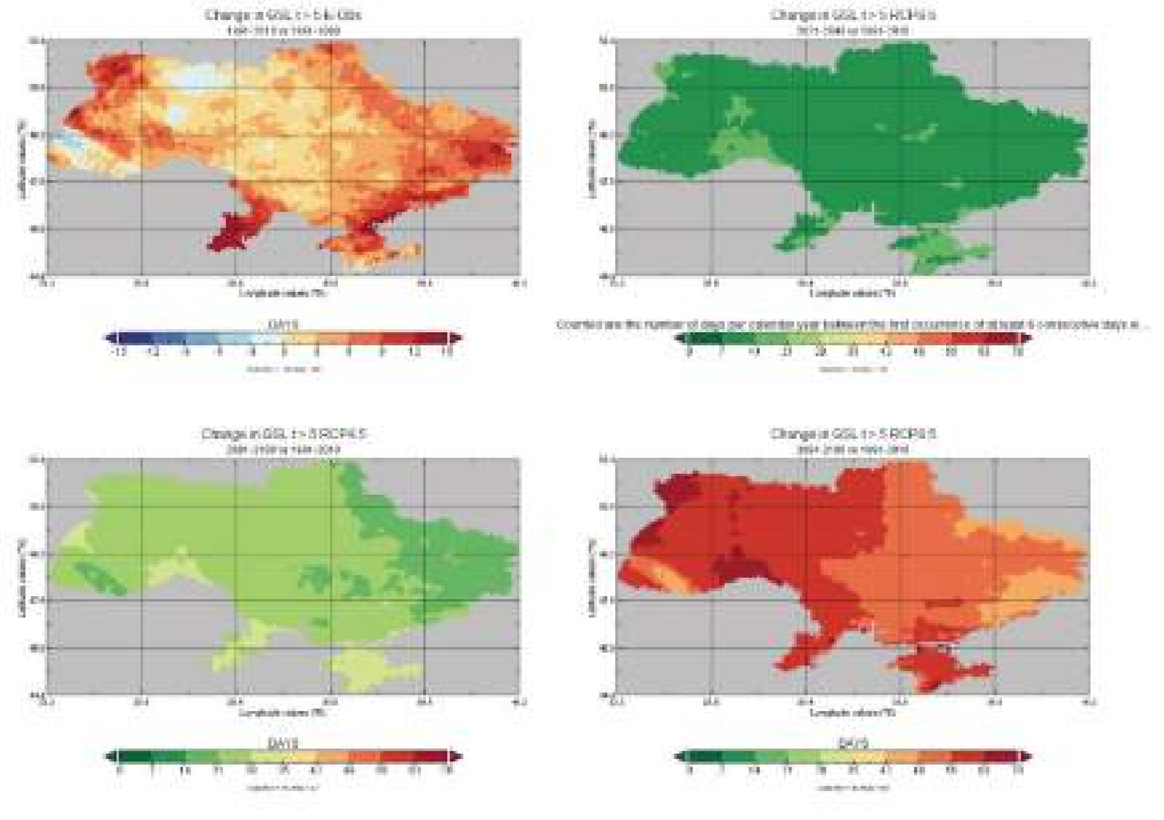


Figure 55: Changes in the Active-Vegetation Season Length in the Recent Period 1991-2010 (E-Obs), Near-Future (RCP8.5) and the End of the Century (RCP4.5 and RC8.5)

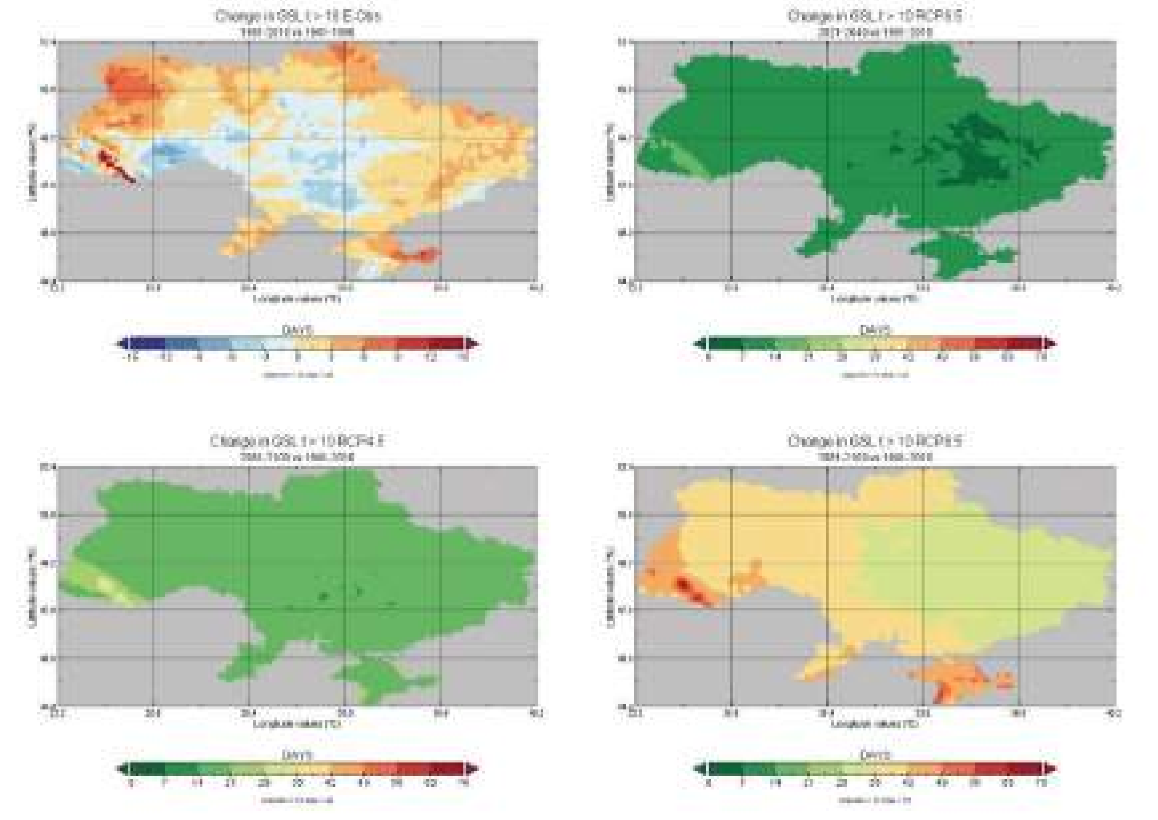
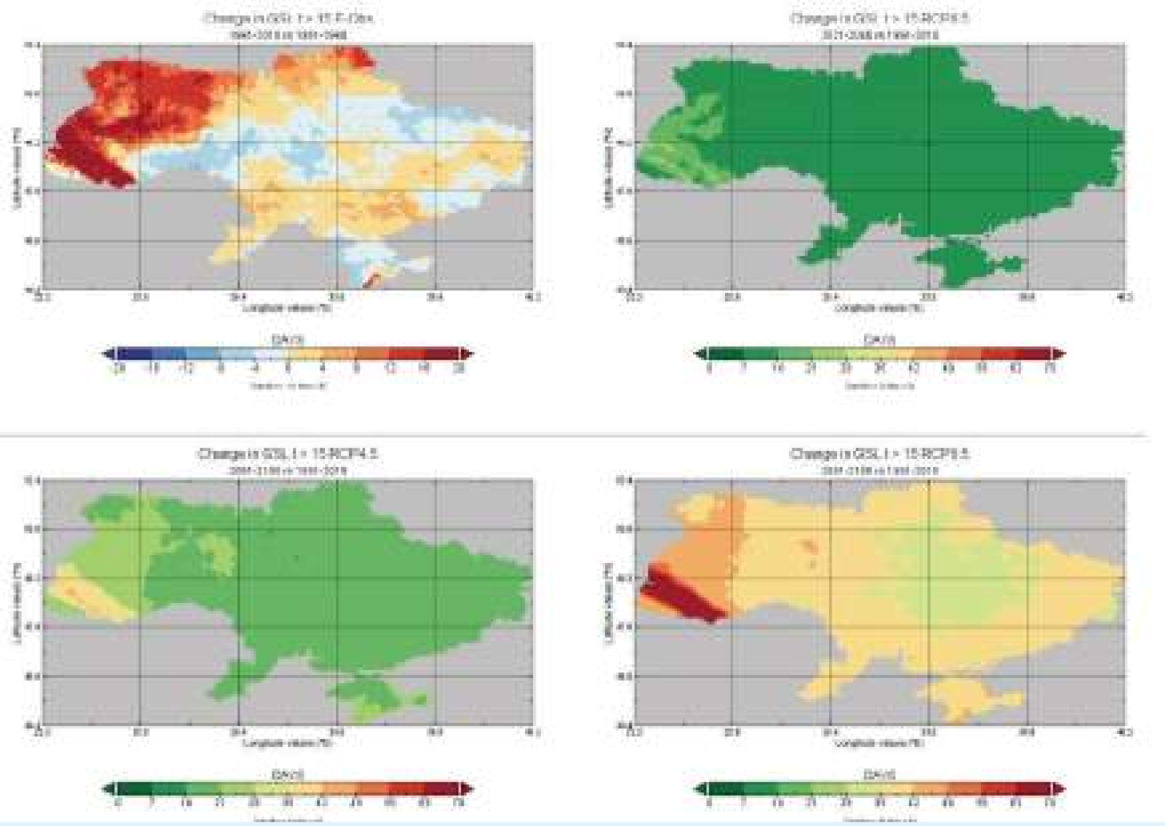


Figure 56: Changes in the Summer Season Length in the Recent Period 1991-2010 (E-Obs), Near-Future (RCP8.5) and the End of the Century (RCP4.5 and RC8.5)



ANNEX 3.
DATA FOR AGRICULTURAL ASSESSMENT & DISTRIBUTIONAL ANALYSIS

Table 13: Weight of Agriculture in Relation to GDP (US Dollars) in 2010, per Oblast[38]

Oblast	GDP	Agricultural value	Weight (%)
Cherkaska	2,857,808,904	592,117,263.27	20.72%
Chernihivska	2,106,574,368	232,681,729.88	11.05%
Chernivetska	1,114,455,551	100,749,797.76	9.04%
Crime	4,101,072,695	296,416,732.28	7.23%
Dnipropetrovska	13,812,309,960	651,102,780.98	4.71%
Donetska	16,436,244,077	435,703,123.88	2.65%
Ivano-Frankivska	2,227,200,337	74,471,167.23	3.34%
Kharkivska	8,067,363,553	533,231,318.82	6.61%
Khemelnytska	2,214,641,971	380,806,627.01	17.19%
Khersonska	1,913,487,374	411,870,822.94	21.52%
Kyivska	25,397,707,265	448,587,023.80	1.77%
Kirovohradska	2,051,491,271	600,015,846.79	29.25%
Luhanska	5,996,086,314	298,154,852.75	4.97%
Lvivska	4,945,012,214	153,535,047.47	3.10%
Mykolaivska	2,887,855,492	355,172,783.72	12.30%
Odeska	6,205,995,595	578,678,861.43	9.32%
Poltavska	5,238,799,486	657,352,685.33	12.55%

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[38] The five types of crops have been incorporated in an aggregate form.

Oblast	GDP	Agricultural value	Weight (%)
Rivnenska	1,804,097,884	148,288,560.15	8.22%
Sumska	2,284,746,506	364,953,365.43	15.97%
Ternopilska	1,447,096,233	228,236,810.39	15.77%
Vinnytska	2,862,959,797	671,406,894.97	23.45%
Volynska	1,612,504,839	120,898,988.46	7.50%
Zakarpatska	1,757,683,060	52,990,606.28	3.01%
Zaporizka	5,431,881,552	477,918,964.09	8.80%
Zhytomyrska	2,266,873,098	164,100,290.30	7.24%

Figure 57: Increase in Expenditure Needed to Keep Wellbeing Constant with Food Price Increases

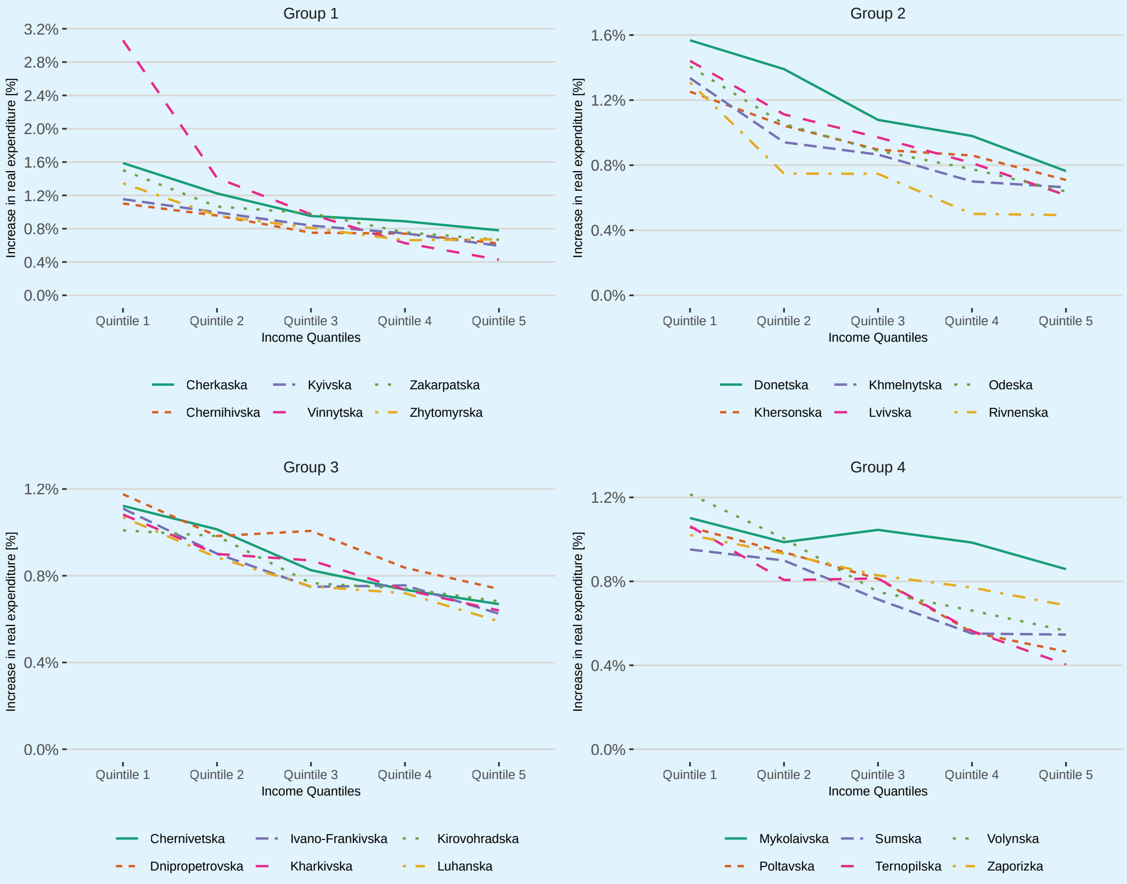

Table 14: Agricultural Production by Type of Unit in Ukraine, 2019

				Production in Tons				
Unit	**Number of Units**	**Area (Ha)**	**Ave. Size (Ha)**	**Wheat**	**Maize**	**Barley**	**Sunflower**	**Soya**
Personal Peasant Households	3,975,100	6,133,600	1.5	8,060	13,631	3,258	3,373	1,096
Personal peasant households as % of total production:				28%	38%	37%	22%	30%
Farm Companies	38,268	15,877,235	414.9	20,268	22,249	5,659	11,881	2,603
Agro Holdings	38,428	27,841,691	724.5					
Total		49,852,526		28,328	35,880	8,917	15,254	3,699
			% of total production:	31%	39%	10%	17%	4%

Sources: https://feodal.online/, *Ukrainian Statistics 2021.*

Table 15: Percent Changes in Value of Selected Crops[39] in Ukraine, 2010-2030

Oblast	**2010 Mn Hrv.**	**Percent Change to 2030**		
		Low	**Medium**	**High**
Cherkaska	530.59	-32.09%	15.92%	63.94%
Chernihivska	228.53	-37.92%	35.41%	108.75%
Chernivetska	97.41	-47.37%	14.28%	75.94%
Crimea	287.99	-42.12%	43.37%	128.86%
Dnipropetrovska	547.83	-19.65%	36.05%	91.75%
Donetska	349.58	-12.30%	41.25%	94.81%
Ivano-Frankivska	72.77	-39.49%	22.41%	84.32%
Kharkivska	446.91	-28.93%	27.95%	84.83%

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[39] Selected crops include barley, wheat, maize, sunflower, and soybean.

Oblast	2010 Mn Hrv.	Percent Change to 2030		
		Low	Medium	High
Khemelnytska	377.89	-37.25%	15.97%	69.19%
Khersonska	384.58	-25.42%	32.79%	91.06%
Kyivska	435.98	-40.36%	11.92%	64.20%
Kirovohradska	515.89	-24.86%	27.47%	79.81%
Luhanska	241.56	-24.52%	41.00%	106.52%
Lvivska	152.28	-34.41%	23.18%	80.78%
Mykolaivska	286.92	-7.86%	43.74%	95.35%
Odesska	510.87	-18.79%	38.43%	95.64%
Poltavska	588.95	-32.67%	19.17%	71.02%
Rivnenska	150.02	-42.46%	12.46%	67.38%
Sumska	349.25	-42.42%	21.00%	84.43%
Ternopilska	227.11	-32.51%	19.52%	71.55%
Vinnytska	648.93	-28.98%	16.89%	62.76%
Volynska	120.67	-36.58%	28.05%	92.69%
Zakarpatska	49.94	-41.56%	27.04%	95.65%
Zaporizka	398.1	-20.41%	39.95%	100.32%
Zhytomyrska	160.66	-48.20%	8.34%	64.88%

Source: World Bank staff calculations

Table 16: Poverty Consequences of Agricultural Impacts of Climate Change (Only Price Effects Considered) RCP 8.5, 2030

Oblast	Poverty Headcount		Poverty Gap		Severity of Poverty	
	Base %	Change %	Base %	Change %	Base %	Change %
Cherkaska	14.85%	1.06%	15.2%	0.34%	4.0%	0.22%
Chernihivska	16.48%	0.38%	22.5%	0.40%	8.9%	-0.88%
Chernivetska	18.18%	0.96%	15.6%	0.17%	3.9%	0.08%
Dnipropetrovska	15.07%	0.24%	20.3%	0.63%	6.4%	0.28%
Donetska	21.18%	1.47%	19.2%	-0.02%	5.5%	0.08%
Ivano-Frankivska	9.65%	0.00%	13.13%	1.93%	3.1%	0.47%
Kharkivska	23.17%	1.17%	19.9%	-0.14%	5.9%	0.01%
Khemelnytska	20.75%	0.00%	20.8%	1.00%	6.4%	0.44%
Khersonska	24.17%	0.76%	17.5%	0.44%	5.8%	-0.78%
Kyivska	15.61%	1.12%	14.9%	-0.39%	3.7%	-0.24%
Kyiv City	10.74%	0.31%	19.4%	0.94%	6.7%	0.38%
Kirovohradska	16.86%	0.38%	21.5%	-0.57%	7.2%	0.11%
Luhanska	15.18%	1.56%	16.5%	-0.64%	4.5%	-0.14%
Lvivska	12.14%	1.43%	20.8%	-0.98%	6.1%	-0.17%
Mykolaivska	17.11%	1.07%	14.9%	0.03%	3.4%	0.05%
Odeska	18.79%	1.45%	15.5%	0.02%	3.9%	0.07%
Poltavska	15.55%	0.00%	15.2%	0.95%	3.8%	0.28%
Rivnenska	17.99%	0.36%	18.1%	1.49%	5.1%	1.15%
Sumska	15.27%	0.30%	14.1%	0.57%	3.7%	0.14%
Ternopilska	16.36%	0.91%	17.0%	-0.05%	4.8%	0.03%
Vinnytska	11.21%	0.00%	23.0%	0.99%	8.3%	1.29%
Volynska	23.11%	1.33%	22.23%	-0.27%	7.7%	-0.07%
Zakarpatska	12.18%	1.52%	16.5%	-0.51%	4.3%	-0.08%
Zaporizka	15.85%	0.27%	19.0%	-0.12%	4.3%	-0.05%
Zhytomyrska	20.88%	1.20%	23.6%	-0.36%	8.4%	-0.03%

Table 17: Poverty Consequences of Agricultural Impacts of Climate Change (Low Scenario) RCP 8.5, 2030

Oblast	Poverty Headcount		Poverty Gap		Severity of Poverty	
	Base %	Change %	Base %	Change %	Base %	Change %
Cherkaska	14.85%	1.59%	15.2%	0.67%	4.0%	0.30%
Chernihivska	16.48%	2.30%	22.5%	-0.56%	7.9%	-0.15%
Chernivetska	18.18%	1.44%	15.6%	1.94%	3.9%	0.62%
Dnipropetrovska	15.07%	0.48%	20.3%	0.70%	6.4%	0.30%
Donetska	22.28%	0.37%	19.2%	0.18%	5.5%	0.14%
Ivano-Frankivska	9.65%	0.00%	13.13%	1.93%	3.1%	0.47%
Kharkivska	23.17%	2.05%	19.9%	-0.25%	5.9%	-0.01%
Khemelnytska	20.75%	0.41%	20.8%	2.13%	6.4%	0.84%
Khersonska	24.17%	1.53%	17.5%	0.87%	4.9%	0.33%
Kyivska	15.61%	1.86%	14.9%	0.85%	3.7%	0.22%
Kyiv City	10.74%	0.61%	19.4%	1.38%	6.7%	0.48%
Kirovohradska	16.86%	1.92%	20.6%	-0.21%	7.2%	-0.10%
Luhanska	15.18%	2.53%	16.5%	-0.39%	4.5%	-0.07%
Lvivska	12.14%	1.90%	20.8%	-0.46%	6.1%	0.00%
Mykolaivska	17.11%	1.07%	14.9%	0.28%	3.4%	-0.04%
Odeska	18.79%	1.45%	15.5%	0.69%	3.9%	0.24%
Poltavska	15.55%	0.71%	15.2%	2.08%	3.8%	0.61%
Rivnenska	17.99%	2.52%	18.1%	0.56%	5.1%	0.30%
Sumska	15.27%	1.80%	14.1%	1.67%	3.7%	0.43%
Ternopilska	16.36%	2.27%	17.0%	0.55%	4.8%	0.24%
Vinnytska	11.21%	0.93%	23.0%	1.88%	8.3%	0.95%
Volynska	23.11%	1.78%	22.2%	1.39%	7.7%	0.51%
Zakarpatska	12.18%	1.52%	16.5%	0.56%	4.3%	0.23%
Zaporizka	15.85%	1.09%	19.0%	-0.54%	4.3%	-0.21%
Zhytomyrska	20.88%	2.81%	23.6%	-0.23%	8.4%	-0.03%

Source: World Bank staff calculations

Table 18: Poverty Consequences of Agricultural Impacts of Climate Change (Mean Scenario) RCP 8.5, 2030

Oblast	Poverty Headcount		Poverty Gap		Severity of Poverty	
	Base %	**Change %**	**Base %**	**Change %**	**Base %**	**Change %**
Cherkaska	14.85%	0.53%	15.20%	0.53%	4.00%	0.27%
Chernihivska	16.48%	0.38%	22.50%	-0.74%	8.90%	-1.31%
Chernivetska	18.18%	0.48%	15.60%	0.00%	3.90%	0.03%
Dnipropetrovska	15.07%	0.00%	20.30%	0.30%	6.40%	0.19%
Donetska	22.28%	-1.29%	19.20%	0.82%	5.50%	0.32%
Ivano-Frankivska	9.65%	0.00%	13.13%	1.93%	3.10%	0.47%
Kharkivska	23.17%	1.17%	19.90%	-0.65%	5.90%	-0.15%
Khemelnytska	20.75%	-0.83%	20.80%	1.27%	6.40%	0.52%
Khersonska	24.17%	0.76%	17.50%	-0.27%	5.80%	-1.00%
Kyivska	15.61%	1.12%	14.90%	-0.39%	3.70%	-0.24%
Kyiv City	10.74%	0.31%	19.40%	0.68%	6.70%	0.31%
Kirovohradska	16.86%	0.00%	20.60%	-0.38%	7.20%	-0.12%
Luhanska	15.18%	-1.36%	16.50%	0.79%	4.50%	0.27%
Lvivska	12.14%	0.95%	20.80%	-0.94%	6.10%	-0.17%
Mykolaivska	17.11%	-0.80%	14.90%	0.98%	3.40%	0.23%
Odeska	18.79%	-0.87%	15.50%	0.78%	3.90%	0.27%
Poltavska	15.55%	0.00%	15.20%	0.00%	3.80%	0.04%
Rivnenska	17.99%	0.36%	18.10%	1.01%	5.10%	0.34%
Sumska	15.27%	-0.90%	14.10%	0.65%	3.70%	0.19%
Ternopilska	16.36%	-0.45%	17.00%	0.33%	4.80%	0.12%
Vinnytska	11.21%	0.31%	23.00%	1.80%	8.30%	0.82%
Volynska	23.11%	0.00%	22.23%	-0.36%	7.70%	-0.09%
Zakarpatska	12.18%	1.02%	16.50%	-0.51%	4.30%	-0.09%
Zaporizka	15.85%	-0.27%	19.00%	-0.34%	4.30%	-0.09%
Zhytomyrska	20.88%	0.80%	23.60%	-0.17%	8.40%	0.04%

Source: World Bank staff calculations

Table 19: Poverty Consequences of Agricultural Impacts of Climate Change (High Scenario) RCP 8.5, 2030

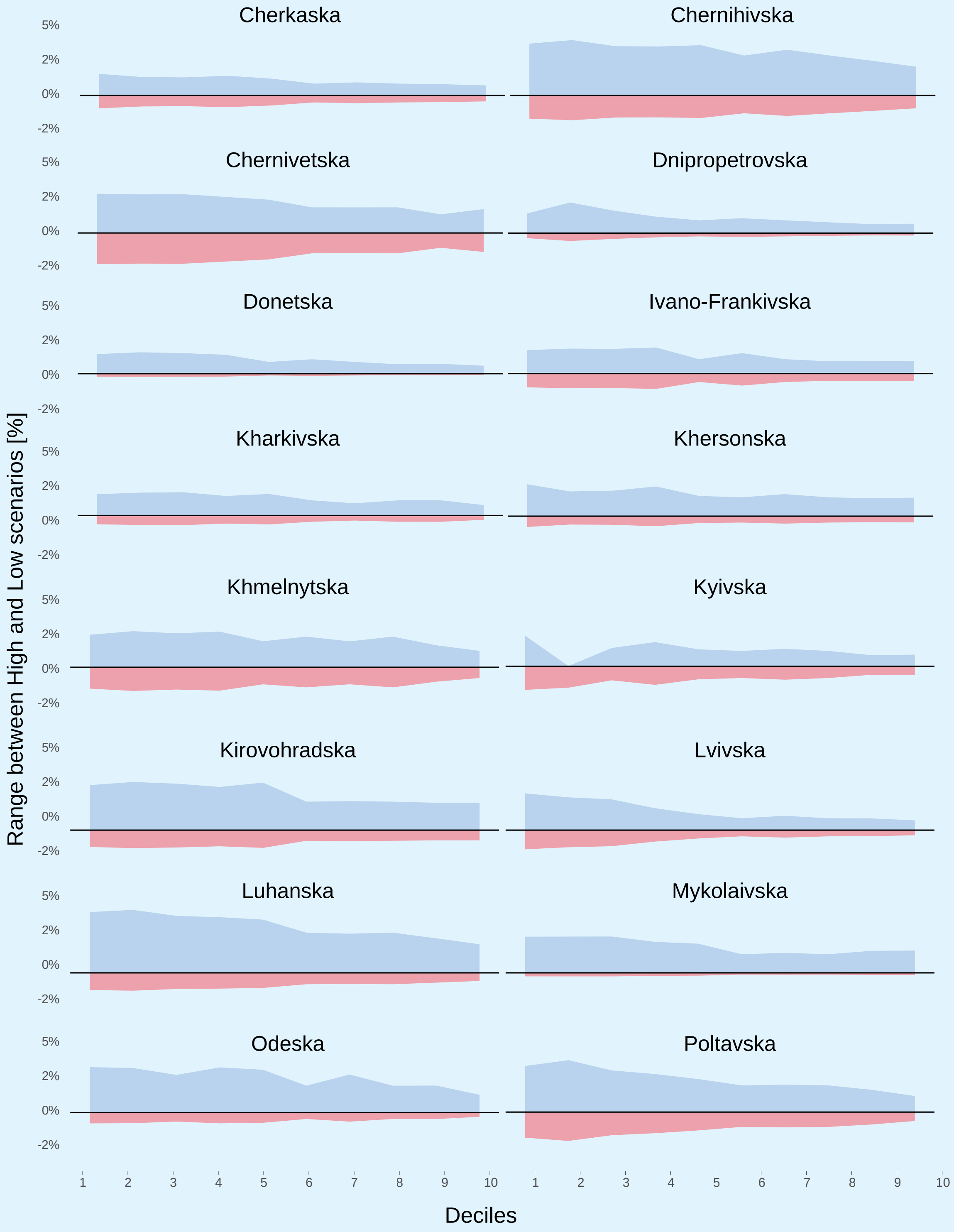
Oblast	Poverty Headcount		Poverty Gap		Severity of Poverty	
	Base %	**Change %**	**Base %**	**Change %**	**Base %**	**Change %**
Cherkaska	14.85%	0.00%	15.2%	0.11%	4.0%	0.17%
Chernihivska	16.48%	-1.15%	22.5%	-0.66%	8.9%	-1.32%
Chernivetska	18.18%	-1.91%	15.6%	-0.04%	3.9%	0.01%
Dnipropetrovska	15.07%	-1.44%	20.3%	1.49%	6.4%	0.63%
Donetska	21.18%	-0.55%	19.2%	0.47%	5.5%	0.20%
Ivano-Frankivska	9.65%	0.00%	13.13%	1.93%	3.1%	0.47%
Kharkivska	23.17%	-1.17%	19.9%	0.47%	5.9%	0.17%
Khemelnytska	20.75%	-1.66%	20.8%	0.52%	6.4%	0.25%
Khersonska	24.17%	-0.51%	17.5%	-0.47%	5.8%	-1.07%
Kyivska	15.61%	1.12%	14.9%	-0.39%	3.7%	-0.24%
Kyiv City	10.74%	-0.31%	19.4%	0.80%	6.7%	0.44%
Kirovohradska	16.86%	-2.68%	21.5%	0.32%	7.2%	0.53%
Luhanska	15.18%	-3.31%	16.5%	1.12%	4.5%	0.35%
Lvivska	12.14%	-0.48%	20.8%	-0.05%	6.1%	0.05%
Mykolaivska	17.11%	-1.34%	14.9%	-0.25%	3.4%	-0.10%
Odeska	18.79%	-1.73%	15.5%	0.17%	3.9%	0.10%
Poltavska	15.55%	-1.41%	15.2%	-0.90%	3.8%	-0.14%
Rivnenska	17.99%	-1.08%	18.1%	0.01%	5.1%	-0.04%
Sumska	15.27%	-2.40%	14.1%	-0.39%	3.7%	-0.04%
Ternopilska	16.36%	-1.82%	17.0%	-0.61%	4.8%	-0.15%
Vinnytska	11.21%	0.00%	23.0%	-0.59%	8.3%	0.58%
Volynska	23.11%	-2.22%	22.23%	-0.71%	7.7%	-0.18%
Zakarpatska	12.18%	0.00%	16.5%	-0.48%	4.3%	-0.10%
Zaporizka	15.85%	-1.37%	19.0%	-0.05%	4.3%	0.04%
Zhytomyrska	20.88%	-1.61%	23.6%	1.19%	8.4%	0.53%

Source: World Bank staff calculations

Table 20: Base Values of the Gini Coefficient and Changes in the Coefficient RCP 8.5, 2030

Oblast		Percentage Change in Gini			
	Base Value	With Income and Price Effects			Only Price Effect
		Agricultural Impact Scenario			
		Low	Medium	High	
Cherkaska	0.31	0.58%	0.19%	-0.13%	0.32%
Chernihivska	0.3	0.40%	-0.10%	-0.51%	0.11%
Chernivetska	0.32	0.81%	0.17%	-0.29%	0.30%
Dnipropetrovska	0.33	0.39%	0.00%	-0.34%	0.25%
Donetska	0.34	0.47%	0.21%	-8.27%	0.40%
Ivano-Frankivska	0.32	-2.75%	-3.23%	-3.51%	-3.05%
Kharkivska	0.3	0.42%	0.12%	-0.06%	0.27%
Khemelnytska	0.3	0.50%	0.19%	-0.10%	0.30%
Kherson	0.31	0.34%	0.37%	0.42%	0.34%
Kyivska	0.31	0.76%	0.08%	-0.38%	0.22%
Kyiv City	0.38	0.60%	0.38%	0.22%	0.43%
Kirovohradska	0.31	0.46%	0.05%	-0.30%	0.27%
Luhanska	0.31	0.60%	-0.10%	-0.62%	0.33%
Lvivska	0.31	0.62%	0.32%	0.07%	0.41%
Mykolaivska	0.29	0.34%	-0.03%	-0.29%	0.29%
Odeska	0.34	0.38%	0.34%	0.33%	0.34%
Poltavska	0.35	0.81%	0.14%	-0.39%	0.37%
Rivnenska	0.29	0.73%	0.29%	-0.02%	0.39%
Sumska	0.31	1.07%	-0.01%	-0.87%	0.29%
Ternopilska	0.35	0.55%	0.23%	-0.04%	0.39%
Vinnytska	0.33	1.40%	1.15%	0.63%	1.36%
Volynska	0.33	0.64%	-0.02%	-0.42%	0.26%
Zakarpatska	0.32	0.71%	0.41%	0.29%	0.53%
Zaporizka	0.32	0.32%	0.08%	-0.08%	0.22%
Zhytomyrska	0.33	0.66%	0.18%	-0.08%	0.24%

Figure 58: Range of Change in Income for all Deciles between Low and High Scenario, RCP 8.5, 2030



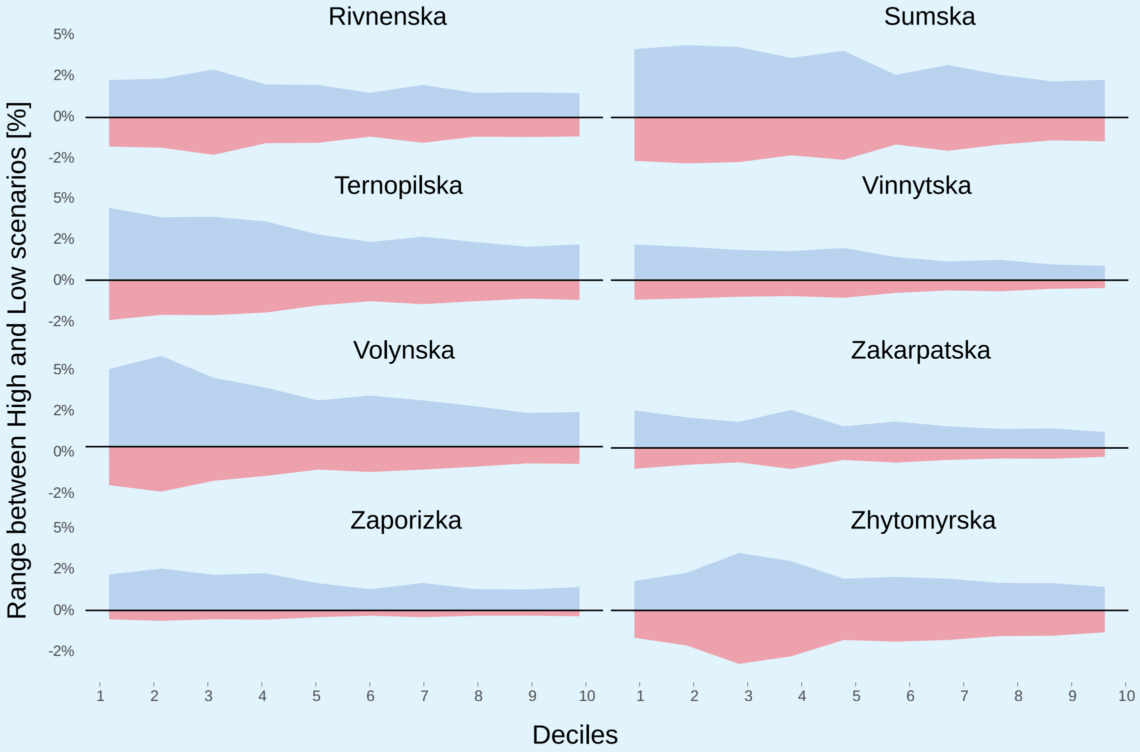

Rivnenska
Sumska
Ternopilska
Vinnytska
Volynska
Zakarpatska
Zaporizka
Zhytomyrska
5%
2%
0%
-2%
Range between High and Low scenarios [%]
1
2
3
4
5
6
7
8
9
10
Deciles

Table 21: Rating of Oblasts with the Highest Share of Agriculture in GDP

Oblast	GDP ($) in 2010	Agricultural value ($S) in 2010	Share (%) of agricultural sector in the oblast GDP	Share (%) of agricultural sector in Ukraine GDP	Rating	Normalized rating
Kirovohradska	2,051,491,271	600,015,846	29%	0.47%	6.6	1
Vinnytska	2,862,959,797	671,406,894	23%	0.53%	7.6	0.95
Cherkaska	2,857,808,904	592,117,263	21%	0.47%	8.5	0.91
Khersonska	1,913,487,374	411,870,822	22%	0.32%	8.8	0.89
Poltavska	5,238,799,486	657,352,685	13%	0.52%	10.9	0.79
Khemelnytska	2,214,641,971	380,806,627	17%	0.30%	10.2	0.82
Sumska	2,284,746,506	364,953,365	16%	0.29%	10.7	0.8
Odeska	6,205,995,595	578,678,861	9%	0.46%	12.8	0.7
Mykolaivska	2,887,855,492	355,172,783	12%	0.28%	12.3	0.72
Zaporizka	5,431,881,552	477,918,964	9%	0.38%	13.6	0.66
Ternopilska	1,447,096,233	228,236,810	16%	0.18%	11.7	0.75
Kharkivska	8,067,363,553	533,231,318	7%	0.42%	14.9	0.6
Dnipropetrovska	13,812,309,960	651,102,780	5%	0.51%	16.1	0.54
Chernihivska	2,106,574,368	232,681,729	11%	0.18%	13.9	0.65
Crime	4,101,072,695	296,416,732	7%	0.23%	15.9	0.55
Luhanska	5,996,086,314	298,154,852	5%	0.23%	18.2	0.44
Rivenska	1,804,097,884	148,288,560	8%	0.12%	16.9	0.5
Zhytomyrska	2,266,873,098	164,100,290	7%	0.13%	17.5	0.47
Donetska	16,436,244,077	435,703,123	3%	0.34%	20.6	0.32
Chernivetska	1,114,455,551	100,749,797	9%	0.08%	17.2	0.49
Volynska	1,612,504,839	120,898,988	7%	0.10%	18	0.45

Oblast	GDP ($) in 2010	Agricultural value ($S) in 2010	Share (%) of agricultural sector in the oblast GDP	Share (%) of agricultural sector in Ukraine GDP	Rating	Normalized rating
Kyivska	25,397,707,265	448,587,023	2%	0.35%	22.8	0.22
Lvivska	4,945,012,214	153,535,047	3%	0.12%	23.3	0.19
Ivano-Frankivska	2,227,200,337	74,471,167	3%	0.06%	25.3	0.09
Zakarpatska	1,757,683,060	52,990,606	3%	0.04%	27.3	0
TOTAL	127,041,949,396	9,029,442,932				
				Min	6.58	0.00
				Max	27.25	1.00
				Mean	15.26	0.58

Rating values do not have specific interpretation and only serve to establish the order of oblasts by the value of the share of agriculture in GDP of the oblast and Ukraine. The values are estimated as:

r = ln(Share (%) of agricultural sector in the oblast GDP) *
ln(Share (%) of agricultural sector in Ukraine GDP)

Table 22: Rating of Oblasts by the Highest Change in Agriculture Production

			Change in the value of agricultural production without adaptation measures for the low projection	
Oblast	**Rating**	**Normalized rating**	**For 2030**	**For 2050**
Zhytomyrska	0.25	1	-59%	-62%
Kyivska	0.53	0.83	-52%	-44%
Chernivetska	0.59	0.8	-59%	-32%
Rivnenska	0.66	0.76	-50%	-38%
Lvivska	0.72	0.72	-47%	-38%
Khemelnytska	0.78	0.68	-48%	-35%
Sumska	0.82	0.66	-55%	-25%
Volynska	0.83	0.66	-49%	-32%
Poltavska	0.88	0.63	-50%	-29%
Zakarpatska	0.92	0.6	-54%	-23%
Ivano-Frankivska	0.94	0.59	-51%	-25%
Kirovohradska	0.95	0.58	-45%	-31%
Kharkivska	1.03	0.54	-50%	-23%
Vinnytska	1.05	0.53	-42%	-30%
Ternopilska	1.06	0.52	-44%	-28%
Cherkaska	1.06	0.52	-44%	-27%
Chernihivska	1.09	0.5	-52%	-19%
Luhanska	1.3	0.38	-45%	-19%

			Change in the value of agricultural production without adaptation measures for the low projection	
Oblast	**Rating**	**Normalized rating**	**For 2030**	**For 2050**
Zaporizka	1.33	0.36	-41%	-22%
Dnipropetrovska	1.33	0.36	-41%	-23%
Odeska	1.5	0.26	-39%	-20%
Khersonska	1.53	0.24	-40%	-19%
Mykolaivska	1.67	0.16	-33%	-22%
Donetska	1.94	0	-36%	-15%
Min	0.25	0		
Max	1.94	1		
Mean	1.03	0.54		

Rating values do not have specific interpretation and only serve to establish the order of oblasts by the magnitude of the consecutive impact on the value of agricultural production between the two time periods. The values are estimated as:

$$r=\ln(\text{Change in the value for 2030}) * \ln(\text{Change in the value for 2050})$$

Table 23: Rating of Oblasts by the Combined Social Changes

Oblast	Rating	Normalized Rating	Poverty Headcount: Change to Base [%]	Poverty Gap: Change to Base [%]	Severity of Poverty: Change to Base [%]
Lvivska	-0.06	1	1.90%	-0.46%	0.00%
Zhytomyrska	-0.07	0.97	2.81%	-0.23%	-0.03%
Kharkivska	-0.07	0.97	2.05%	-0.25%	-0.01%
Luhanska	-0.09	0.91	2.53%	-0.39%	-0.07%
Kirovohradska	-0.09	0.9	1.92%	-0.21%	-0.10%
Mykolaivska	-0.1	0.89	1.07%	0.28%	-0.04%
Chernihivska	-0.11	0.84	2.30%	-0.56%	-0.15%
Ternopilska	-0.12	0.81	2.27%	0.55%	0.24%
Rivnenska	-0.12	0.81	2.52%	0.56%	0.30%
Zakarpatska	-0.13	0.77	1.52%	0.56%	0.23%
Donetska	-0.14	0.76	0.37%	0.18%	0.14%
Kyivska	-0.14	0.76	1.86%	0.85%	0.22%
Zaporizka	-0.14	0.75	1.09%	-0.54%	-0.21%
Odeska	-0.14	0.74	1.45%	0.69%	0.24%
Cherkaska	-0.14	0.74	1.59%	0.67%	0.30%
Khersonska	-0.15	0.7	1.53%	0.87%	0.33%
Volynska	-0.18	0.62	1.78%	1.39%	0.51%
Sumska	-0.18	0.62	1.80%	1.67%	0.43%
Dnipropetrovska	-0.18	0.6	0.48%	0.70%	0.30%
Chernivetska	-0.21	0.52	1.44%	1.94%	0.62%
Kyiv City	-0.22	0.48	0.61%	1.38%	0.48%
Poltavska	-0.25	0.39	0.71%	2.08%	0.61%

Oblast	Rating	Normalized Rating	Poverty Headcount: Change to Base [%]	Poverty Gap: Change to Base [%]	Severity of Poverty: Change to Base [%]
Vinnytska	-0.25	0.38	0.93%	1.88%	0.95%
Khmelnytska	-0.3	0.23	0.41%	2.13%	0.84%
Ivano-Frankivska	-0.37	0	0.00%	1.93%	0.47%
Min	-0.37	0			
Max	-0.06	1			
Mean	-0.16	0.69			

Rating values do not have specific interpretation and only serve to establish the order of oblasts by the magnitude of the impact on three indicators of poverty. The values are estimated as:

$$r = \frac{\ln(\text{ Headcount Poverty Change })}{\ln(\text{ Poverty Gap Change }) * \ln(\text{ Severity of Poverty Change })}$$

ANNEX 4.
DATA FOR FORESTRY ASSESSMENT

Table 24: Average Annual Air Temperature in Forest Regions of Ukraine

Time periods / projections	Carpathian	Polissya	Right-bank Forest-steppe	Left-bank Forest-steppe	Mountain Crimea	Northern Steppe	Southern Steppe
Average annual temperature, T oC							
1961-1990	6.5±1.5	7.1±0.4	7.7±0.4	7.3±0.5	9.3±0.8	8.4±0.5	10.1±0.5
1991-2010	7.1±1.4	8.1±0.4	8.5±0.4	8.2±0.4	9.8±0.8	9.1±0.5	10.7±0.5
RCP 4.5 2021-2040	7.9±1.4	8.9±0.4	9.3±0.4	9.1±0.4	10.5±0.9	10±0.5	11.5±0.5
RCP 4.5 2041-2060	8.4±1.4	9.5±0.4	9.9±0.5	9.7±0.4	11.1±0.8	10.6±0.4	12.1±0.5
RCP 4.5 2081-2100	9.1±1.4	10.1±0.4	10.5±0.5	10.3±0.4	11.6±0.8	11.2±0.4	12.6±0.5
RCP 8.5 2021-2040	8.1±1.4	9.1±0.4	9.5±0.4	9.3±0.4	10.7±0.8	10.2±0.5	11.7±0.5
RCP 8.5 2041-2060	9±1.4	10±0.4	10.4±0.4	10.2±0.4	11.6±0.8	11.2±0.4	12.6±0.5
RCP 8.5 2081-2100	11.3±1.3	12.3±0.4	12.8±0.5	12.7±0.4	13.9±0.9	13.6±0.4	15±0.4
The average temperature of the coldest month, Cr, oC							
1961-1990	-5±1.1	-5.9±0.9	-5.1±0.5	-6.8±0.6	-1.4±0.5	-5.6±1.1	-2.5±1.1
1991-2010	-3.4±1	-3.4±0.6	-3±0.3	-4.3±0.5	-0.6±0.6	-3.6±0.7	-1.3±0.9
RCP 4.5 2021-2040	-2.5±1	-2.3±0.5	-2±0.3	-3.1±0.5	0.1±0.6	-2.6±0.7	-0.5±0.9
RCP 4.5 2041-2060	-2.3±1.1	-2.2±0.5	-1.8±0.3	-3±0.4	0.5±0.6	-2.3±0.7	-0.2±0.9

Time periods / projections	**Carpathian**	**Polissya**	**Right-bank Forest-steppe**	**Left-bank Forest-steppe**	**Mountain Crimea**	**Northern Steppe**	**Southern Steppe**
RCP 4.5 2081-2100	-1.3±1.1	-0.9±0.5	-0.7±0.3	-1.9±0.5	1±0.5	-1.5±0.6	0.5±0.8
RCP 8.5 2021-2040	-2.9±1.1	-2.7±0.6	-2.5±0.4	-3.7±0.5	-0.2±0.6	-3.1±0.7	-1±0.9
RCP 8.5 2041-2060	-1.7±1.1	-1.5±0.6	-1.2±0.4	-2.6±0.5	0.9±0.6	-2±0.7	0.2±0.9
RCP 8.5 2081-2100	1.4±1.2	2±0.5	2.1±0.4	0.9±0.5	3.2±0.6	1.1±0.6	2.8±0.8
The average air temperature of the warmest month, Tx, oC							
1961-1990	16.2±1.7	18.4±0.5	18.7±0.9	19.9±0.6	20±1.1	21.1±0.4	22.2±0.4
1991-2010	17.6±1.6	20.1±0.5	20.3±0.9	21.3±0.5	21.2±1.1	22.5±0.3	23.5±0.3
RCP4.5 2021-2040	18.4±1.5	20.7±0.5	21±1	22±0.5	22.3±1.2	23.4±0.4	24.5±0.3
RCP4.5 2041-2060	18.9±1.6	21.2±0.6	21.6±1	22.7±0.6	22.9±1.1	24.1±0.4	25.2±0.3
RCP4.5 2081-2100	19.5±1.5	21.9±0.6	22.2±1	23.3±0.5	23.4±1.2	24.7±0.4	25.7±0.3
RCP8.5 2021-2040	18.6±1.6	21.1±0.6	21.3±1	22.3±0.5	22.4±1.1	23.6±0.4	24.8±0.3
RCP8.5 2041-2060	19.5±1.6	21.9±0.6	22.2±1	23.4±0.6	23.5±1.2	24.8±0.4	25.8±0.3
RCP8.5 2081-2100	21.8±1.6	24.2±0.7	24.6±1.2	26±0.7	26.5±1.2	27.6±0.5	28.7±0.4

Table 25: Changes in the Area of Vorobjov's Heat Availability Index (T) for Forests of Ukraine, %

Type of climates by Vorobjov's heat availability index for forests	1961-1990	1991-2010	RCP4.5			RCP8.5		
			2021-2040	2041-2060	2081-2100	2021-2040	2041-2060	2081-2100
c – relatively temperate	1.8	1.2	0.6	0.4	0.4	0.1	0.1	0
d – temperate	41.0	10.6	2.1	1.9	1.7	1.3	1.3	0.1
e – relatively warm	48.5	70.2	63.2	43.0	27.3	53.2	26.1	1.1
f – warm	8.7	17.7	31.1	46.1	54.5	40.1	56.1	4.5
g – very warm*	0	0.3	3.0	8.6	15.4	5.3	15.8	67.0
h – hot*	0	0	0	0	0.6	0	0.5	27.3
Total	100	100	100	100	100	100	100	100

* types of climate not described by Vorobjov

Table 26: Changes in Area of Climatic Zones for Vorobjov's Humidity Index (W) for Forests, %

Climatic zones of Vorobjov's humidity index for forests	1961-1990	1991-2010	RCP4.5			RCP8.5		
			2021-2040	2041-2060	2081-2100	2021-2040	2041-2060	2081-2100
Extremely dry (-1)*	0	0	0	0.2	0.7	0.1	0.7	18.7
Very dry (0)	12.4	18.6	21.9	28.7	36.1	25.4	35.6	28.7
Dry (1)	35.8	31.0	32.4	34.4	33.7	34.8	33.3	42.3
Fresh (2)	31.0	40.1	37.3	30.4	24.0	34.1	25.1	7.8
Moist (3)	17.2	7.3	5.6	3.9	3.5	3.1	3.0	1.2
Humid (4)	0.8	1.0	1.0	1.1	1.4	1.1	1.3	1.2
Wet (5)	0.7	1.1	1.0	0.9	0.5	1.0	0.8	0.1
Very wet (6)	2.2	0.9	0.8	0.4	0.1	0.5	0.2	0
Total	100	100	100	100	100	100	100	100

* not described by Vorobjov

Figure 59: Spatial-Temporal Dynamics of Vorobjov's Moisture Availability Index for Forests

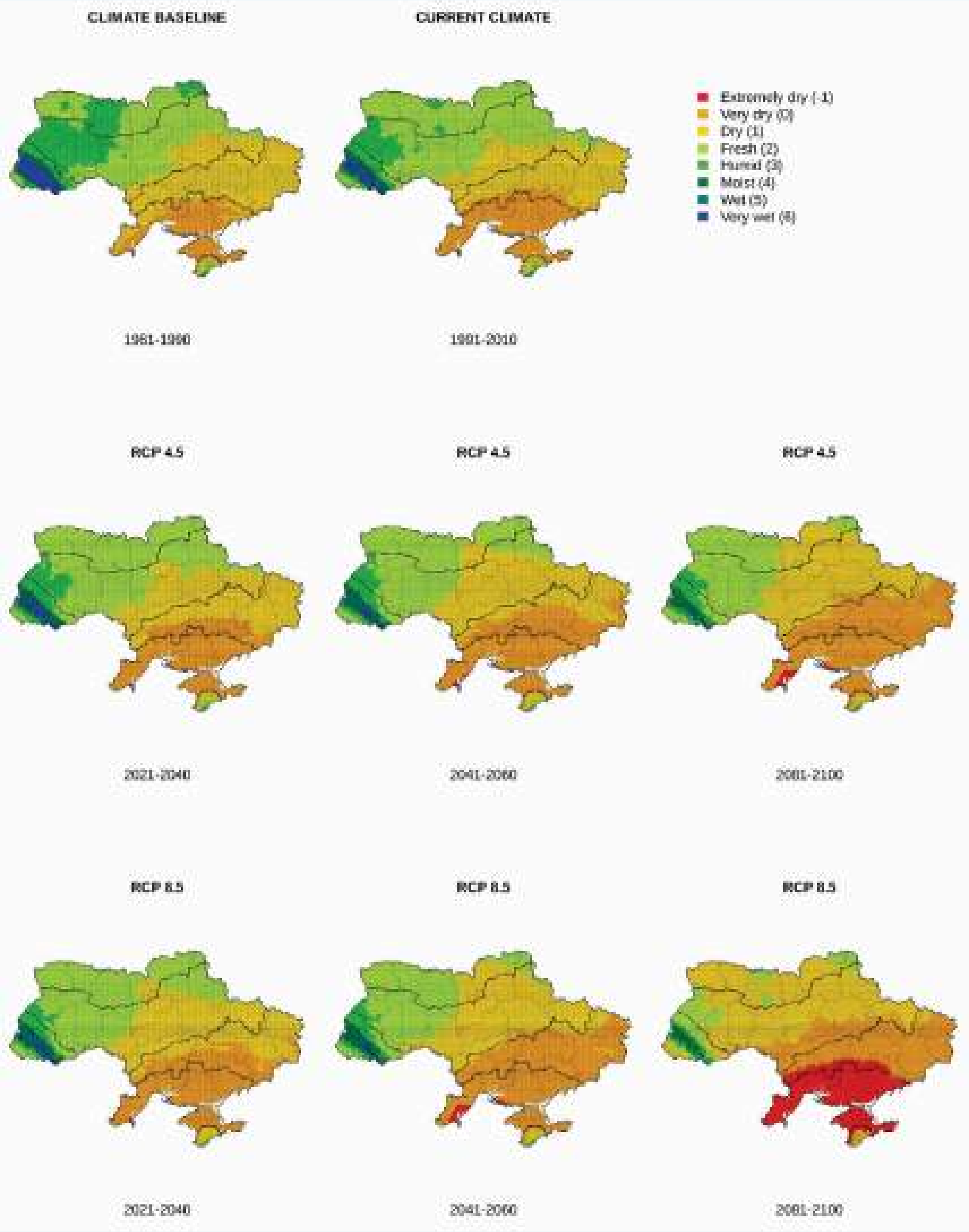


Figure 60: Spatial-Temporal Dynamics of the Suitability Ombroregime (Om) of Climate for Scots Pine (Pinus sylvestris L.)

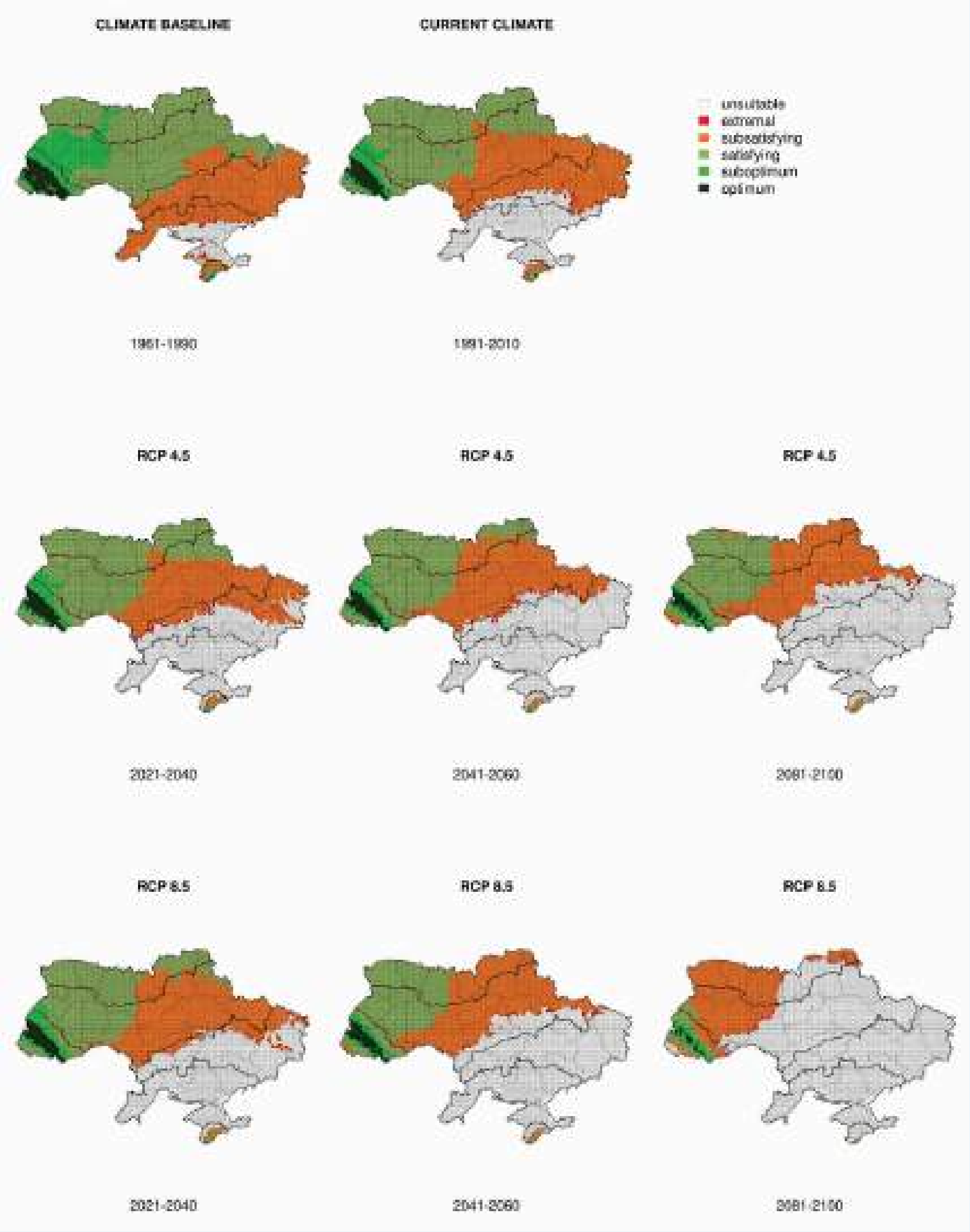


Figure 61: Spatial-Temporal Dynamics of the Suitability Ombroregime (Om) of Climate for English Oak (Quercus robur L.)

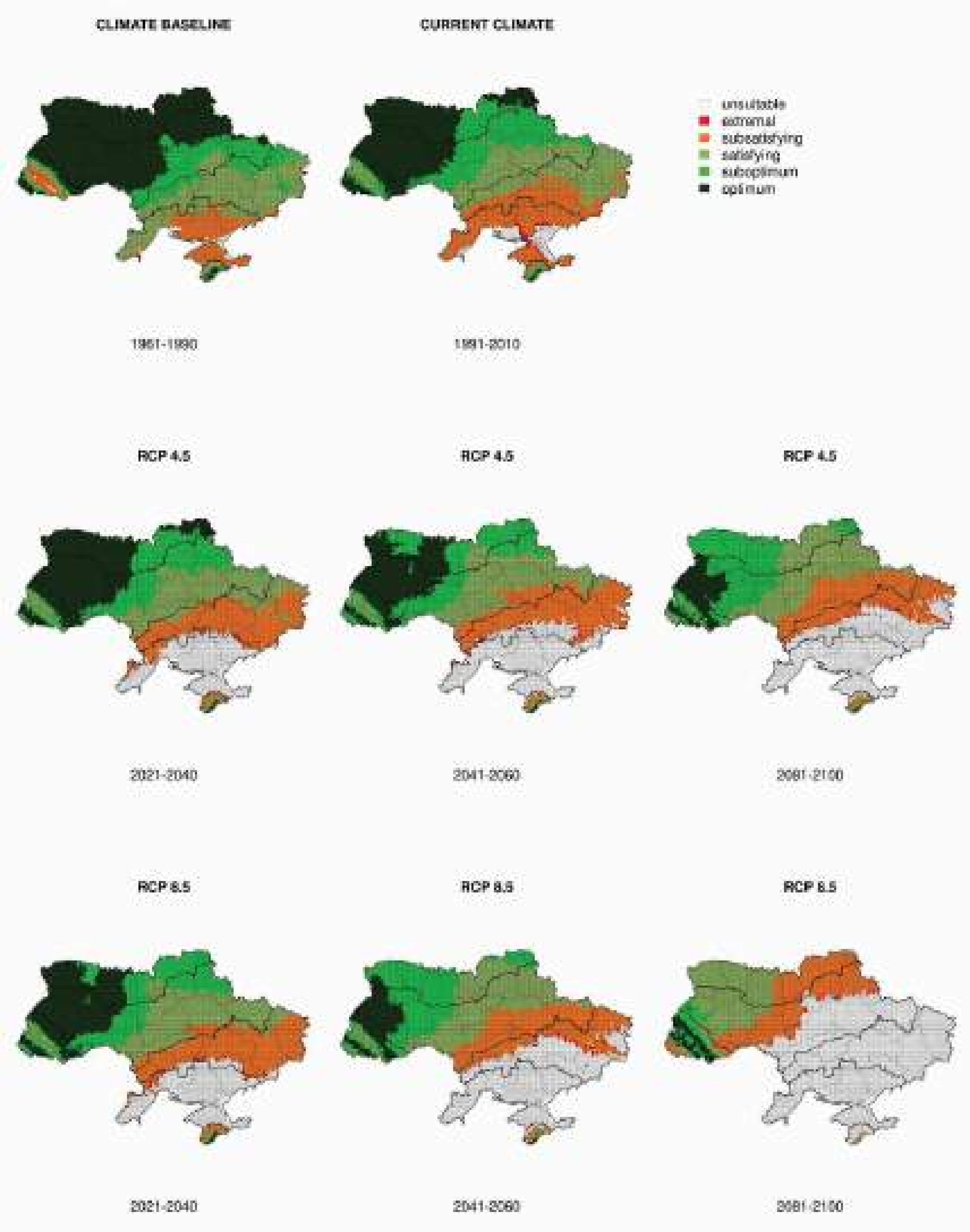


Figure 62: Spatial-Temporal Dynamics of the Suitability Ombroregime (Om) of Climate for European Beech (Fagus sylvatica L.)

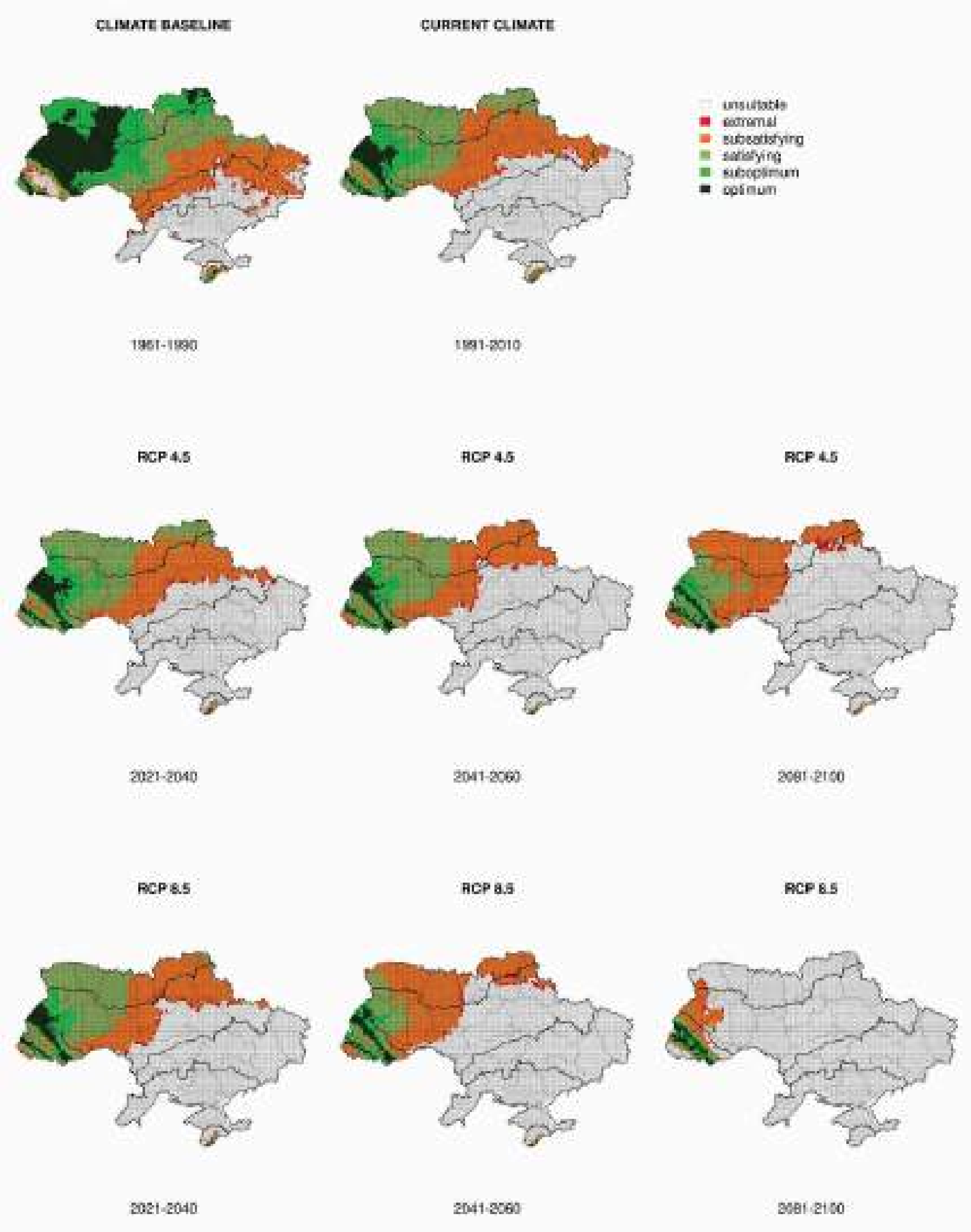


Figure 63: Spatial-Temporal Dynamics of the Suitability Ombroregime (Om) of Climate for Norway Spruce (Picea abias L.)

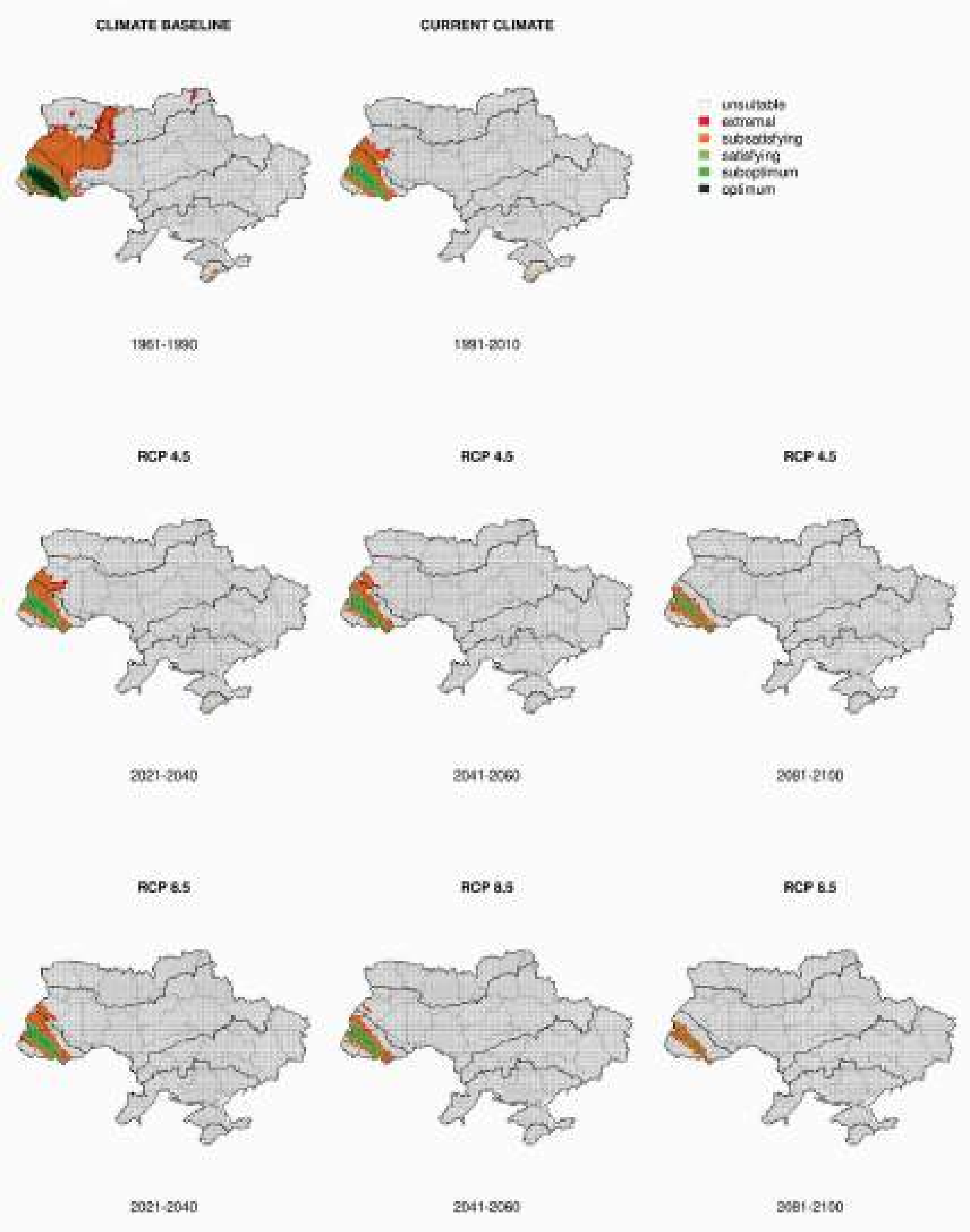
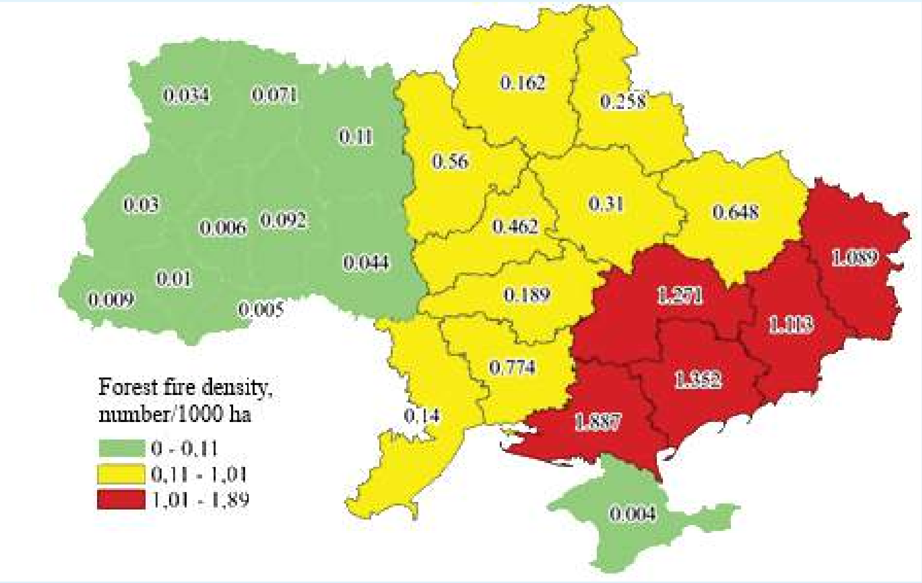


Table 27: Distribution of Forest Areas by Classes of Natural Fire Hazard

Forestry regions (by Gensiruk)	Classes of natural fire hazard					Average class of natural fire hazard
	I	II	III	IV	V	
	Forested area, thousand ha /%					
Carpathians	164.4/9.8	125.7/7.5	684.1/40.8	701.7/41.9	0.01/0.0	3.15+0.02
Polissya	654.2/27.3	759.1/31.7	574.424.0	393.0/16.4	17.3/0.7	2.32+0.01
Right-bank Forest-Steppe	101.0/6.3	262.0/16.4	990.0/62.0	239.6/15.0	5.1/0.3	2.87+0.01
Left-bank Forest-Steppe	72.8/8.0	294.0/32.5	420.3/46.5	109.2/12.1	8.6/1.0	2.65+0.02
Mountain Crimea	48.9/19.4	110.2/43.6	93.2/36.9	0.2/0.1	0/0	2.18+0.04
Northern Steppe	77.0/13.7	329.6/58.4	125.0/22.2	31.7/5.6	0.7/0.1	2.20+0.02
Southern Steppe	58.6/31.6	82.6/44.6	29.3/15.8	11.5/6.2	3.4/1.8	2.02+0.04
Ukraine	1176.9/15.5	1963.2/25.9	2916.4/38.5	1487.0/19.6	35.1/0.5	2.64+0.01

Figure 64: Density of Forest Fires in Ukraine by Oblast in Forests Subordinated to the State Forest Resources Agency of Ukraine, 2007–2020



Source: Forest Ecology Laboratory of URIFFM, 2020

ANNEX 5.
BENEFITS OF ADAPTION MEASURES

Table 28: Effect of Adaptation Measures to Maintain the Optimal Water Availability on Change in the Value of Agricultural Output for Selected Crops (mean projection)

	Value of Agricultural Output	Change[1] in the Value of Agricultural Output		Adjusted Change[1,2] in the Value of Agricultural Output		Costs of the Absence of Adaptation			
						(per year)	(10-year sum)[3]		
							3%	6%	10%
	[Million $]	[%]	[Million $]	[%]	[Million $]	[Million $]	[Million $]		
	2010	2030	2030	2030	2030	2030	2026-2035		
Maize	1700.8	-18.7%	-317.8	-13.2%	-225.1	-92.7	-643.0	-453.8	-292.3
Soybean	34.6	26.5%	9.2	39.6%	13.7	-4.6	-31.6	-22.3	-14.4
Sunflower	809.1	3.8%	30.8	5.7%	46.1	-15.2	-105.7	-74.6	-48.0
Total	2544.5	-10.9%	-277.8	-6.5%	-165.3	-112.5	-780.3	-550.7	-354.7

[1] Change [%] in the value of agricultural production as a percent of 2010 value of agricultural production. Value in million $\text{US}\$^{2010}$ is given for real prices.

[2] The estimated adjusted change in the value of water scarce agricultural production as a percent of 2010 value of agricultural production by oblast in 2030 with adaptation measures in the agricultural sector directed to maintain the optimal water availability.

[3] The net present value (to base year 2021) of costs of inaction over the period of climate projections for the agricultural outputs 2026-2035.

Table 29: Effect of Adaptation Measures to Maintain the Optimal Water Availability on Change in the Value of Agricultural Output for Selected Crops (low projection)

	Value of Agricultural Output	**Change[1] in the Value of Agricultural Output**		**Adjusted Change[1,2] in the Value of Agricultural Output**		**Costs of the Absence of Adaptation**			
						(per year)	**(10-year sum)[3]**		
							3%	6%	10%
	[Million $]	[%]	[Million $]	[%]	[Million $]	[Million $]	[Million $]		
	2010	2030	2030	2030	2030	2030	2026-2035		
Maize	1700.8	-75.0%	-127.,3	-51.4%	-874,6	-401.6	-2785.8	-1966.0	-1266.4
Soybean	34.6	8.9%	3.1	14.8%	5,1	-2.0	-14.1	-10.0	-6.4
Sunflower	809.1	-24.2%	-195.8	-11.8%	-95,5	-100.3	-695.5	-490.8	-316.2
Total	2544.5	-57.7%	-1469.0	-37.9%	-965,0	-504.0	-3495.4	-2466.8	-1589.0

[1] Change [%] in the value of agricultural production as a percent of 2010 value of agricultural production. Value in million $^{2010} is given for real prices.

[2] The estimated adjusted change in the value of water scarce agricultural production as a percent of 2010 value of agricultural production by oblast in 2030 with adaptation measures in the agricultural sector directed to maintain the optimal water availability.

[3] The net present value (to base year 2021) of costs of inaction over the period of climate projections for the agricultural outputs 2026-2035.

Table 30: Effect of Adaptation Measures to Maintain the Optimal Water Availability on Change in the Value of Agricultural Output for Selected Crops (high projection)

	Value of Agricultural Output	Change[1] in the Value of Agricultural Output		Adjusted Change[1,2] in the Value of Agricultural Output		Costs of the Absence of Adaptation			
						(per year)	(10-year sum)[3]		
							3%	6%	10%
	[Million $]	[%]	[Million $]	[%]	[Million $]	[Million $]	[Million $]		
	2010	2030	2030	2030	2030	2030	2026-2035		
Maize	1700.8	37.7%	640.7	45.9%	780.8	-140.1	-971.8	-685.8	-441.8
Soybean	34.6	44.0%	15.2	65.0%	22.5	-7.3	-50.3	-35.5	-22.9
Sunflower	809.1	31.8%	257.5	46.3%	374.3	-116.8	-810.0	-571.6	-368.2
Total	2544.5	31.8%	913.4	46.3%	1177.5	-264.2	-1832.1	-1293.0	-832.9

[1] Change [%] in the value of agricultural production as a percent of 2010 value of agricultural production. Value in Million US $2010 is given for real prices.

[2] The estimated adjusted change in the value of water scarce agricultural production as a percent of 2010 value of agricultural production by oblast in 2030 with adaptation measures in the agricultural sector directed to maintain the optimal water availability.

[3] The net present value (to base year 2021) of costs of inaction over the period of climate projections for the agricultural outputs 2026-2035.

Table 31: Change in Value of Agricultural Output Relative to 2010 (Maize): Water Optimal vs Water Scarce Projection

Oblast	Value of Agricultural Output [Million $]	Change in the value[1] [%]			Ratio of water-optima to scarce yield[2]			Adjusted change in the value[3] [%]		
	2010	2030			2030			2030		
		low	mean	high	low	mean	high	low	mean	high
Crimea	5.69	-46	-31	-16	74	71	68	-12	-9	-5
Chernihivska	0	0	0	0	50	46	41	0	0	0
Kyivska	121.91	-64	-23	18	49	44	39	-33	-13	25
Volynska	10.03	-56	-20	16	46	42	38	-30	-12	22
Khersonska	100.21	-63	-21	22	45	40	34	-35	-12	30
Zhytomyrska	77	-61	-22	18	44	39	34	-34	-13	24
Rivnenska	14.23	-63	-21	21	42	38	34	-37	-13	28
Cherkaska	212.04	-61	-21	20	39	33	27	-37	-14	25
Sumska	109.35	-74	-17	41	36	31	26	-48	-12	51
Luhanska	16.88	-124	-22	81	36	30	24	-80	-15	100
Zaporizka	8.58	-124	-23	78	34	30	25	-81	-16	98
Mykolaivska	12.73	-91	-16	58	33	28	24	-61	-12	72
Poltavska	281.03	-65	-15	35	32	28	24	-44	-11	43
Odeska	43.58	-104	-16	72	30	27	23	-73	-12	88
Donetska	10.61	-127	-23	81	31	26	22	-87	-17	99
Zakarpatska	25.65	-69	-3	63	28	26	24	-50	-2	78
Vinnytska	173.18	-73	-23	27	29	25	22	-51	-17	33
Kharkivska	88.67	-102	-19	64	28	23	18	-73	-14	76
Khmelnytska	15.08	-75	-20	34	26	23	20	-56	-16	41

Oblast	Value of Agricultural Output [Million $]	Change in the value[1] [%]			Ratio of water-optima to scarce yield[2]			Adjusted change in the value[3] [%]		
	2010	2030			2030			2030		
		low	mean	high	low	mean	high	low	mean	high
Lvivska	24.59	-70	-15	40	25	22	18	-53	-12	47
Dnipropetrovska	58	-119	-19	82	25	21	17	-90	-15	96
Kirovohradska	165.12	-84	-15	53	22	18	15	-65	-13	61
Ternopilska	53.86	-80	-18	43	17	15	13	-66	-16	48
Chernivetska	48.87	-86	-16	53	14	12	11	-74	-14	59
Ivano-Frankivska	23.91	-75	-9	56	12	12	11	-66	-8	62
Total	1700.8	-75	-19	38	32	28	24	-51	-13	46

[1] Change in the value of agricultural production as a percent of 2010 value of agricultural production by oblast in 2030 for water scarce mean projection. It is taken from the technical report on Agriculture.

[2] The estimated ratio of the water-optimal yield to the water- scarce yield by oblast in 2030.

[3] The estimated adjusted change in the value of water scarce agricultural production as a percent of 2010 value of agricultural production by oblast in 2030 with adaptation measures in the agricultural sector directed to maintain the water optimum.

Table 32: Change in Value of Agricultural Output Relative to 2010 (Soybean): Water Optimal vs Water Scarce Projection

Oblast	Value of Agricultural Output [Million US$]	Change in the value[1] [%]			Ratio of water-optima to scarce yield[2] [%]			Adjusted change in the value[3] [%]		
	2010	2030			2030			2030		
		low	mean	high	low	mean	high	low	mean	high
Crimea	1.45	-10	15	40	65	63	61	-3	25	65
Volynska	0	0	0	0	63	61	59	0	0	0
Zhytomyrska	0.06	-2	29	59	62	60	58	-1	46	93
Kyivska	1.42	1	31	61	62	59	57	2	50	95
Rivnenska	0	0	0	0	61	59	57	0	0	0
Sumska	0.39	4	30	56	54	52	50	6	46	83
Khmelnytska	15.71	18	34	50	52	51	50	28	52	75
Lvivska	0	0	0	0	52	51	49	0	0	0
Vinnytska	2.44	14	33	51	51	50	49	21	49	76
Poltavska	5.48	-1	19	38	51	50	49	0	28	56
Khersonska	0.23	17	29	41	53	49	46	26	43	60
Zakarpatska	0	0	0	0	50	49	48	0	0	0
Odeska	0.85	-5	21	47	50	49	47	-3	31	69
Ternopilska	0.05	23	38	52	49	48	48	34	56	78
Chernivetska	0.19	29	42	55	49	48	48	43	62	81
Zaporizka	1.04	7	26	44	50	48	45	11	38	64
Mykolaivska	2	5	28	51	49	47	46	7	41	75
Ivano-Frankivska	0	0	0	0	47	47	47	0	0	0

Oblast	Value of Agricultural Output [Million US$]	Change in the value[1] [%]			Ratio of water-optima to scarce yield[2] [%]			Adjusted change in the value[3] [%]		
	2010	**2030**			**2030**			**2030**		
		low	mean	high	low	mean	high	low	mean	high
Kharkivska	0.55	-10	13	37	49	47	45	-5	19	53
Luhanska	0.14	-13	32	76	49	46	43	-7	46	109
Kirovohradska	1.16	13	32	50	47	46	45	19	46	72
Dnipropetrovska	1.12	1	25	49	47	46	44	2	37	71
Donetska	0.31	-33	12	56	47	45	44	-18	17	81
Total	34.59	9	26	44	52	50	47	15	40	65

[1] Change in the value of agricultural production as a percent of 2010 value of agricultural production by oblast in 2030 for water scarce mean projection. It is taken from the technical report on Agriculture.

[2] The estimated ratio of the water-optimal yield to the water- scarce yield by oblast in 2030.

[3] The estimated adjusted change in the value of water scarce agricultural production as a percent of 2010 value of agricultural production by oblast in 2030 with adaptation measures in the agricultural sector directed to maintain the water optimum.

Table 33: Change in Value of Agricultural Output Relative to 2010 (Sunflower): Water Optimal vs Water Scarce Projection

Oblast	Value of Agricultural Output [Million US$]	Change in the value[1] [%]			Ratio of water-optima to scarce yield[2] [%]			Adjusted change in the value[3] [%]		
	2010	2030			2030			2030		
		low	mean	high	low	mean	high	low	mean	high
Crimea	12.31	-56	14	83	78	77	75	-12	24	145
Khersonska	1.25	-36	8	52	61	58	55	-14	13	81
Chernihivska	3.09	-27	5	38	59	56	53	-11	9	58
Kyivska	75.69	-24	3	30	58	55	52	-10	5	46
Volynska	0	0	0	0	54	51	49	0	0	0
Zaporizka	84.65	-34	2	38	54	50	47	-16	3	55
Zhytomyrska	0.21	-28	3	34	53	50	47	-13	5	50
Cherkaska	32	-20	2	23	54	50	46	-9	2	34
Luhanska	57.62	-34	1	36	53	49	45	-16	2	52
Mykolaivska	61.61	-16	8	33	52	49	46	-8	12	48
Rivnenska	0.03	-28	0	28	51	48	46	-14	1	42
Sumska	13.99	-26	4	34	50	47	44	-13	6	49
Donetska	87.61	-30	1	31	50	47	44	-15	1	45
Odeska	64.61	-15	7	29	50	47	44	-8	10	43
Poltavska	61.91	-15	6	28	49	46	44	-7	9	40
Kharkivska	88.56	-21	2	26	47	43	40	-11	4	36
Dnipropetrovska	102.1	-24	3	29	46	43	40	-13	4	41
Vinnytska	18.9	-23	-1	20	45	42	40	-13	-1	28
Kirovohradska	7.82	-18	5	27	42	40	38	-10	7	38

Oblast	**Value of Agricultural Output [Million US$]**	**Change in the value[1] [%]**			**Ratio of water-optima to scarce yield[2] [%]**			**Adjusted change in the value[3] [%]**		
	2010	**2030**			**2030**			**2030**		
		low	mean	high	low	mean	high	low	mean	high
Khmelnytska	32.46	-29	-2	25	41	39	37	-17	-1	34
Zakarpatska	0.24	-19	11	41	39	37	35	-12	15	55
Lvivska	0	0	0	0	39	37	34	0	0	0
Ternopilska	0.46	-28	-3	22	34	33	32	-18	-2	29
Chernivetska	1.84	-27	1	28	32	30	29	-18	1	36
Ivano-Frankivska	0.19	-23	4	31	30	29	29	-16	5	39
Total	809.13	-24	4	32	50	47	44	-12	6	46

[1] Change in the value of agricultural production as a percent of 2010 value of agricultural production by oblast in 2030 for water scarce mean projection. It is taken from the technical report on Agriculture.

[2] The estimated ratio of the water-optimal yield to the water- scarce yield by oblast in 2030.

[3] The estimated adjusted change in the value of water scarce agricultural production as a percent of 2010 value of agricultural production by oblast in 2030 with adaptation measures in the agricultural sector directed to maintain the water optimum

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