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)

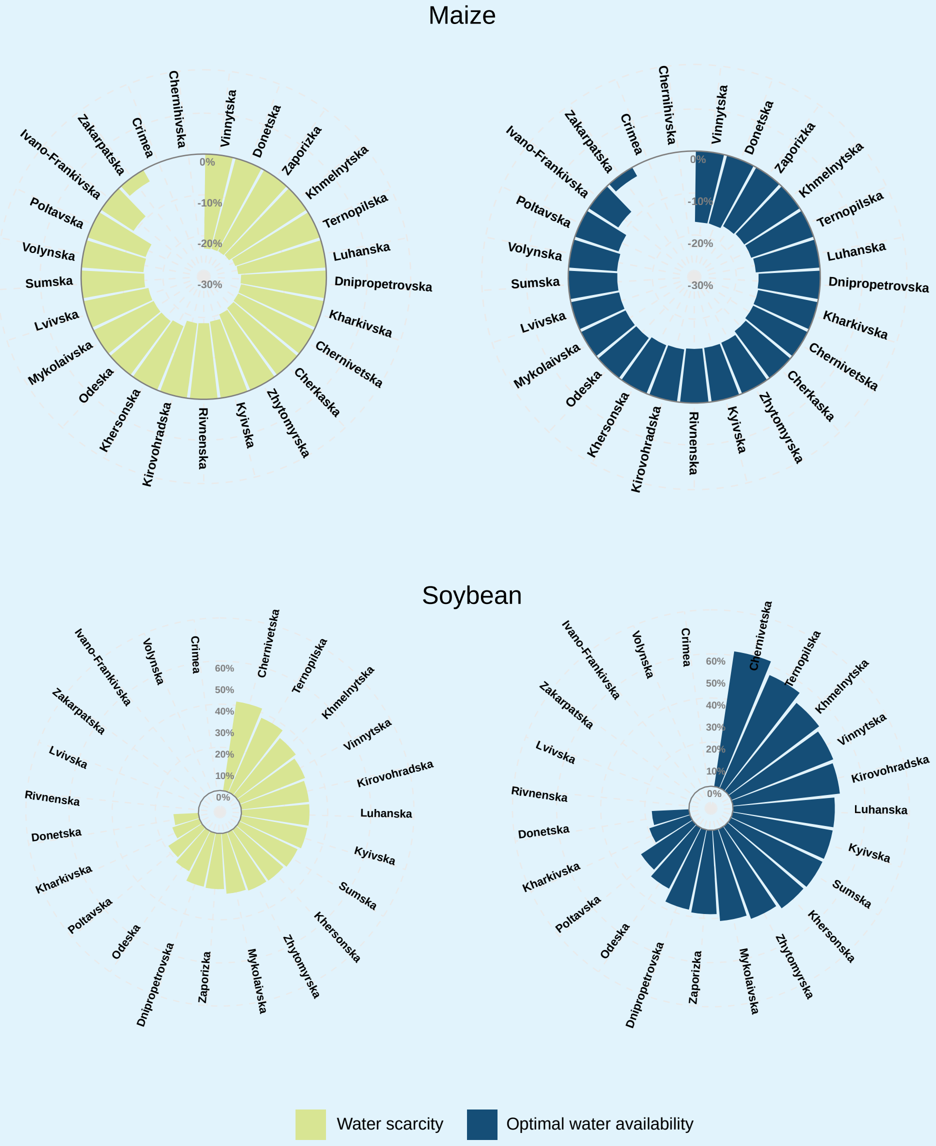
	Value of Agricultural Output	Change* in the Value of Agricultural Output		Adjusted Change† in the Value of Agricultural Output		Impacts of maintaining optimal water availability	
						(per year)	(10-year total) ‡
	US$ million	%	US$ million	%	US$ million	US$ million	US$ million
	2010	2030	2030	2030	2030	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]



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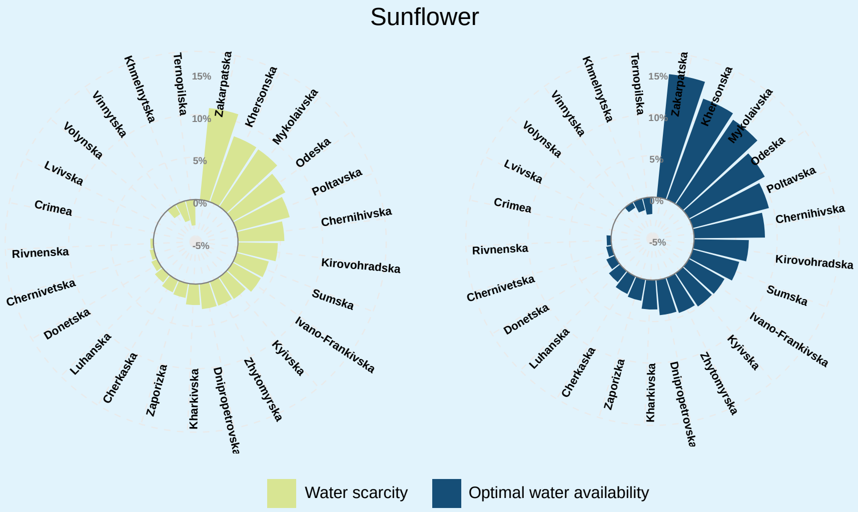
[23] For each projection, oblasts are ordered by the change (%) in value of agricultural output relative to the value of agricultural production in 2010. The circle defines a baseline - 0%. For maize, negative percentage changes signal losses in the value of agricultural output. Implementing adaptation 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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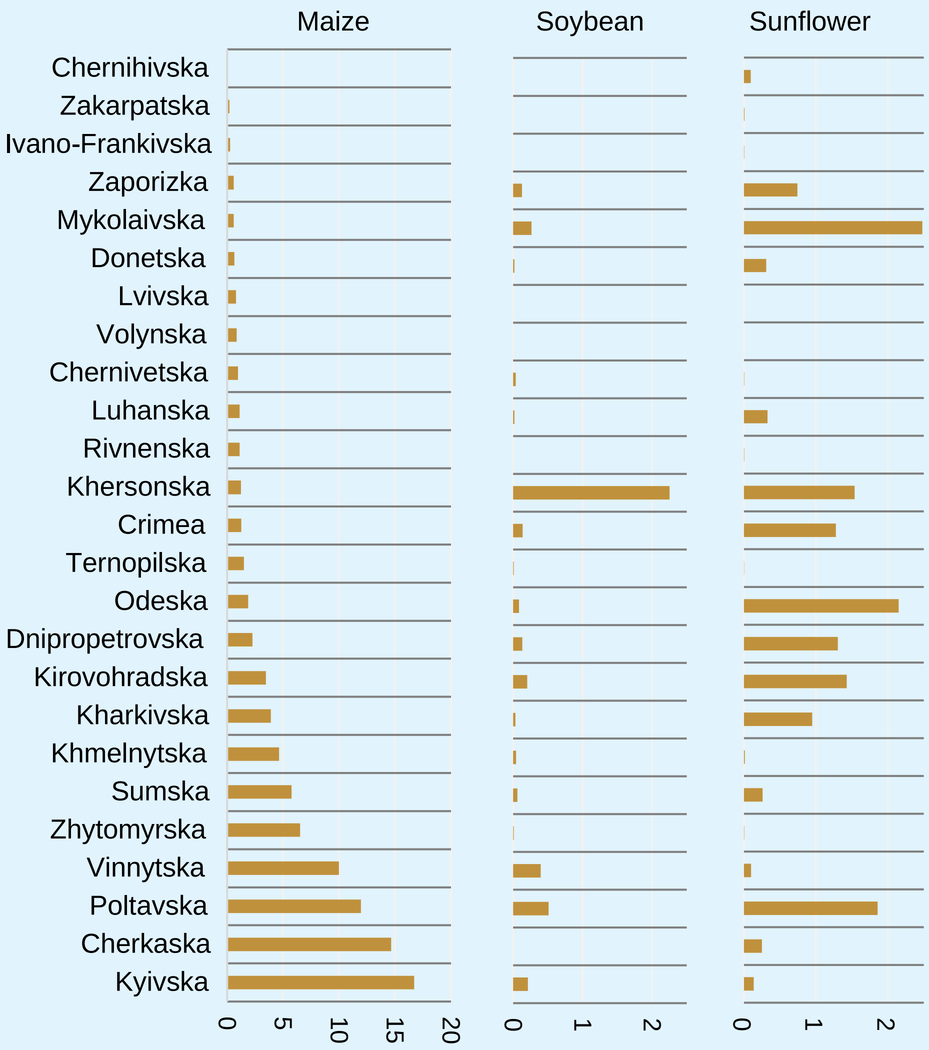
[24] There are many challenges to extending the agricultural impact assessment beyond 2050 and distributional analysis beyond 2030. The uncertainty becomes too high to permit sensible statistical estimations. This challenge is well recognized in the scientific literature and described by the IPCC (2007) 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.

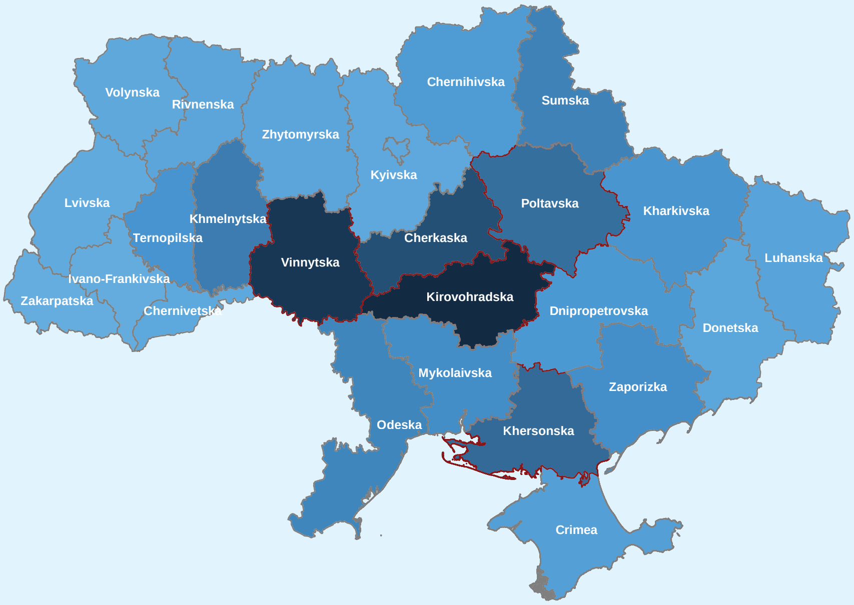
† Based on the findings of the analysis of changes in agricultural production due to climate change. These oblasts show consistent reductions in the value of the agricultural production in 2030 and 2050 under RCP 8.5, assuming no endogenous adaptation measures.

‡ 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.

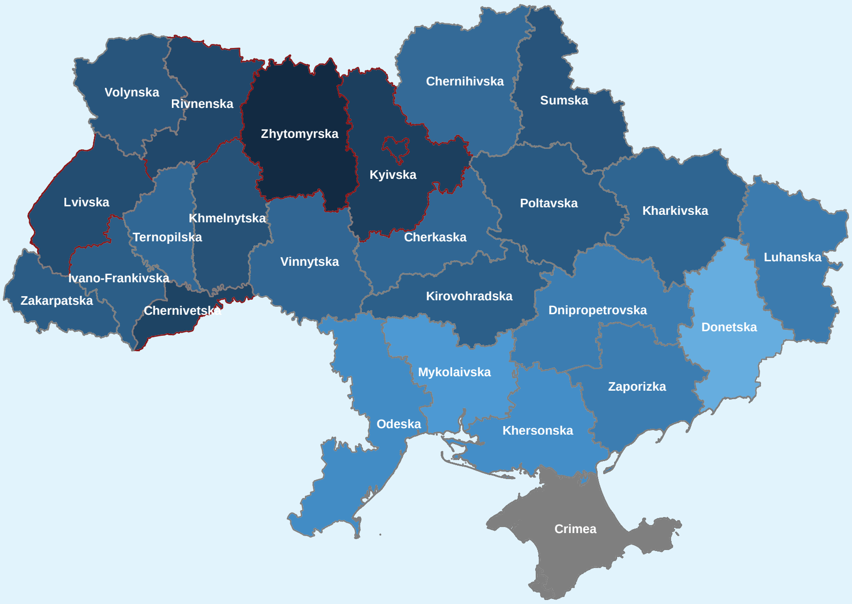
The top five oblasts with the most significant loss in household incomes and the highest increase in poverty and inequality are Lvivska, Zhytomyrska, Kharkivska, Luhanska, and Kirovohradska (Figure 40). Agriculture accounts for less than 5% of GDP in these oblasts and the oblasts are ranked highest in 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



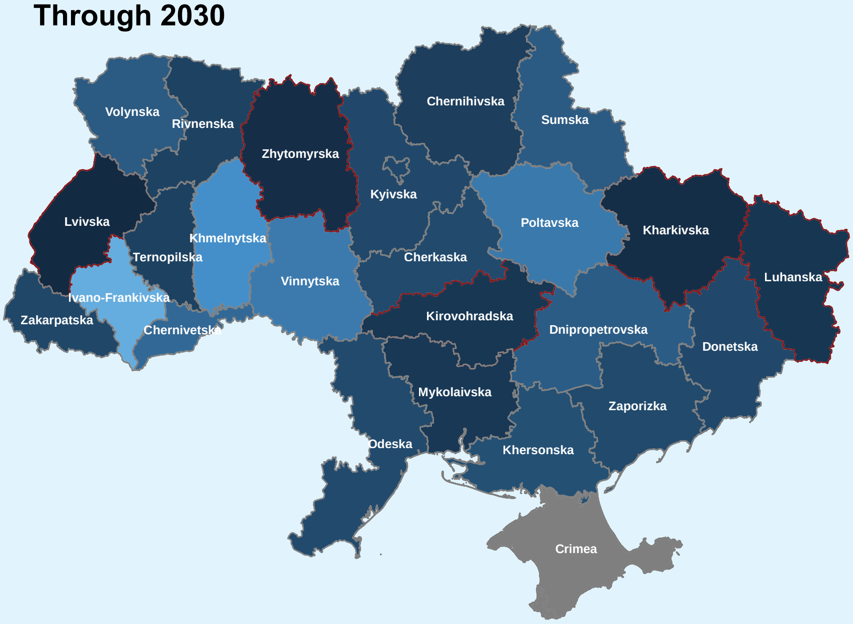
Key: Darker shades of blue denote a higher share of agricultural sector in GDP of Ukraine and oblast. Red borders show the oblasts analyzed in detail in the integrated criteria assessment tables.

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.

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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 (0.11º) 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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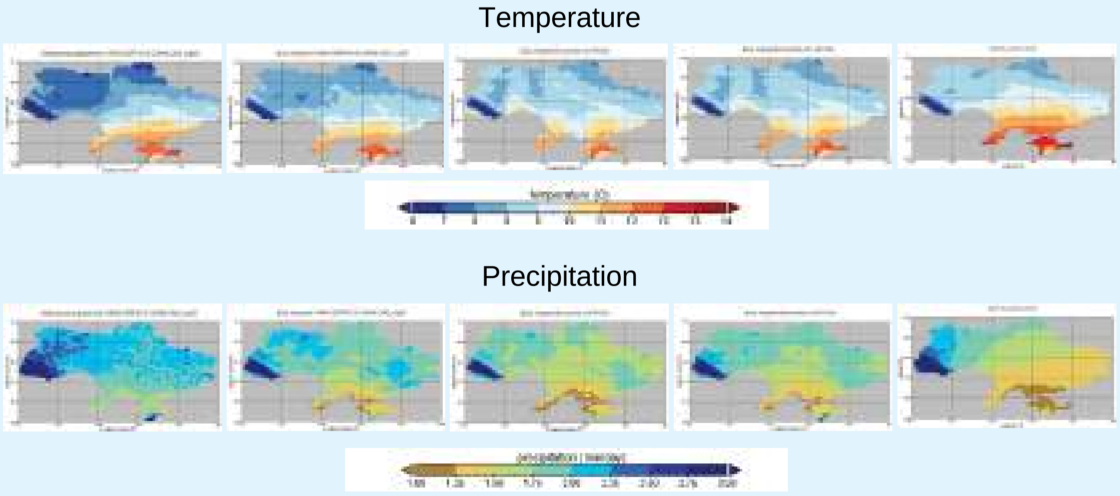
[29] General information on bias-adjustment is provided at https://cordex.org/data-access/bias-adjusted-rcm-data/. A summary of bias adjustment methods applied to CORDEX simulations can be found at http://is-enes-data.github.io/CORDEX_adjust_summary.html.

[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



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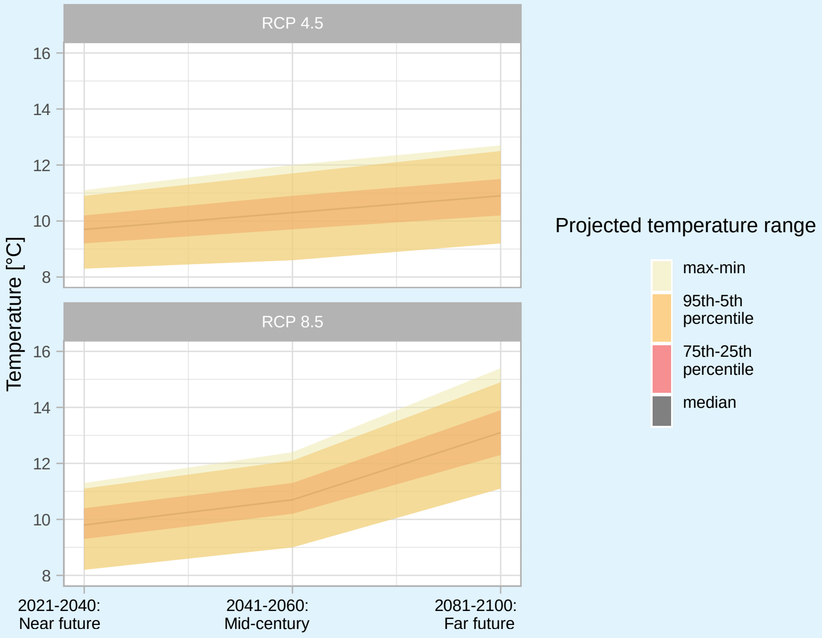
[32] For the periods after 2010, E-OBS climatological data clearly diverges from the reanalysis ERA5 data that heavily relies on modern satellite data (see https://climate.copernicus.eu/climate-reanalysis). One of the reasons could be an absence of up-to-date meteorological data for Ukraine in the European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

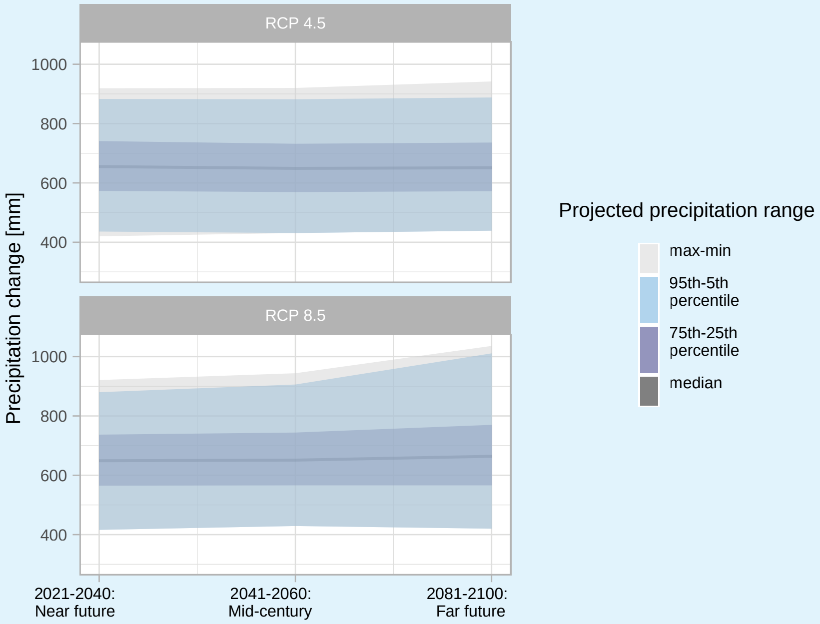
Figure 42: Mean Annual Air Temperature Change (left) and Values for Percentiles over the RCM Ensembles (right) for Three Periods and Two RCPs



	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 2021-2040	2041-2060	2081-2100	RCP8.5 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)

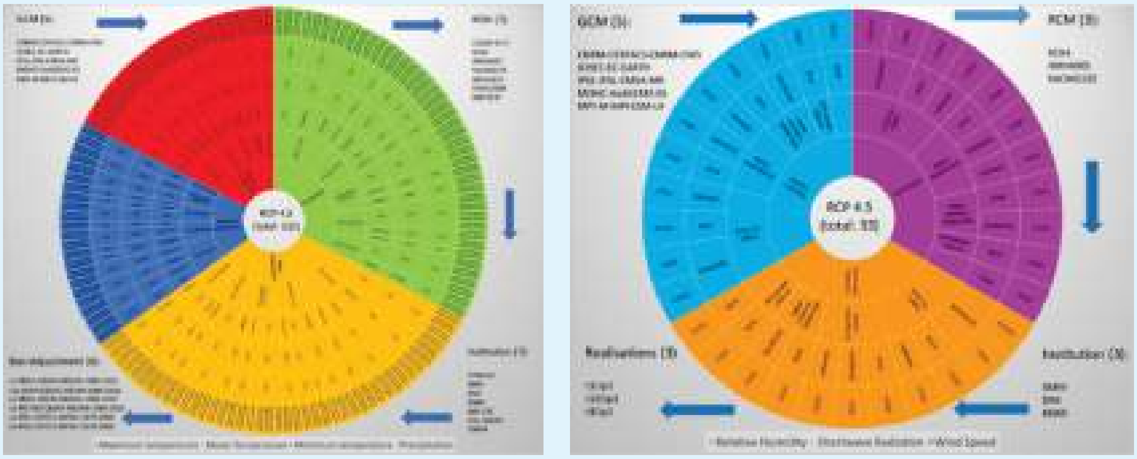
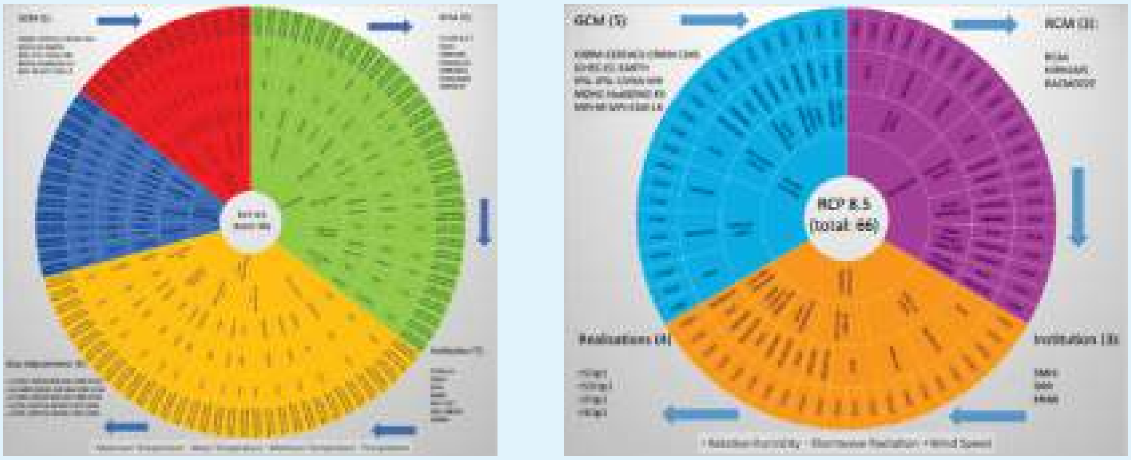


Figure 45: Simulations Prepared for RCP 8.5 for CORDEX-Adjust Output (left) and for Euro-CORDEX Output (right)



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

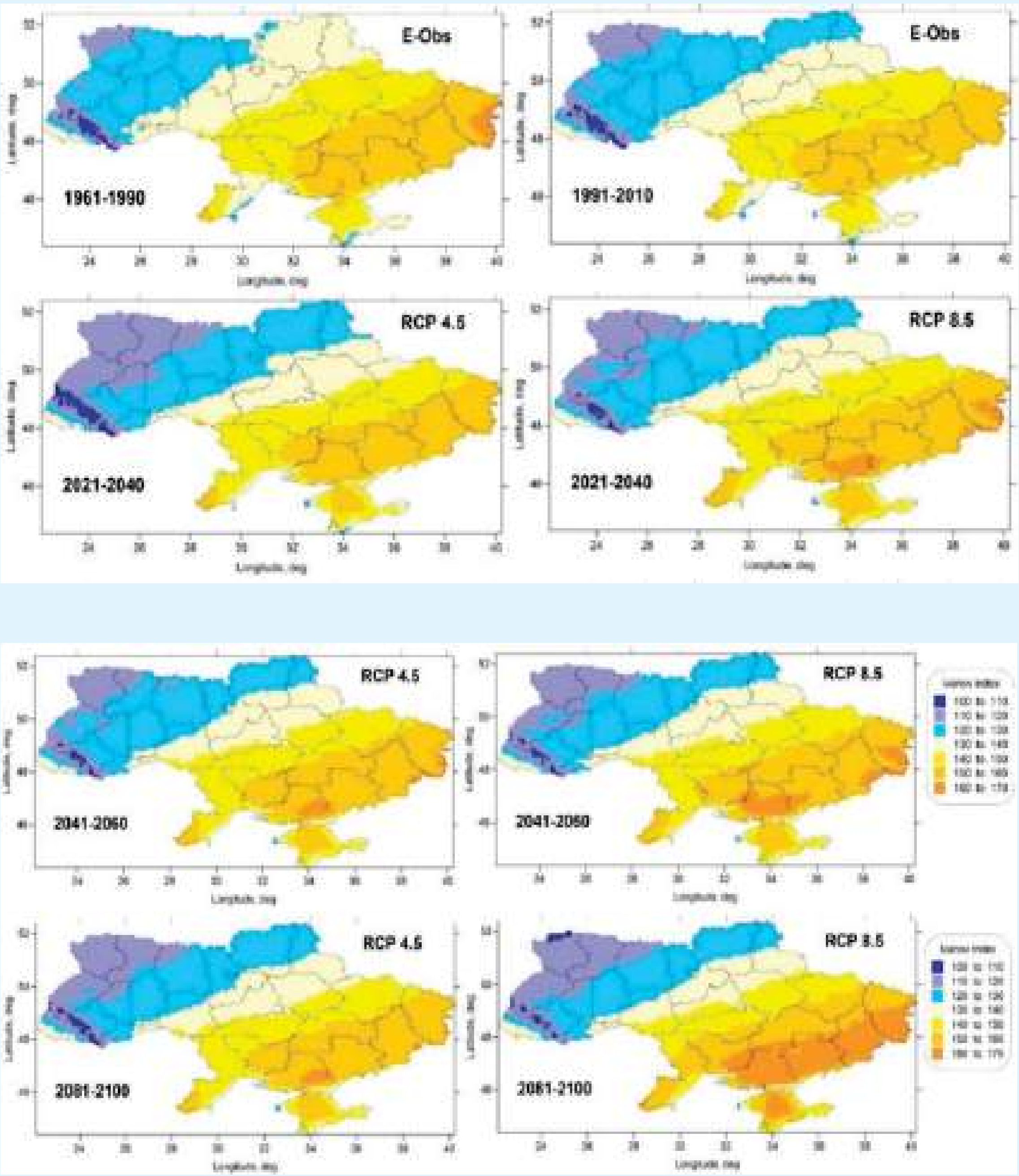
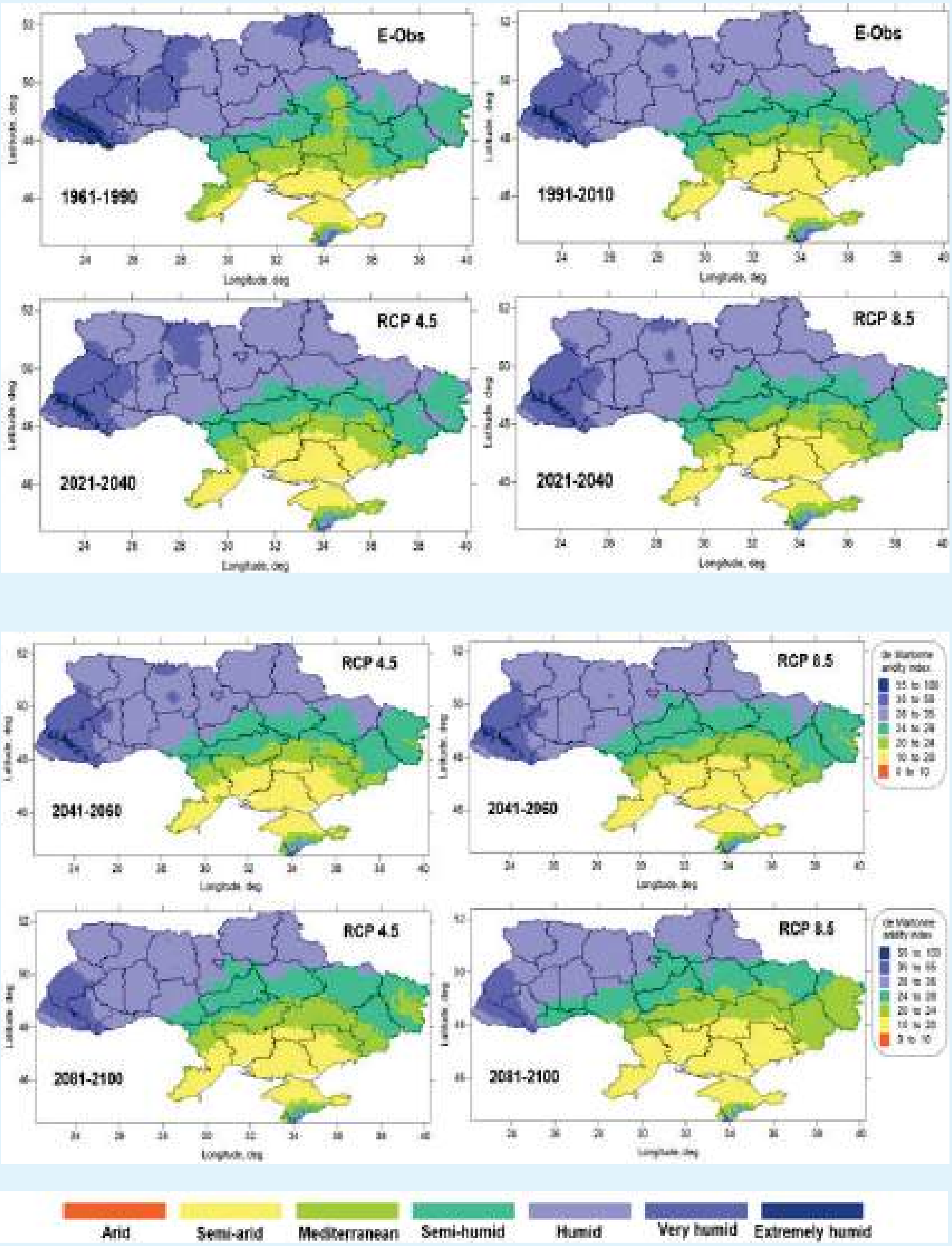


Figure 47: De Martonne Aridity Index



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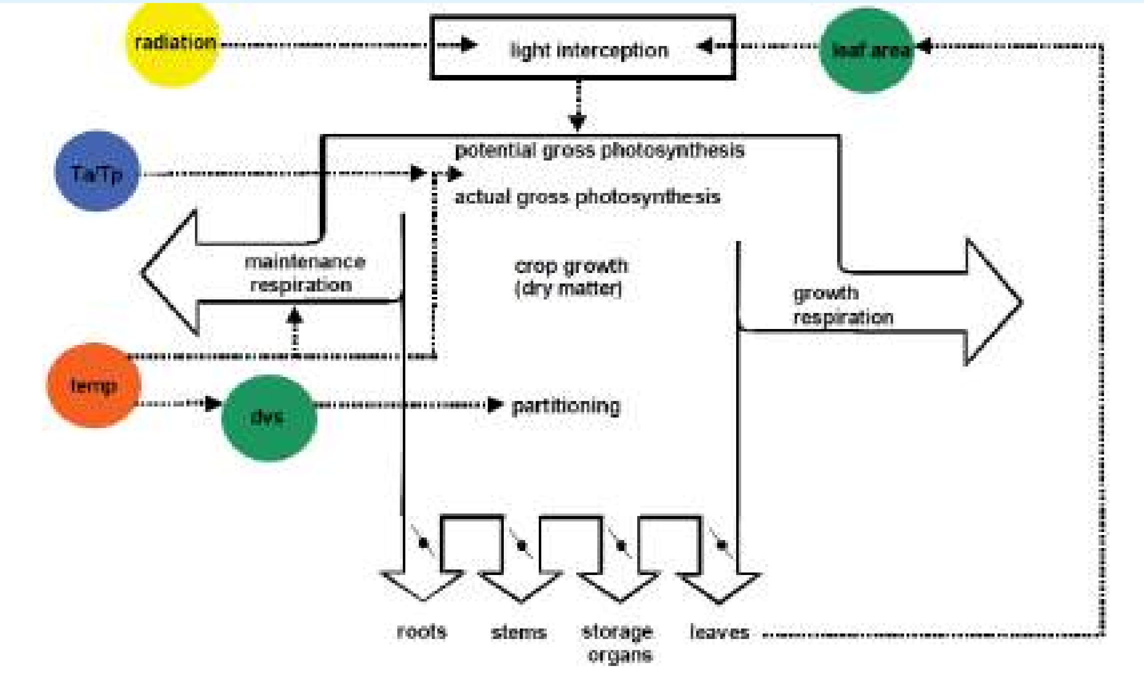
[35] Data is processed for the periods of 2006 – 2015, 2026 – 2035, and 2045 – 2055 with reported central values for 2010, 2030, and 2050, respectively.

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%); $\boldsymbol{\sigma}$ 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 $\boldsymbol{\sigma}$ 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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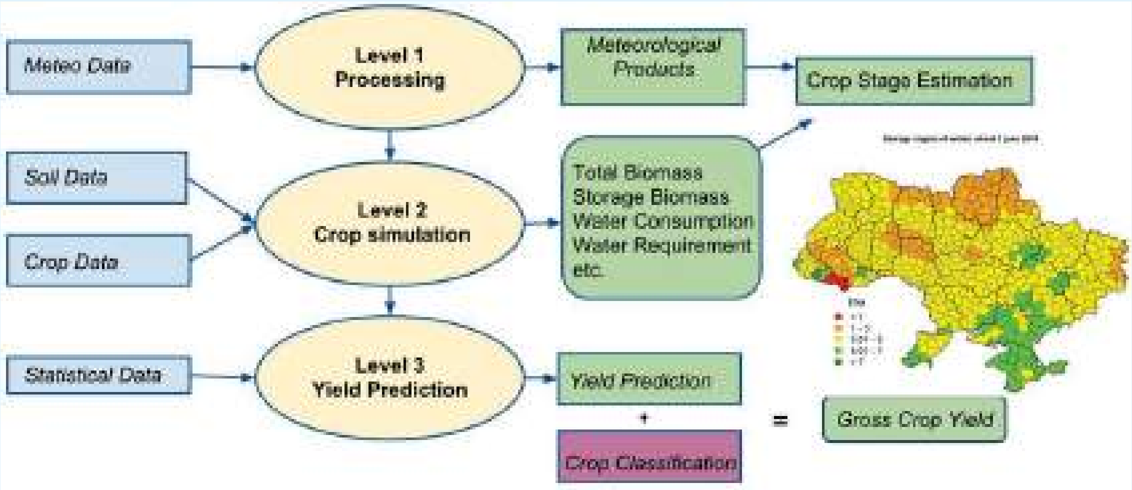
[36] 0-5th and 95-100th percentile ranges are defined as “low likelihood, high impact” outcomes.

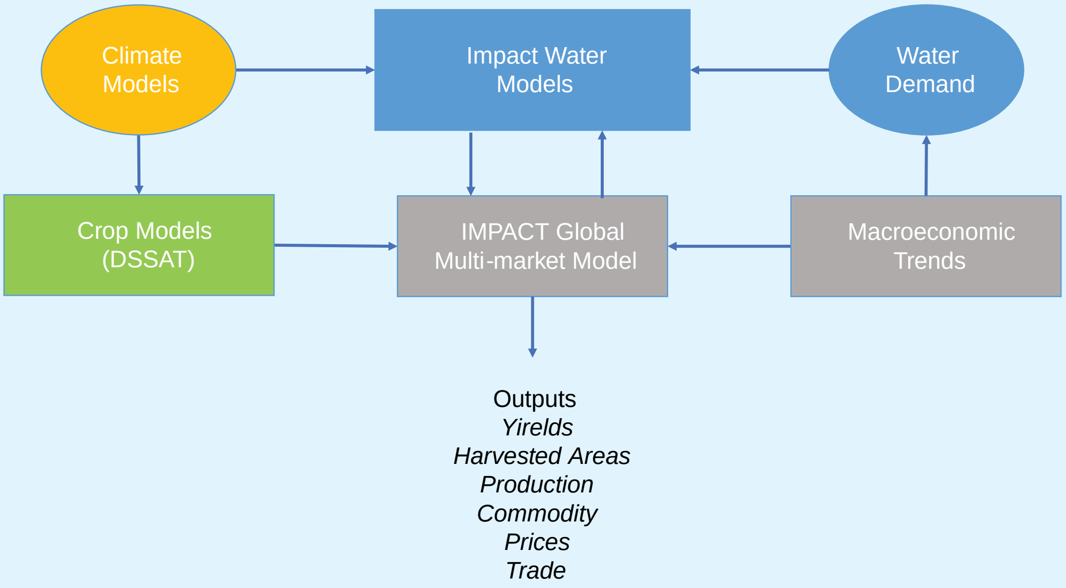
Figure 49: Simulation Model (WOFOST) for Crop Yield Assessment



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



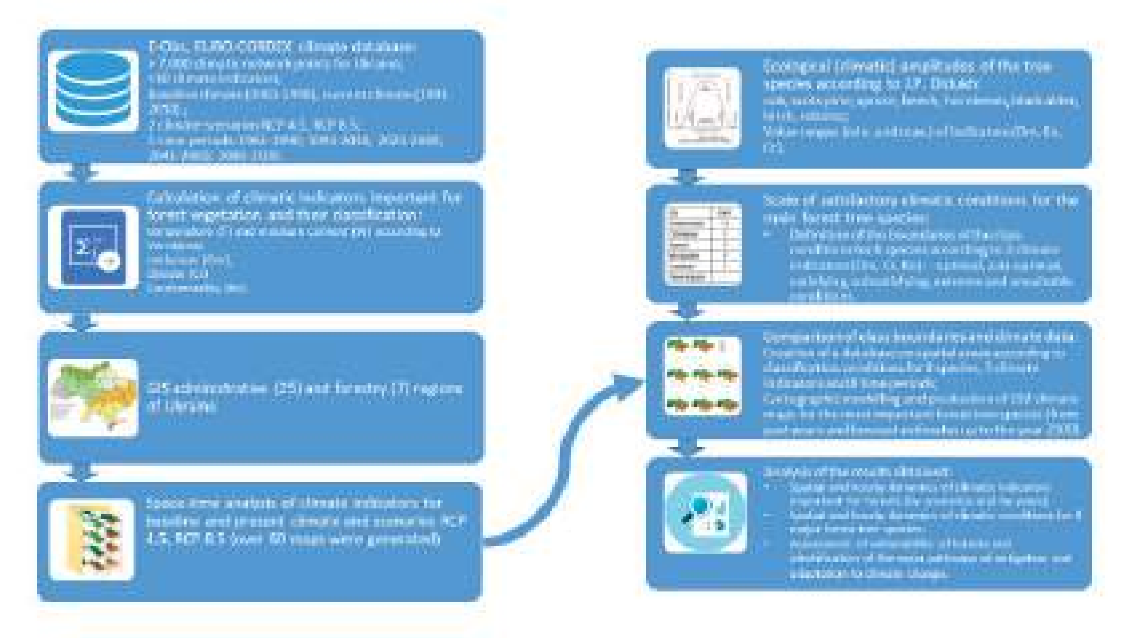
IMPACT is a network of linked economic, climate, water, and crop models. The core of IMPACT is a partial equilibrium multi-market economic model that simulates national and global markets for agricultural commodities and includes 159 countries. The core model is linked to modular models (i.e., climate, 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:

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

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.

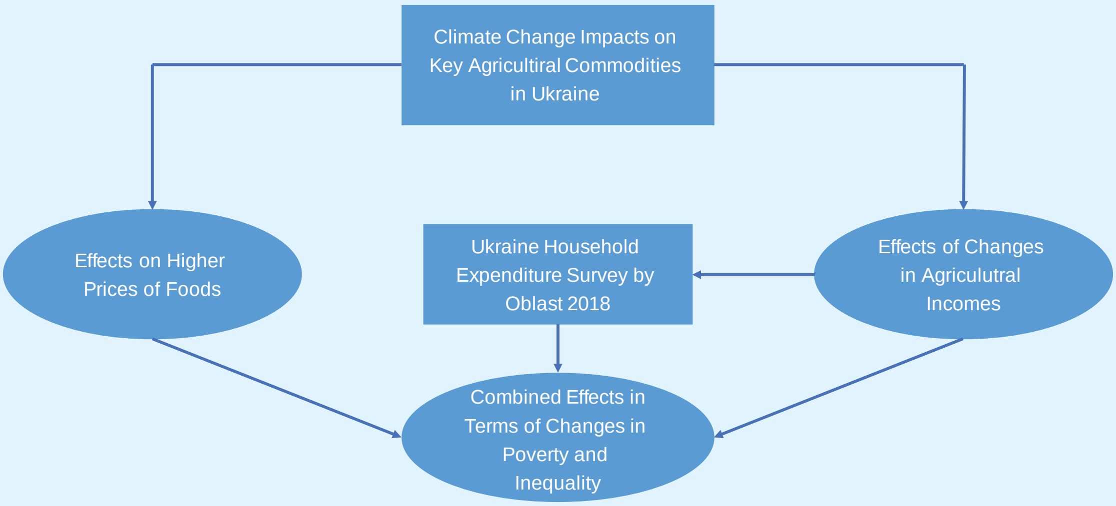
A 1.4 Distributional Analysis

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 –	Describes the deviation of the observed income distribution from the theoretic level of equal distribution of income.
changes in the Gini coefficient	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)	Value of agriculture	Potential risk reduction via irrigation	Loss in the households' income	Poverty Headcount	Impact on inequality Gini coefficient	
	2021-2040 the area under this climate type is rising ▲ or decreasing ▼	2021-2040 change % to base	low or high potential	2021-2040 change % to base	base%+change % to base	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)

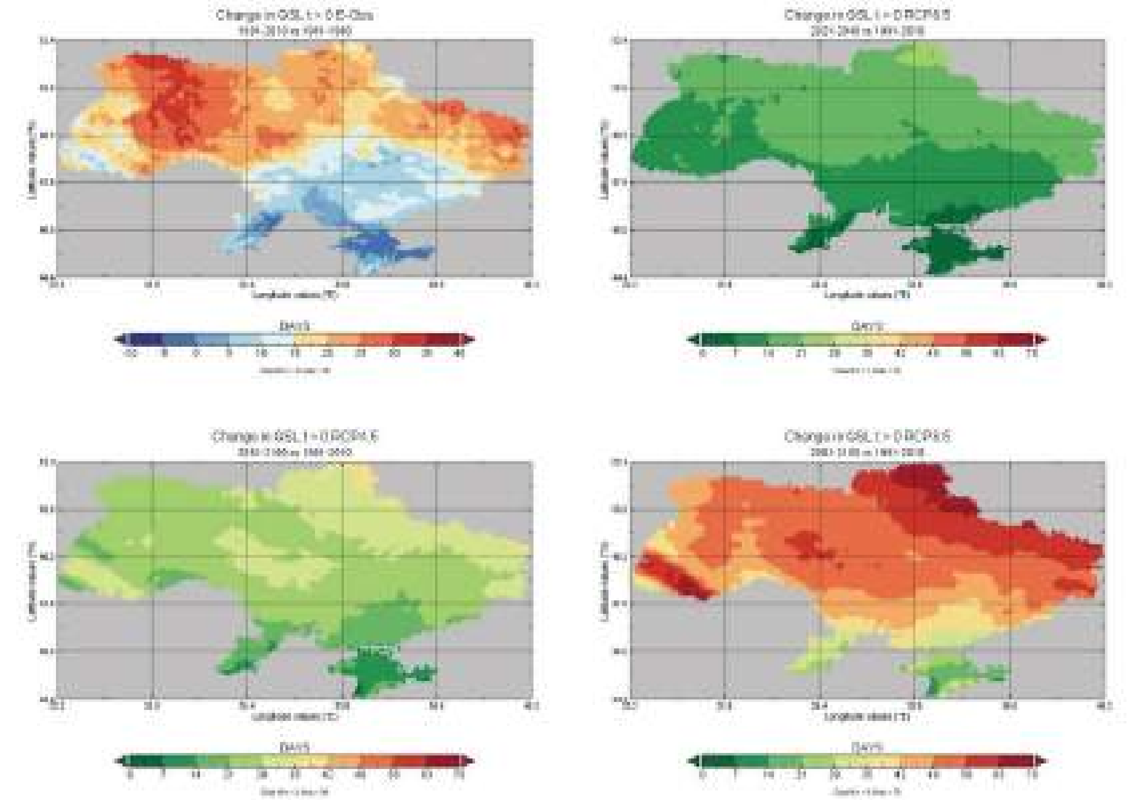


Figure 54: Changes in Growing Season Length in the Recent Period 1991-2010 (E-Obs), Near-Future (RCP 8.5) and the End of the Century (RCP4.5 and RCP 8.5)

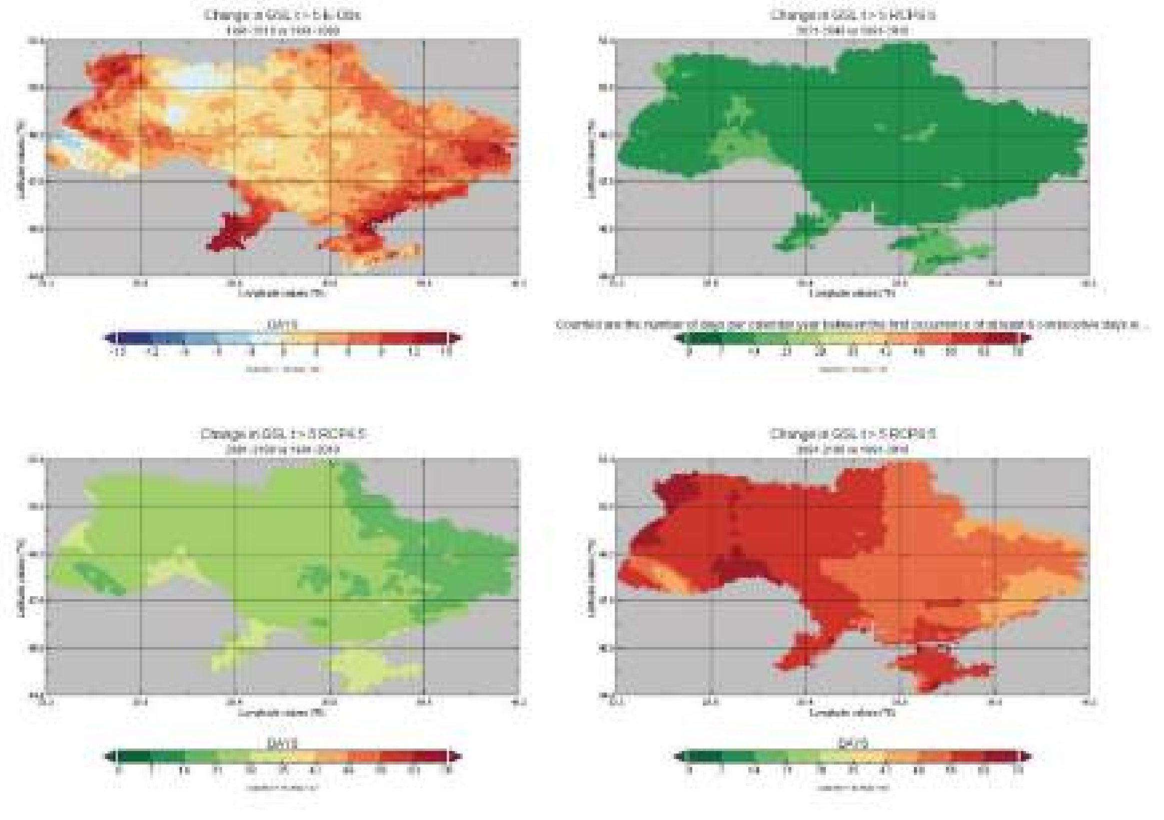


Figure 55: Changes in the Active-Vegetation Season Length in the Recent Period 1991-2010 (E-Obs), Near-Future (RCP8.5) and the End of the Century (RCP4.5 and RC8.5)

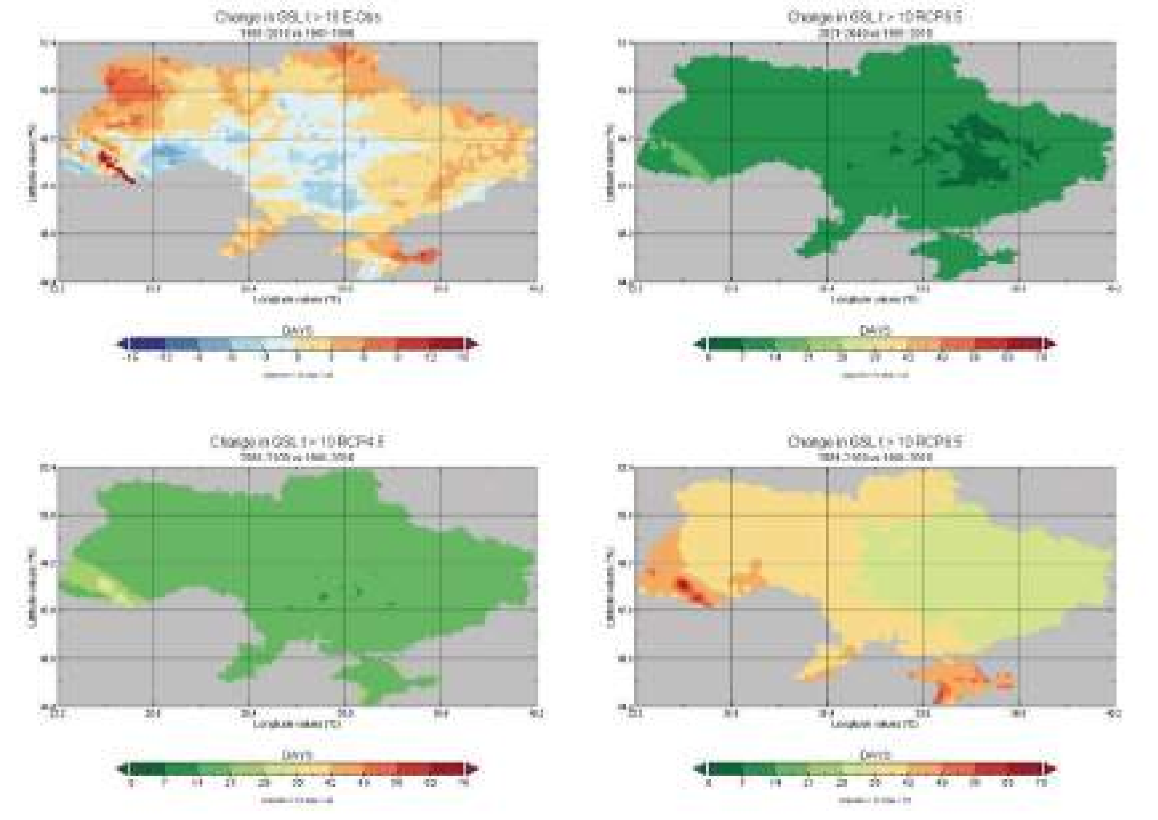
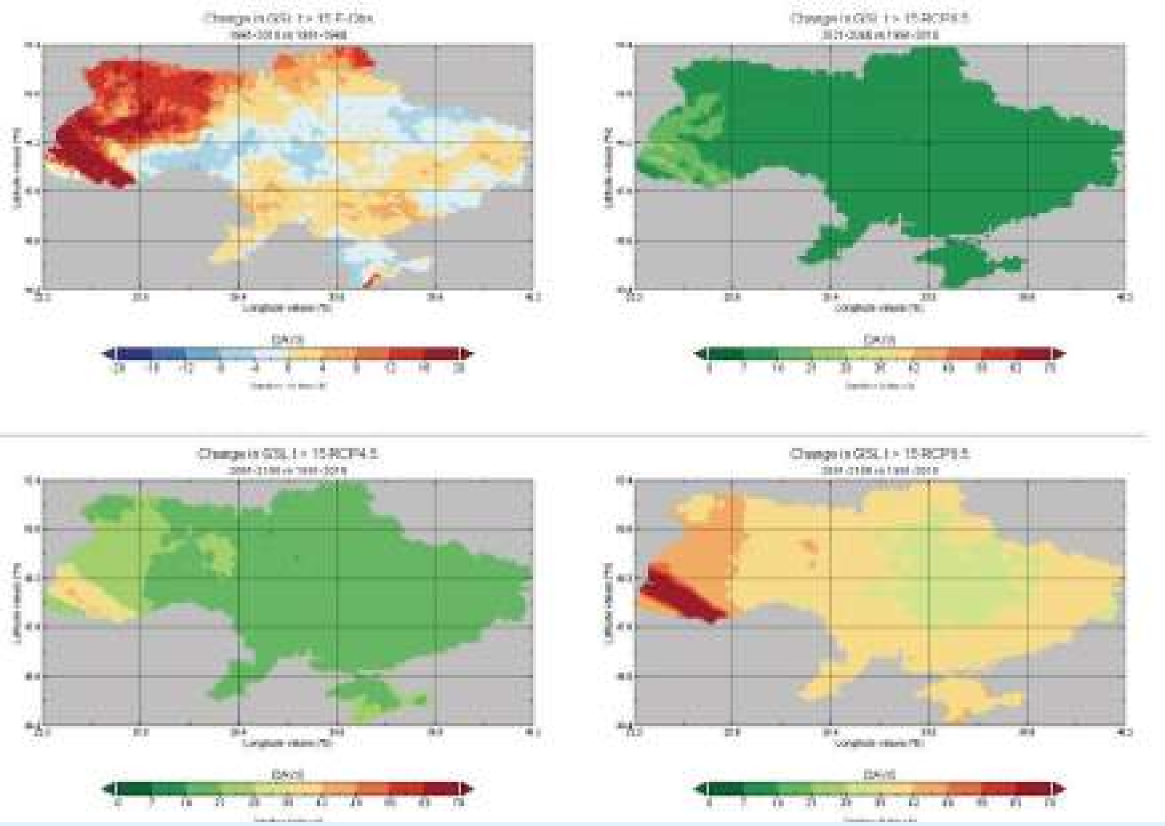


Figure 56: Changes in the Summer Season Length in the Recent Period 1991-2010 (E-Obs), Near-Future (RCP8.5) and the End of the Century (RCP4.5 and RC8.5)



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

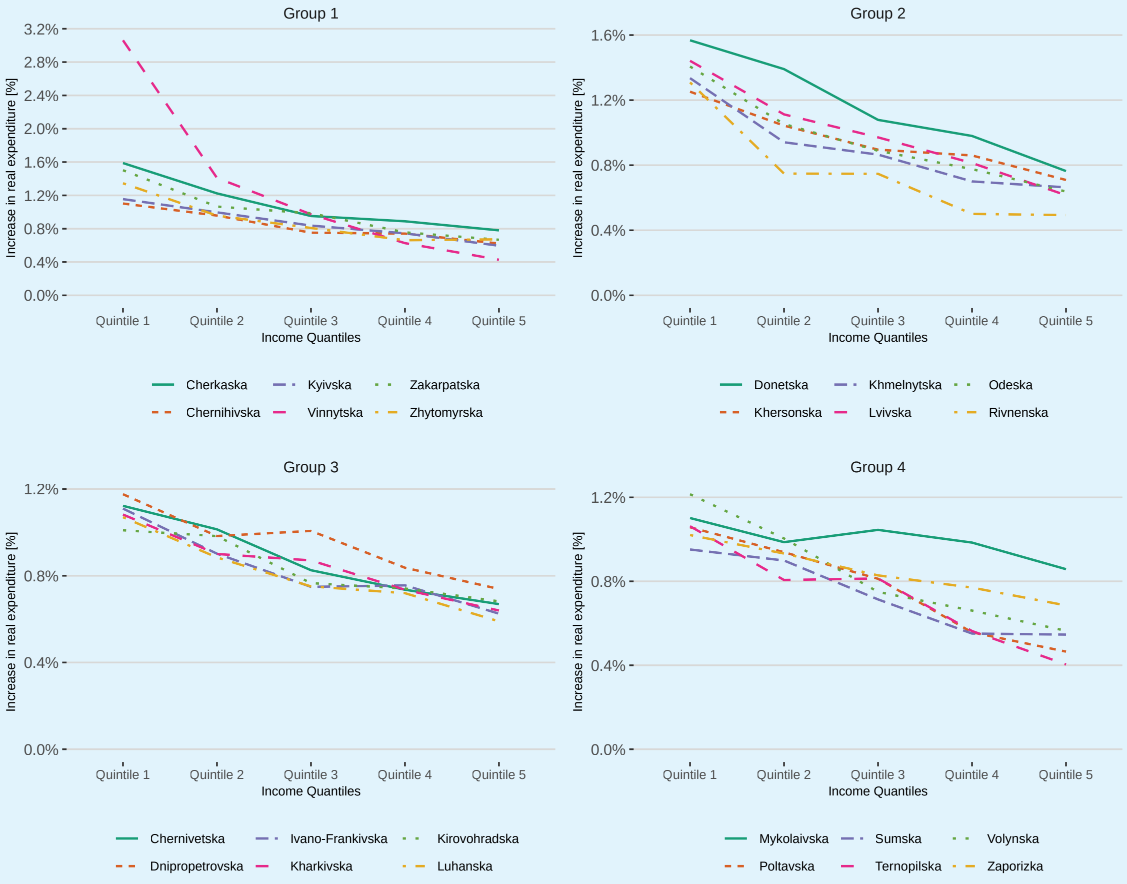

Table 14: Agricultural Production by Type of Unit in Ukraine, 2019

				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

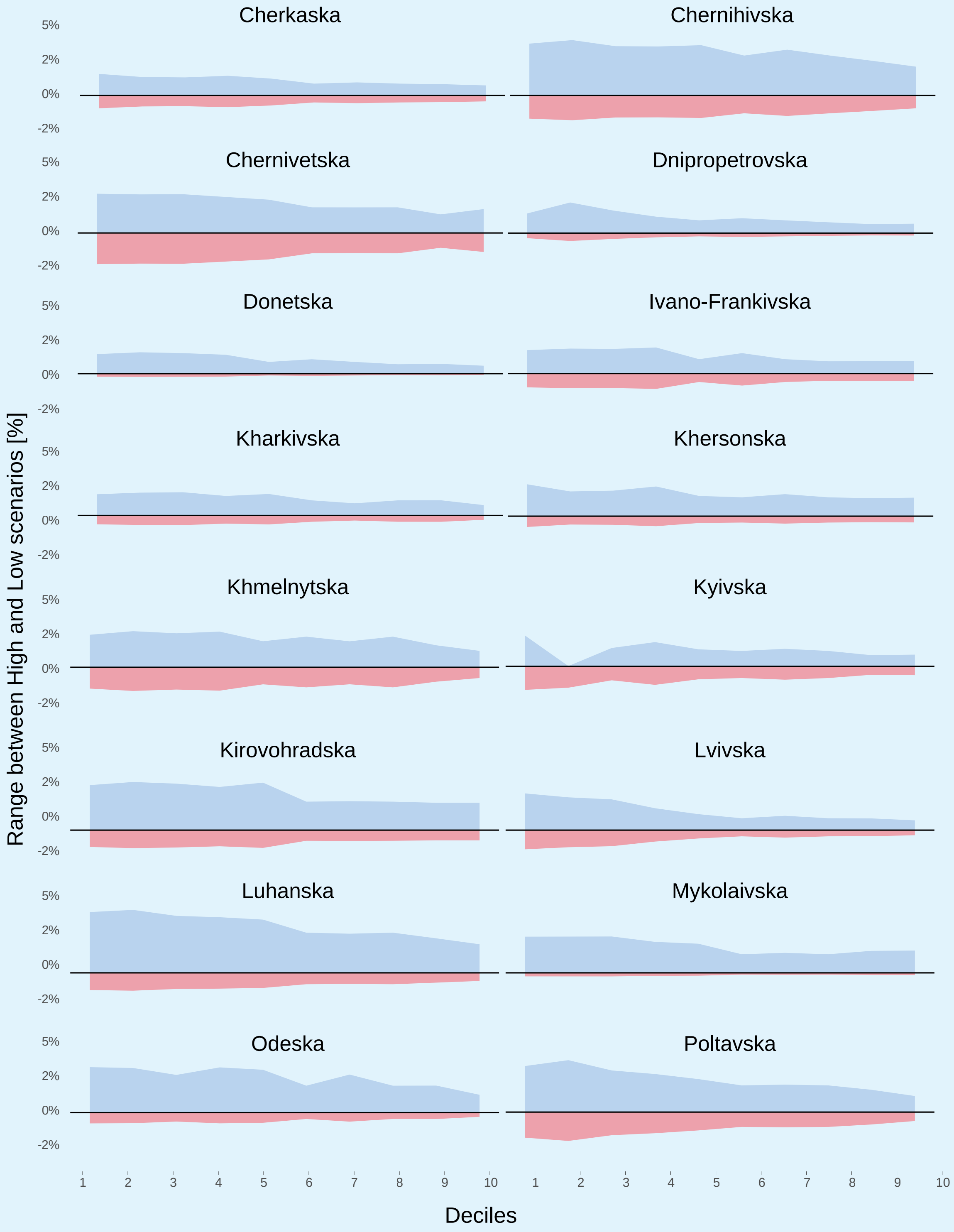
Oblast	Poverty Headcount		Poverty Gap		Severity of Poverty	
	Base %	Change %	Base %	Change %	Base %	Change %
Cherkaska	14.85%	0.00%	15.2%	0.11%	4.0%	0.17%
Chernihivska	16.48%	-1.15%	22.5%	-0.66%	8.9%	-1.32%
Chernivetska	18.18%	-1.91%	15.6%	-0.04%	3.9%	0.01%
Dnipropetrovska	15.07%	-1.44%	20.3%	1.49%	6.4%	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



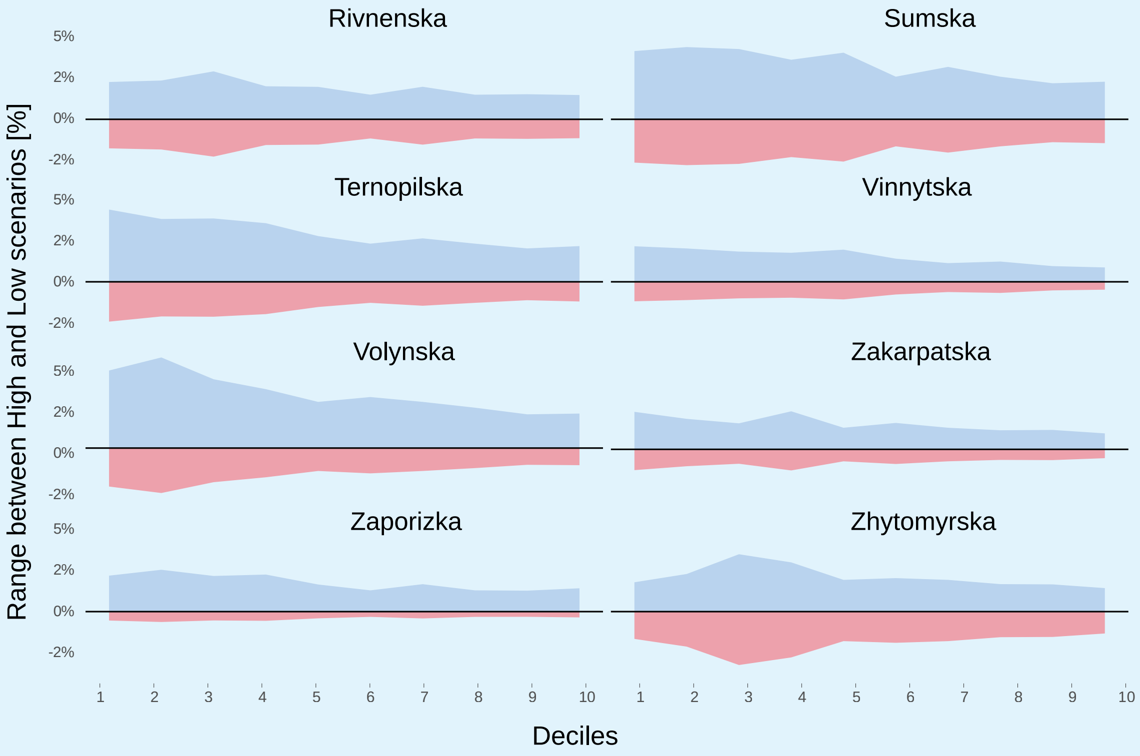

Rivnenska
Sumska
Ternopilska
Vinnytska
Volynska
Zakarpatska
Zaporizka
Zhytomyrska
5%
2%
0%
-2%
Range between High and Low scenarios [%]
1
2
3
4
5
6
7
8
9
10
Deciles

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:

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

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

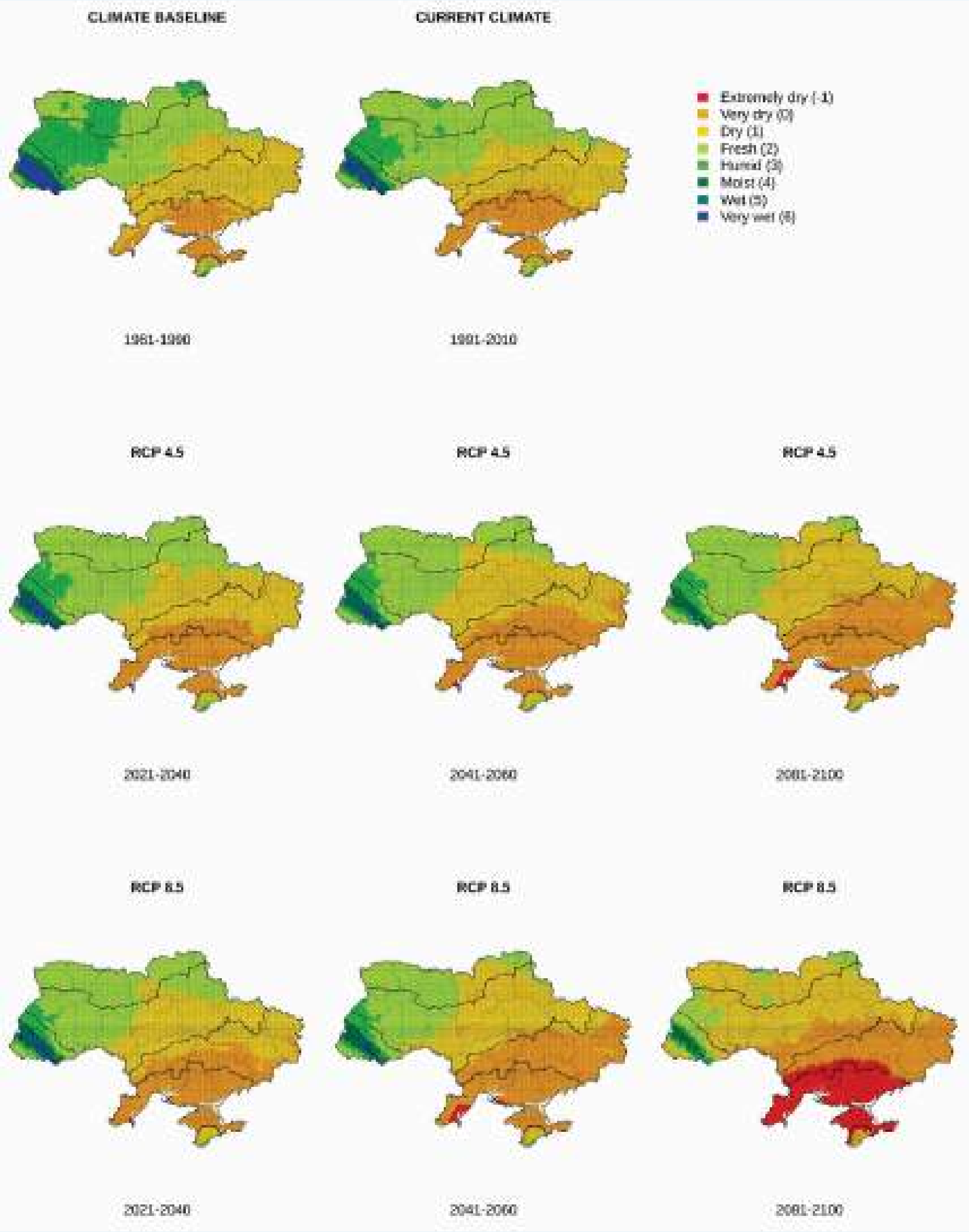


Figure 60: Spatial-Temporal Dynamics of the Suitability Ombroregime (Om) of Climate for Scots Pine (Pinus sylvestris L.)

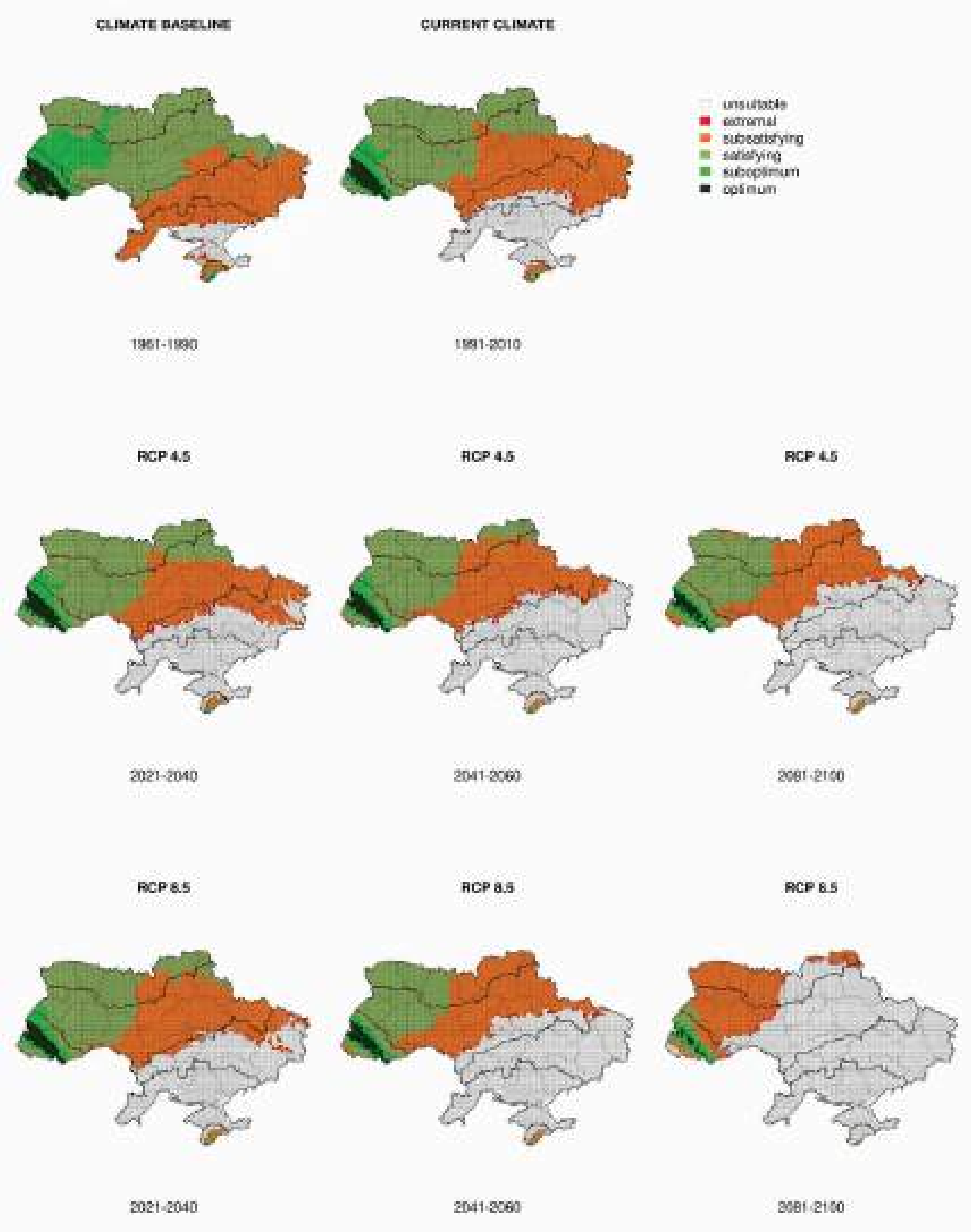


Figure 61: Spatial-Temporal Dynamics of the Suitability Ombroregime (Om) of Climate for English Oak (Quercus robur L.)

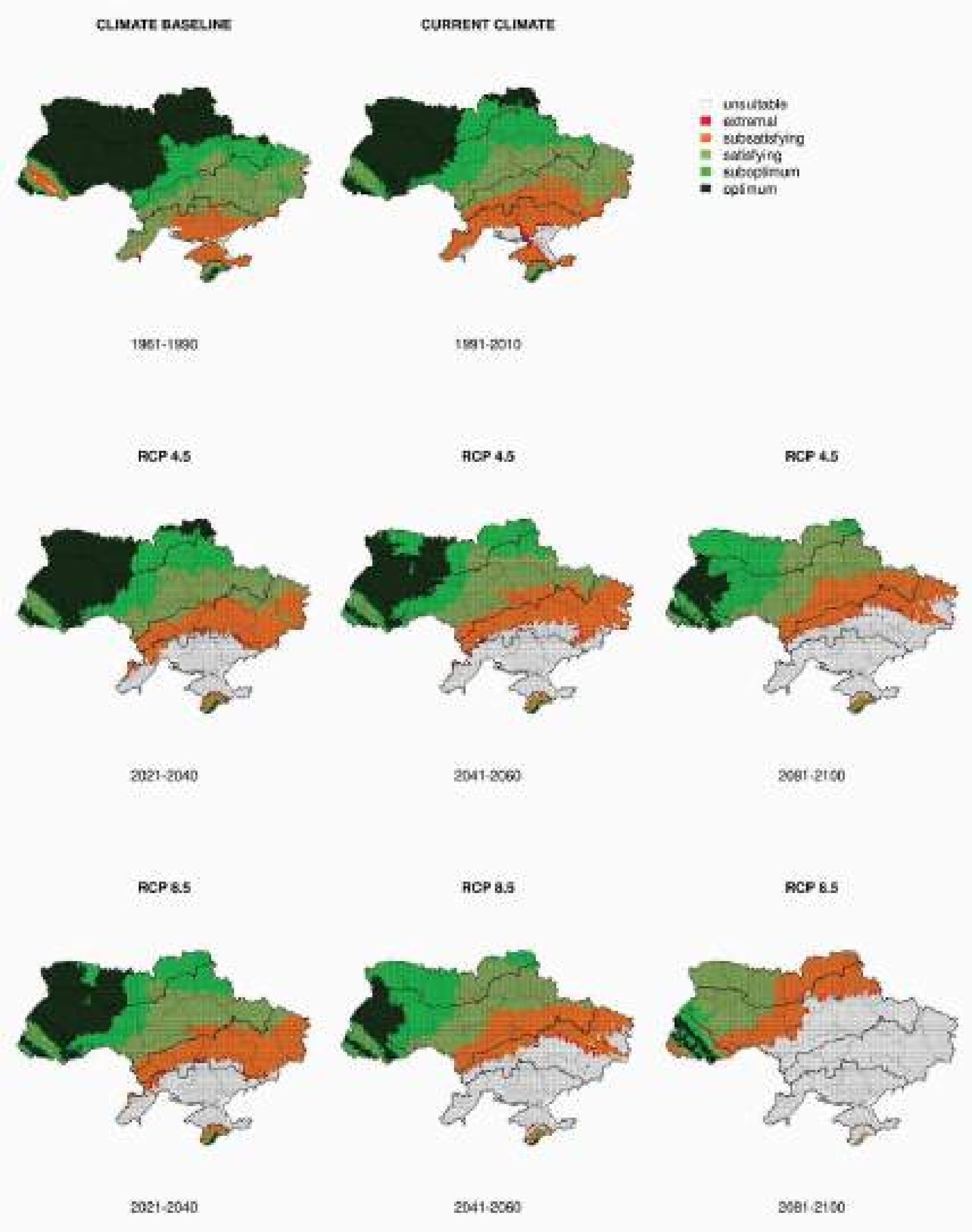


Figure 62: Spatial-Temporal Dynamics of the Suitability Ombroregime (Om) of Climate for European Beech (Fagus sylvatica L.)

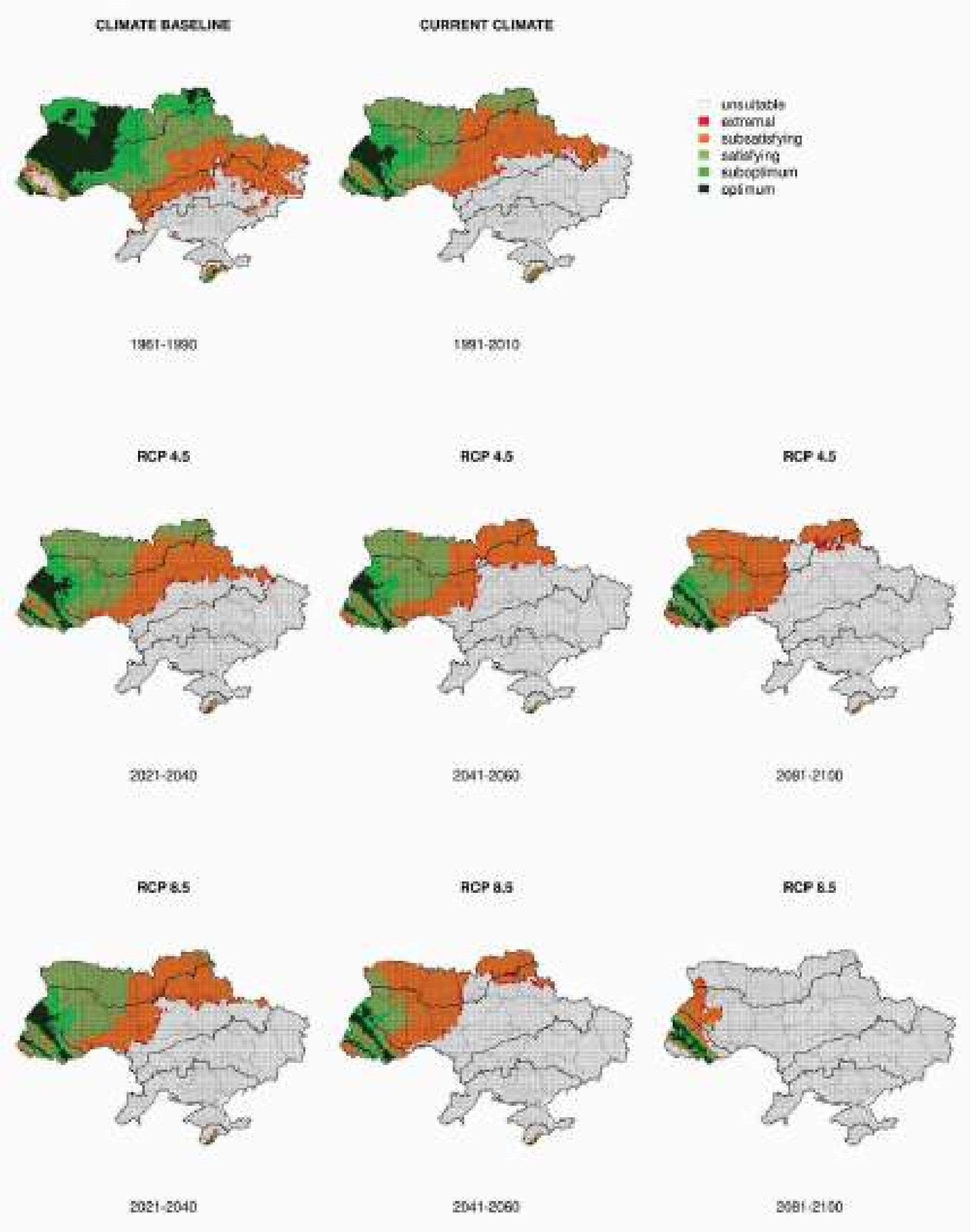


Figure 63: Spatial-Temporal Dynamics of the Suitability Ombroregime (Om) of Climate for Norway Spruce (Picea abias L.)

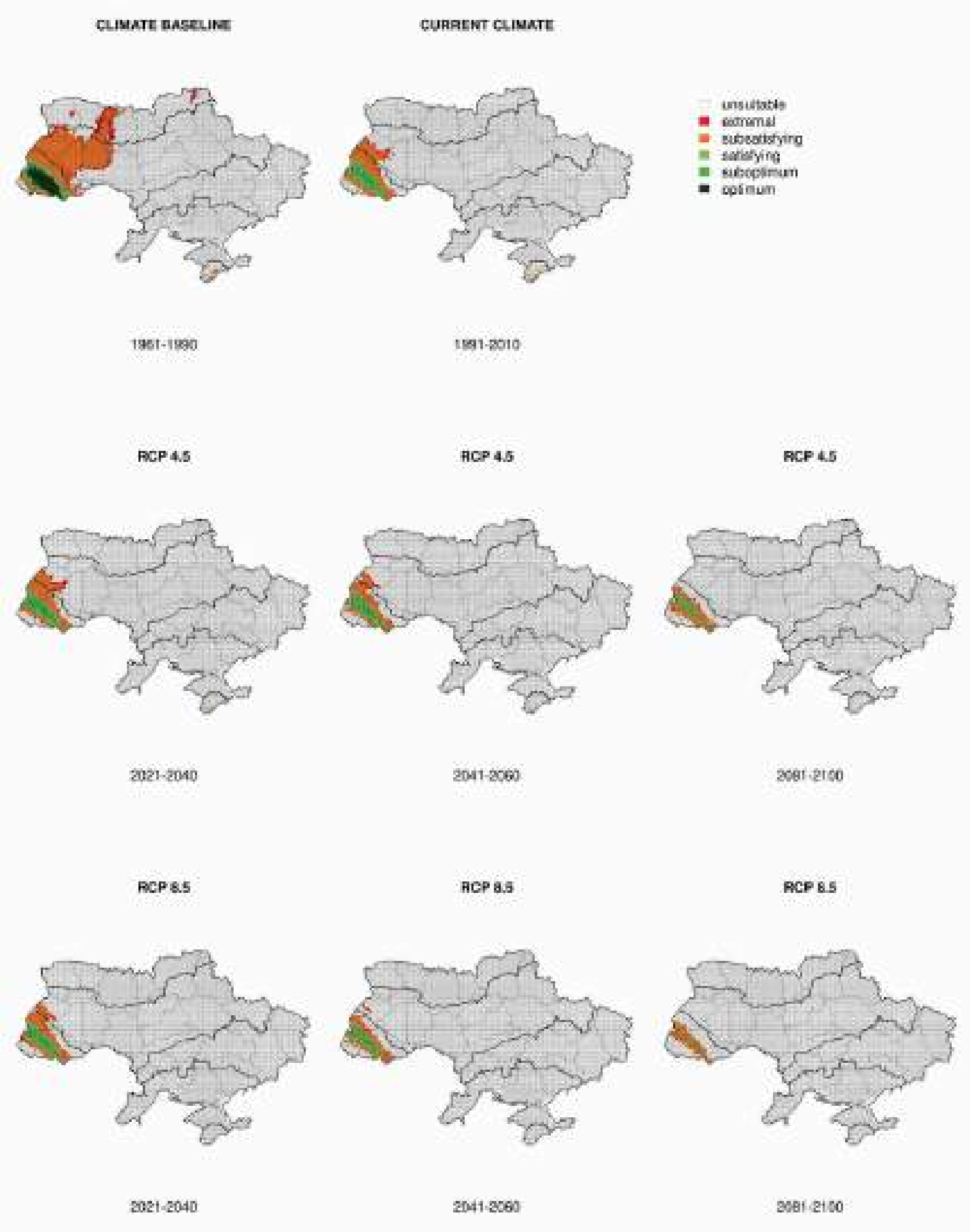
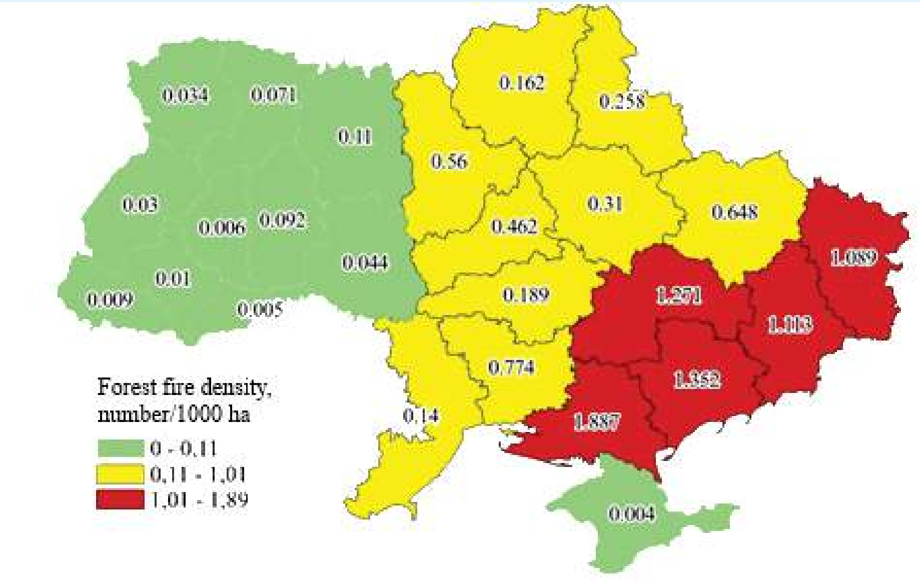


Table 27: Distribution of Forest Areas by Classes of Natural Fire Hazard

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 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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