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C4 Group Project

Climatic prospects of the green energy transition in the city of Zhytomyr

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The aim and relevance

- "Green" transformation of the Zhytomyr energy sector will be an important basis for accelerating the socio-economic development of the city as well as improving the welfare of the population in the face of climate change
- Zhytomyr's case will inspire other cities and communities to develop renewable energy, increase energy efficiency, and contribute to climate change
- The **baseline scenario** and **three "100% RES" scenarios** were created in 2021 for the city of Zhytomyr
- In our group work, **we aimed at investigating the climatic security of these models**



Scenarios of “green” transformation

- **The baseline (Conservative) scenario** is considered as a hypothetical scenario, when the characteristics of most technologies remain unchanged until 2050, as they were in 2017. There is a gradual replacement of technologies only when the service life of certain existing facilities is coming to an end. The cost and efficiency of the technologies that replace the old ones correspond to the current level: the cost decreases over time, and the efficiency increases. At the same time, **most of the existing technologies can still be used during the modelled period (2017-2050).**
- This scenario does not envisage an effective energy and climate policy at the city level.

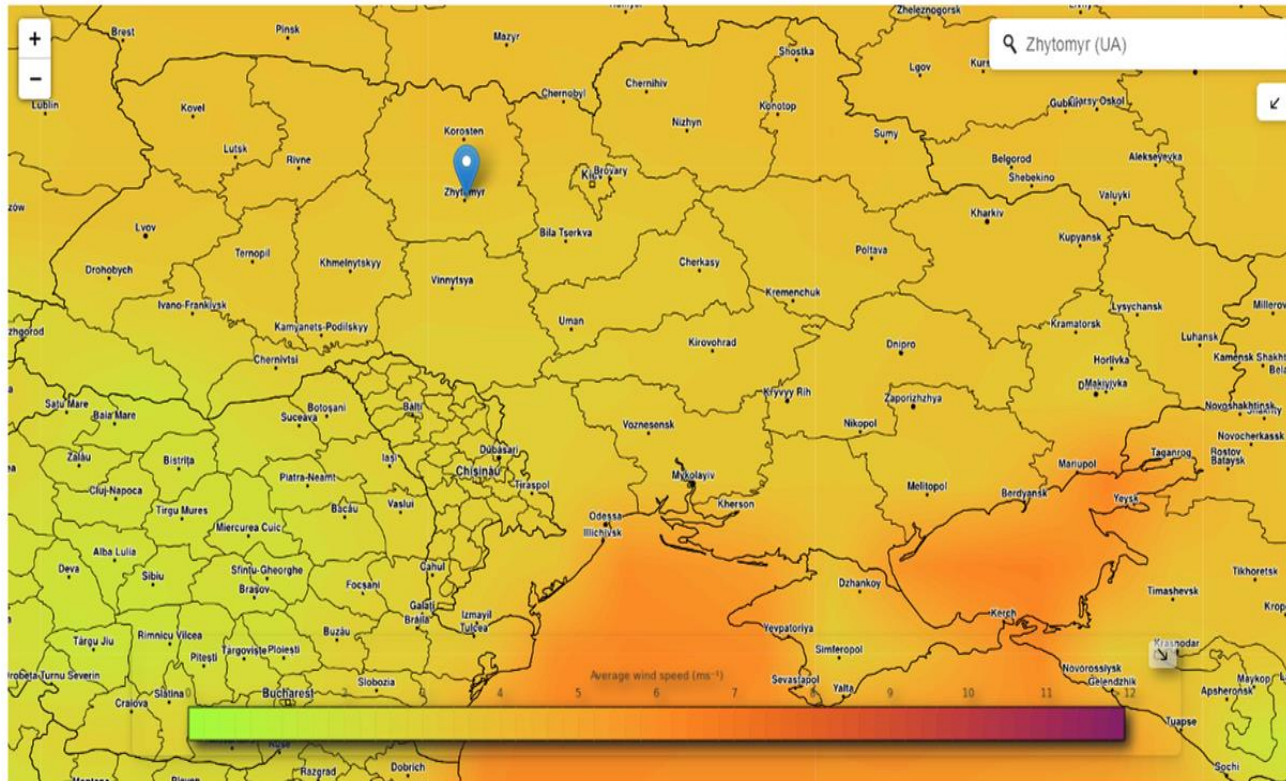
Scenarios of “green” transformation

- **In scenario №1**, it is planned to achieve 100% RES in heat energy and final energy consumption. 50% of electricity production from RES + 50% of electricity imports from RES suppliers from other regions of the country. The possibility of concluding agreements for the supply of electricity from RES appears from 2040.
- **In scenario №2**, it is planned to achieve 100% RES in heat energy and final energy consumption. The volume of electricity production with RES is not less than the total consumption of electricity by the city. Net electricity imports are zero. The possibility of concluding agreements for the supply of electricity from RES appears from 2040.
- **In scenario №3**, it is planned to achieve 100% RES in heat energy and final energy consumption. Volumes of electricity production with RES are not less than 30% of total electricity consumption.

Climatic characteristics

Energy sector	Variables	Data sources	Analysis and visualisation tools
Wind energy	wind force, average wind speed, wind load	Copernicus CDS ERA5-Explorer IPCC WG1 Atlas	https://cds.climate.copernicus.eu/toolbox-editor/108227/031-extract-time-series-and-plot-graph https://cds.climate.copernicus.eu/toolbox-editor/examples/21-calculate-regional-mean-and-anomalies
Solar energy	characteristics of solar radiation and luminosity, the number of clear and semi-clear days	Global Solar Atlas	https://globalsolaratlas.info/map
Bioenergy	the growing season of energy crops (growing degree days)	Copernicus CDS ERA5-Explorer	https://cds.climate.copernicus.eu/toolbox-editor/108227/41-calculate-gdd-1x1
General	heavy precipitation, extreme temperatures, transition of average daily temperature through +8C	Copernicus CDS ERA5-Explorer	https://cds.climate.copernicus.eu/toolbox-editor/examples/11-calculate-time-mean-and-standard-deviation https://cds.climate.copernicus.eu/toolbox-editor/examples/21-calculate-regional-mean-and-anomalies https://cds.climate.copernicus.eu/toolbox-editor/108227/31-calculate-trends-1x1

Zhytomyr: General Information



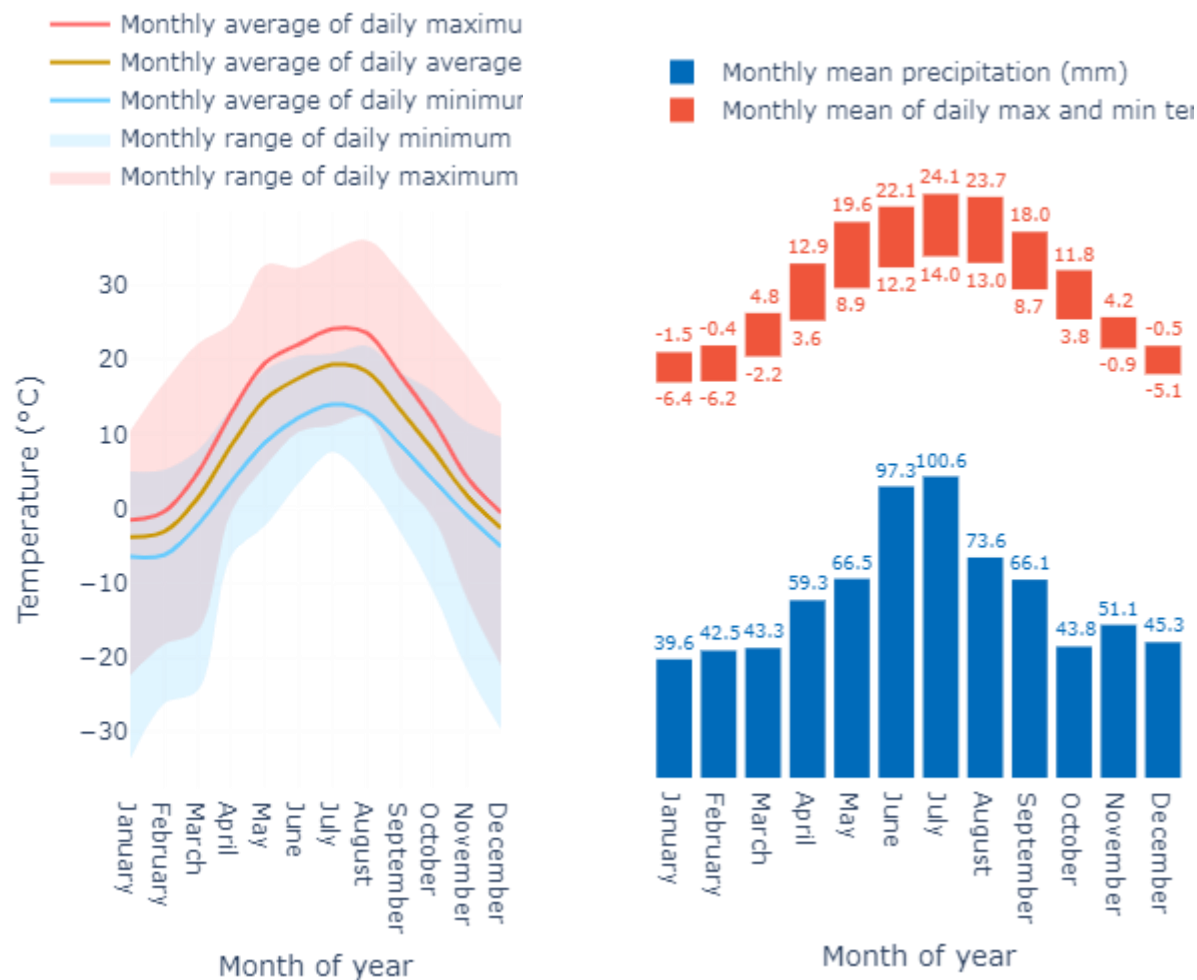
- Location: **E Europe, Ukraine**
- Position: **50.24°N, 28.66°E**
- Status: **Regional Capital City**
- International Status: **an α -level regional city**
- Origin: **884 AD**
- Area: **~61 km²**
- Population (as by 01.2021): **264 000**
- Type of climate: a **warm-summer semi-continental** climate over the 1981-2010 period.

Sources:

<https://uk.wikipedia.org/wiki/%D0%96%D0%B8%D1%82%D0%BE%D0%BC%D0%B8%D1%80>

<https://cds.climate.copernicus.eu/cdsapp#!/software/app-era5-explorer?tab=app>

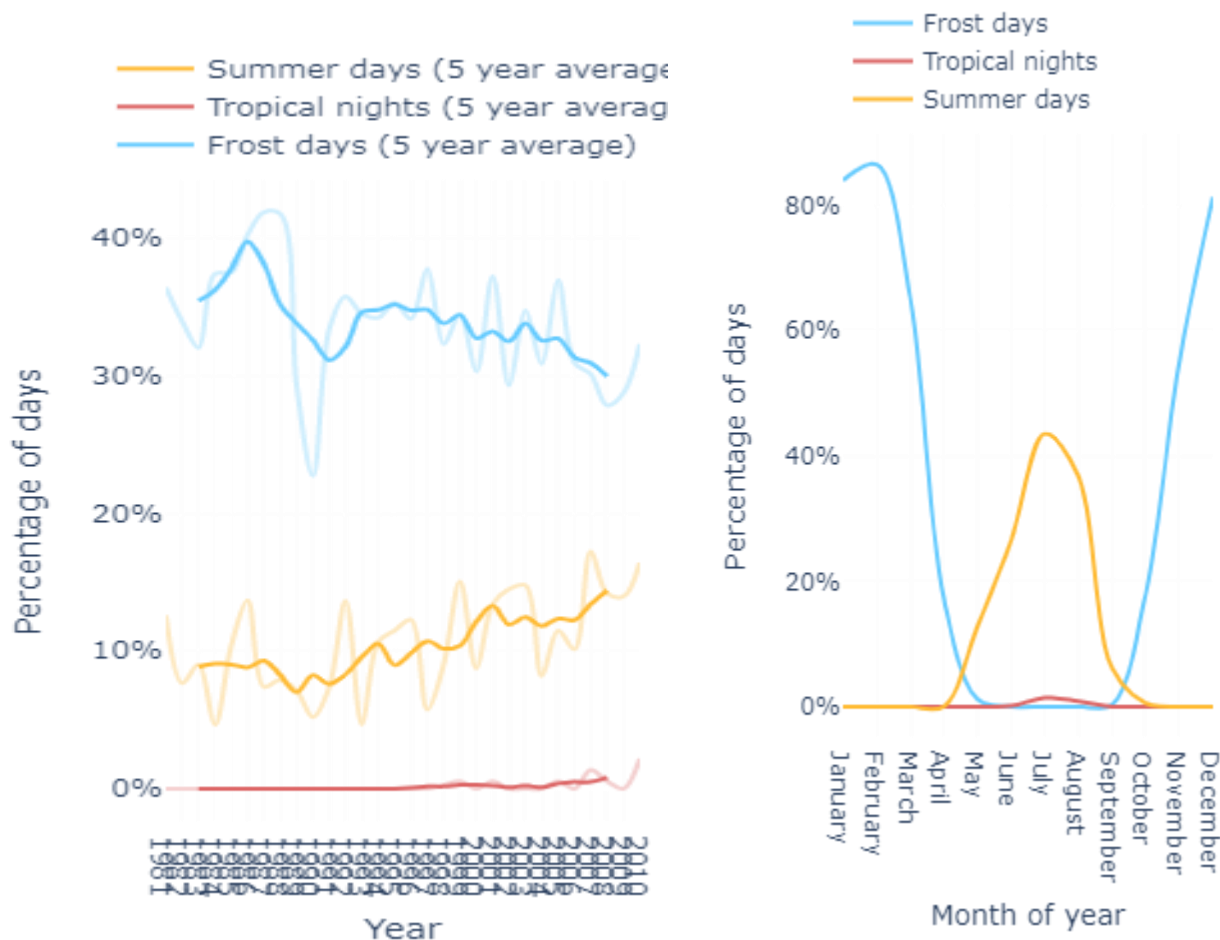
Zhytomyr: Climatology Plot – Temperature & Precipitation (1981-2010)



- For the 1981-2010 reference period, the annual average temperature in Zhytomyr was **7.8°C**.
- Monthly average temperature ranged from **-3.8°C** (January) to **19.4°C** (July).
- For the 1981-2010 reference period, the mean annual total precipitation in Zhytomyr was **624.1 mm**.
- Monthly average precipitation ranged from **39.6 mm** (January) to **100.6 mm** (July).

Source:
<https://cds.climate.copernicus.eu/cdsapp#!/software/app-era5-explorer?tab=app>

Zhytomyr: Frost and Summer Days (1981-2010)



The graph shows the typical monthly percentage of days in Zhytomyr which are classified as **frost days**¹, **summer days**² or **tropical nights**³ averaged over the 1981-2010 period.

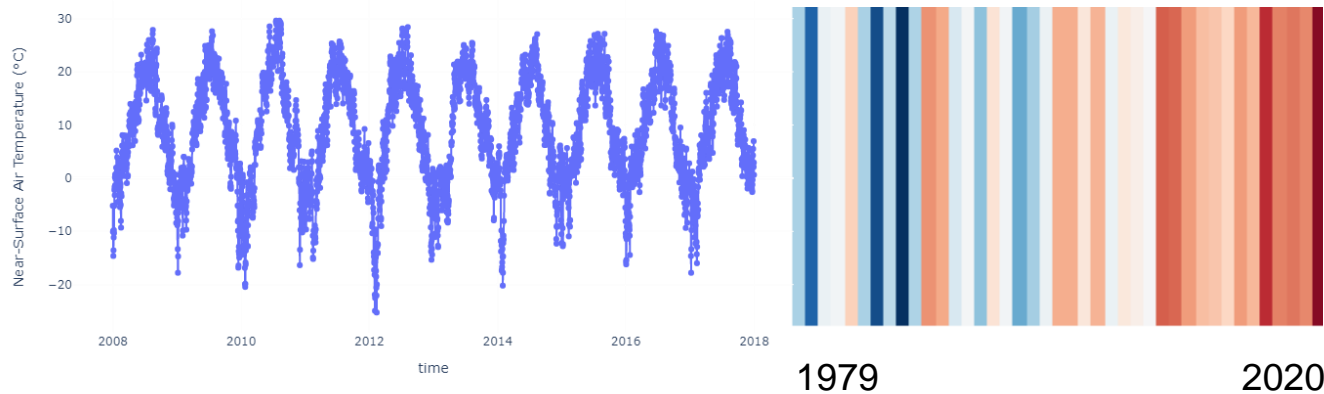
¹**Frost day**: a day in which the minimum temperature is below 0°C.

²**Summer day**: a day in which the maximum temperature is above 25°C.

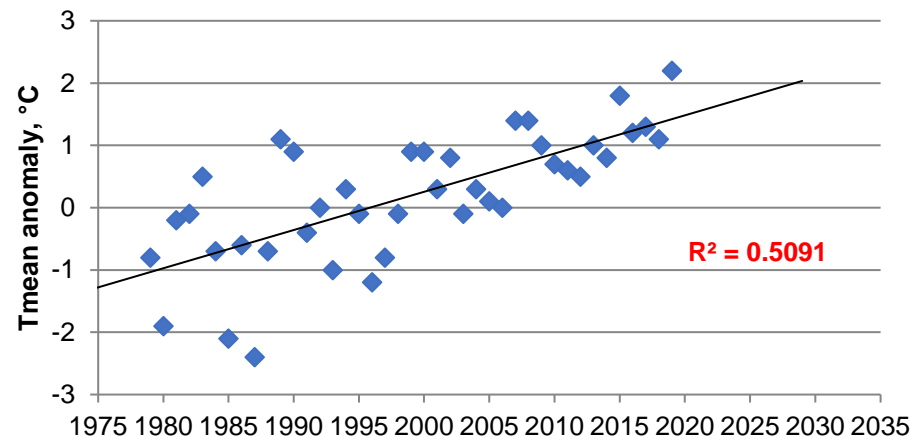
³**Tropical night**: a day in which the minimum temperature is above 20°C.

Source:
<https://cds.climate.copernicus.eu/cdsapp#!/software/app-era5-explorer?tab=app>

Zhytomyr: Climate Trends – Mean Annual Temperature Anomalies



Annual mean T anomalies (°C) in the city
of Zhytomyr (UA)



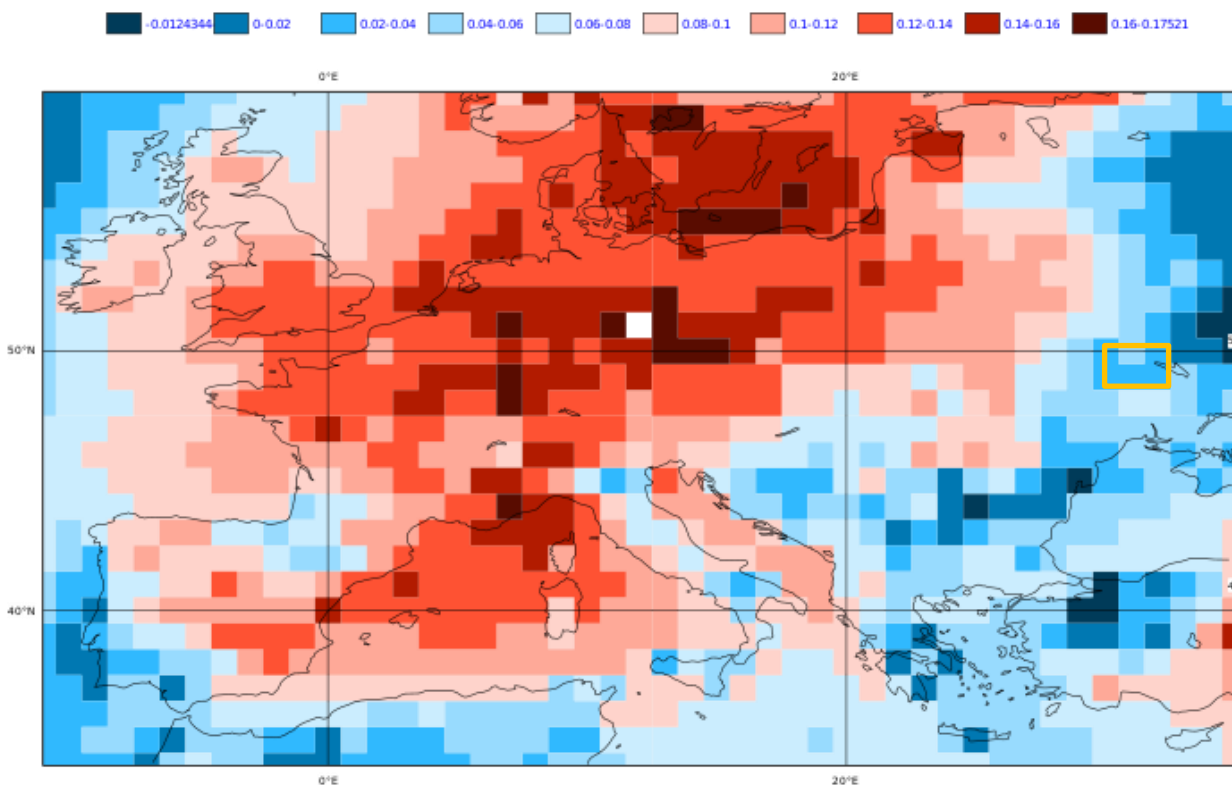
- Warming stripes provide an at-a-glance view of yearly temperature trends in Zhytomyr for the period 1979-2020.
- The colour of each stripe represents the **temperature anomaly** for a given year, or how much warmer (red) or colder (blue) that year was relative to the **long-term reference** period of 1981-2010.
- We found **a clear trend towards increasing mean annual temperatures** over last 20-25 years

Source:

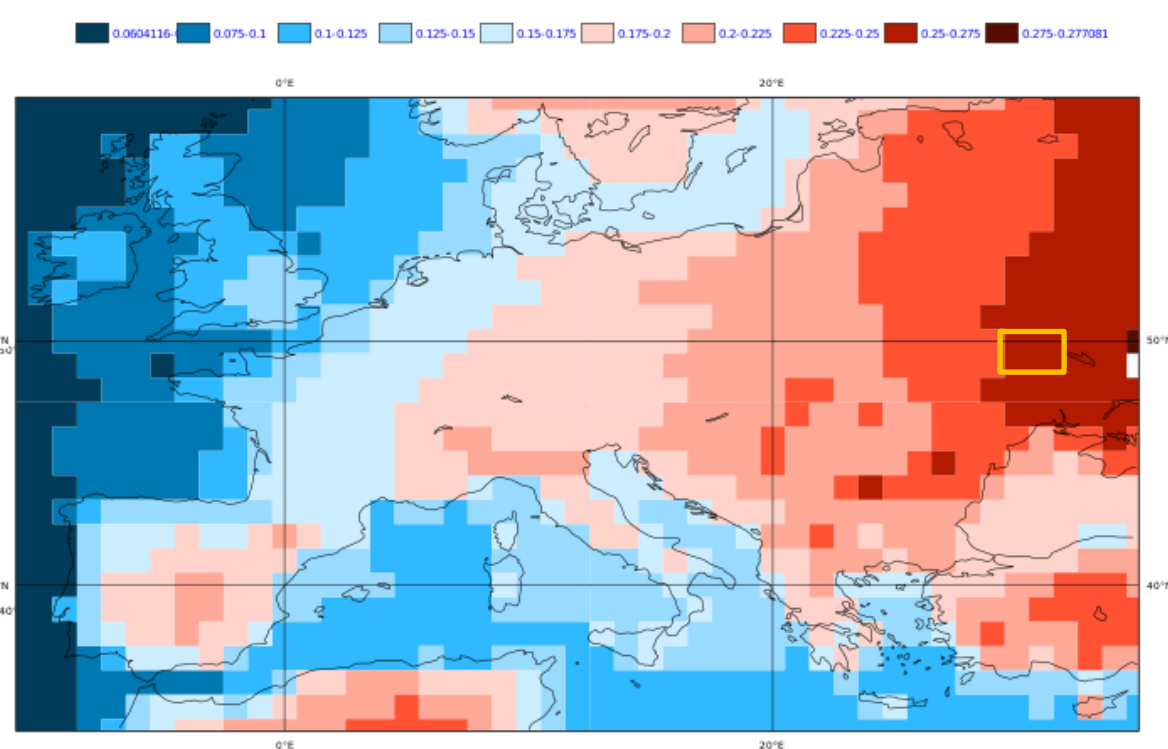
<https://cds.climate.copernicus.eu/cdsapp#!/software/app-era5-explorer?tab=app>

Zhytomyr region: Climate Trends – (a) Mean Annual Surface-area Temperature and (b) Standard Deviation (K year^{-1})

(a)

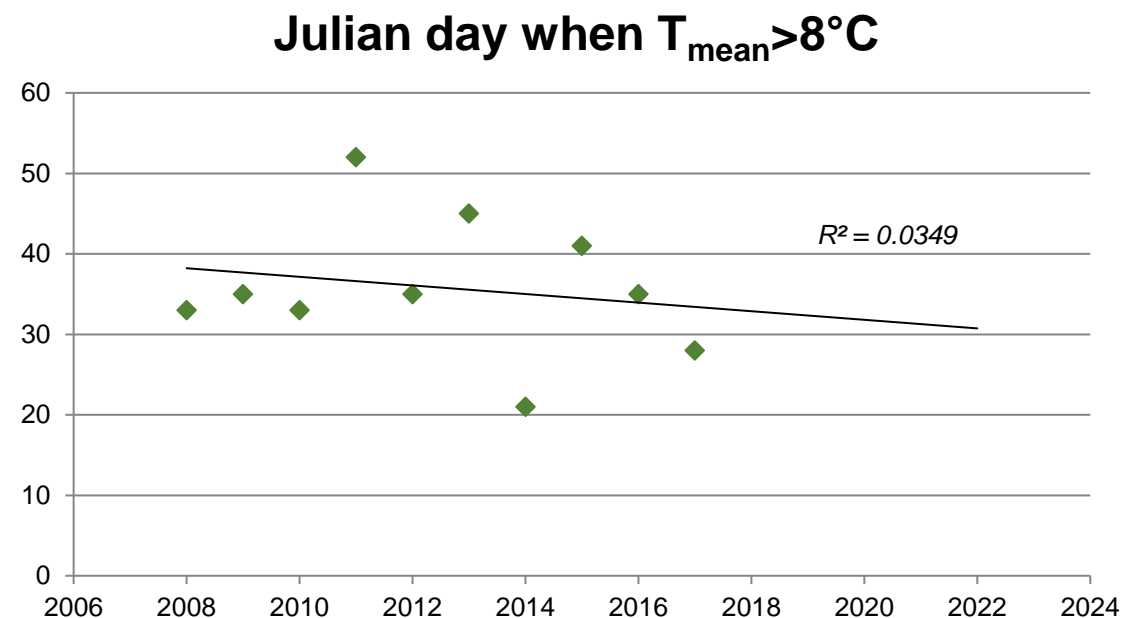
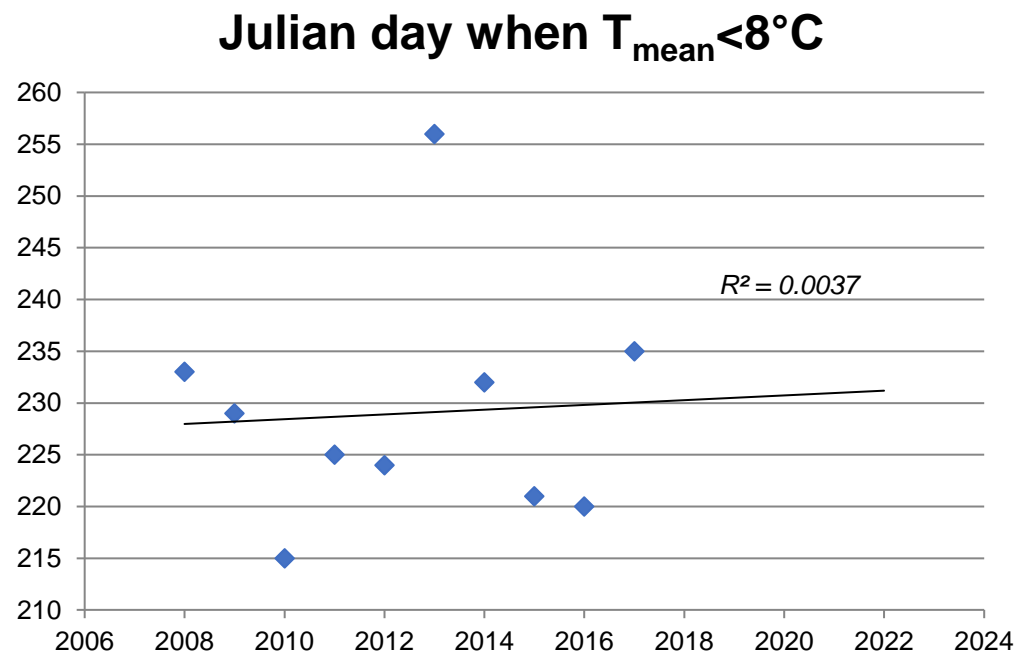


(b)



Zhytomyr: Transition of average daily temperature through +8°C

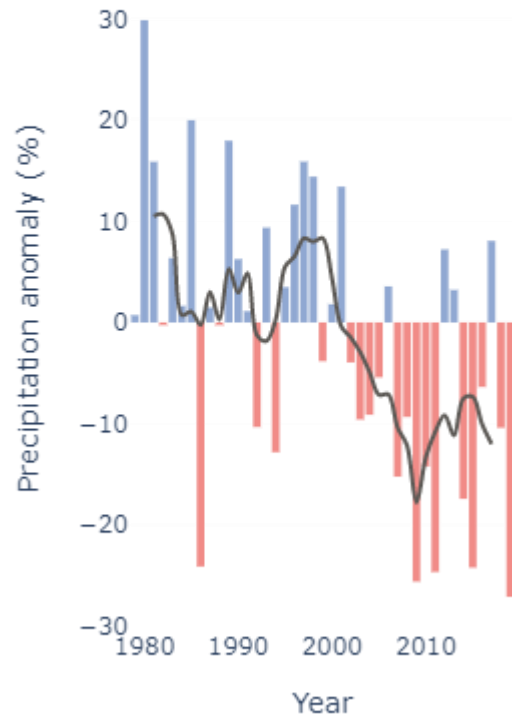
Julian Day 1 = 01.03



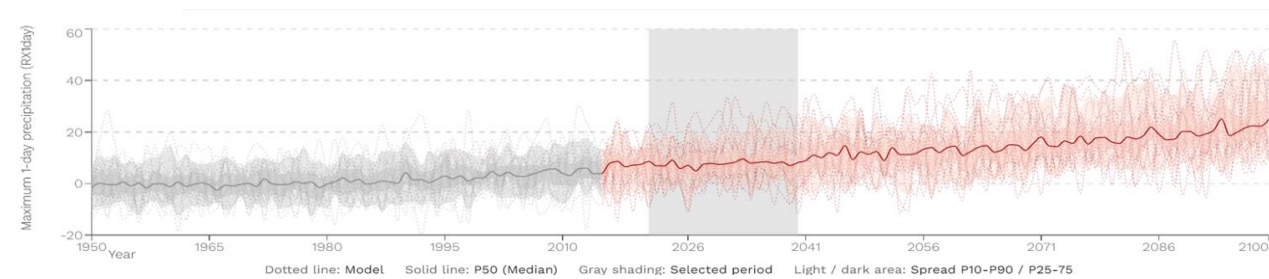
No clear trends over period from 2008 to 2021

Zhytomyr: Climate Trends – Precipitation Anomalies: reference period and projections under IPCC SSP5-8.5 and SSP2-4.5 scenarios

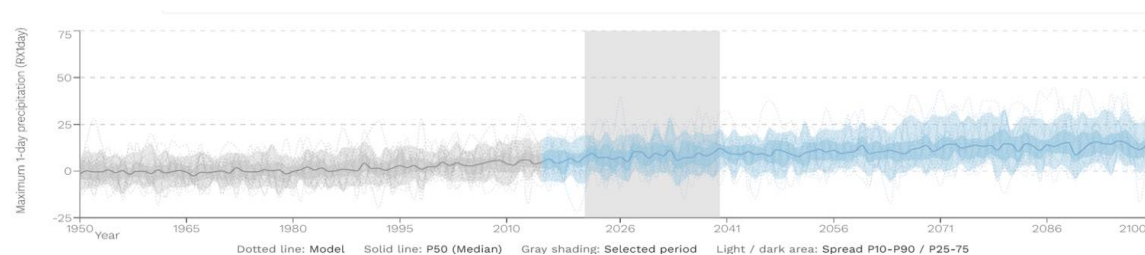
■ Annual precipitation anomaly (%)
— Five-year running mean precipitation a



Maximum 1-day precipitation (RX1day) Change % - Near Term (2021-2040) SSP5-8.5 (rel. to 1850-1900) - Annual (33 models). Regions: Western and Central Europe



Maximum 1-day precipitation (RX1day) Change % - Near Term (2021-2040) SSP2-4.5 (rel. to 1850-1900) - Annual (32 models). Regions: Western and Central Europe



Zhytomyr: Average wind speed (ms^{-1})

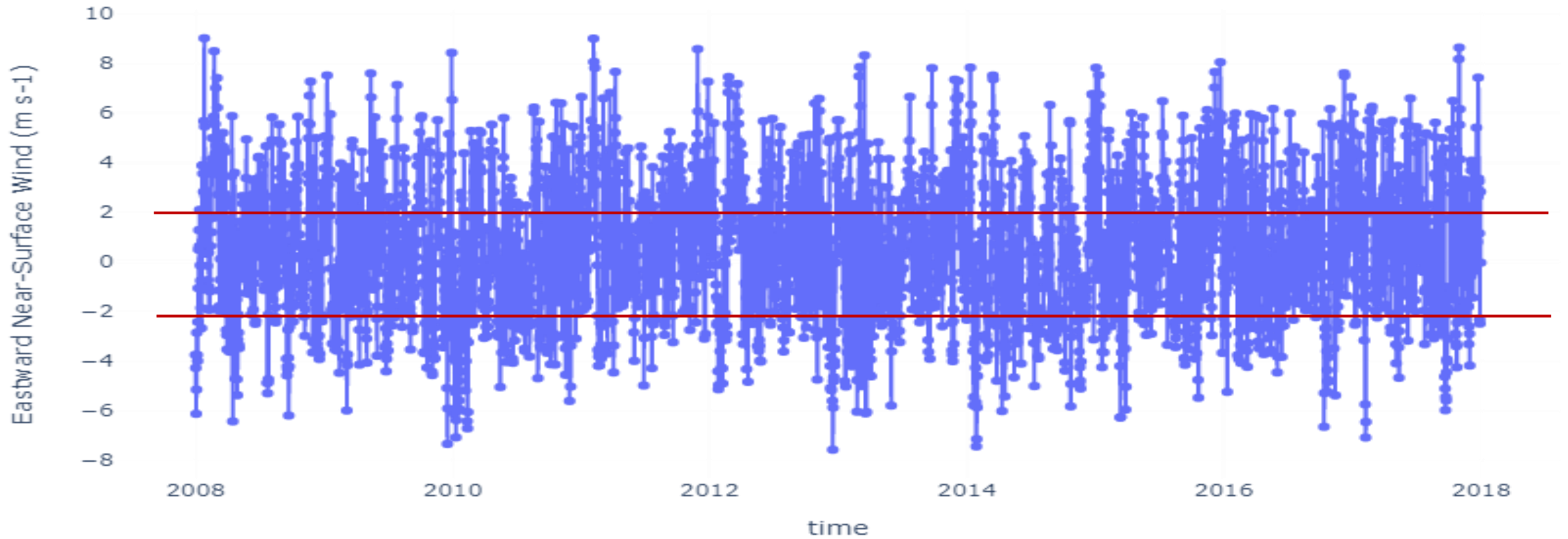
For the 1981-2010 reference period, the annual average wind speed in Zhytomyr was 3.4 ms^{-1} . Monthly average wind speed ranged from **2.9 ms^{-1}** (August) to **3.9 ms^{-1}** (January).

For development of wind energy minimum wind speed should be no less than 2.0 ms^{-1} .

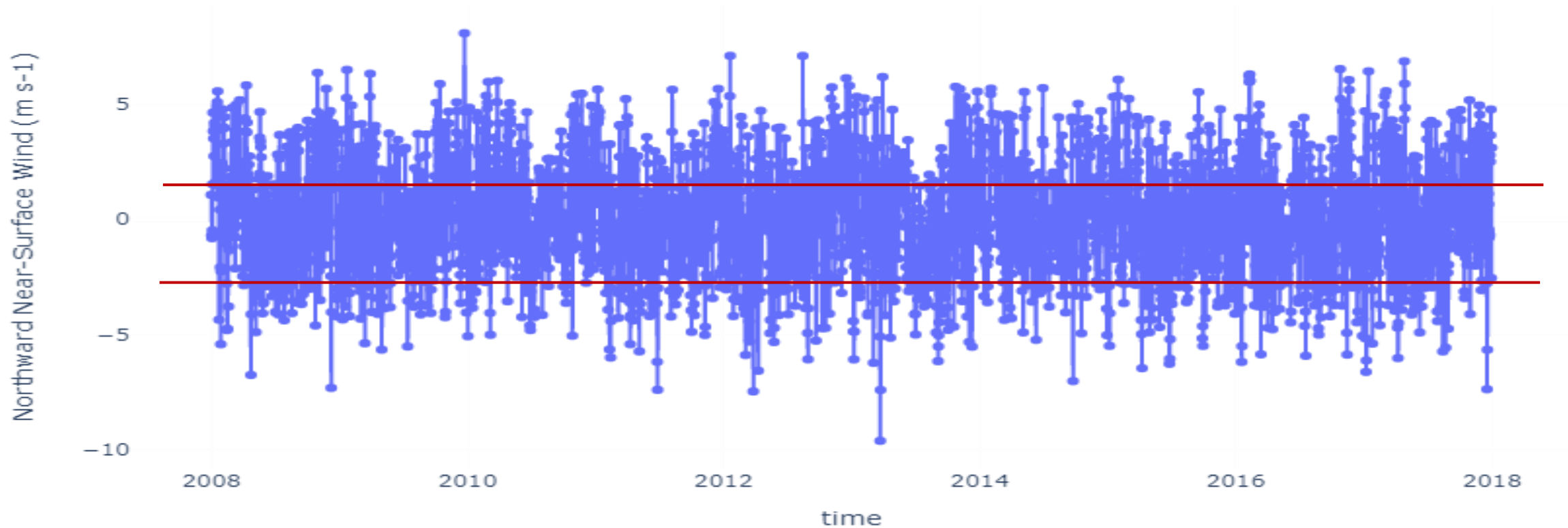
Therefore, the city of Zhytomyr's climatic conditions seem suitable for wind energy development



Zhytomyr: Eastward near-surface wind speed (ms^{-1})



Zhytomyr: Northward near-surface wind speed (ms^{-1})



Climatic projections: surface wind speed (ms⁻¹)

CMIP6 - Annual (31 models)

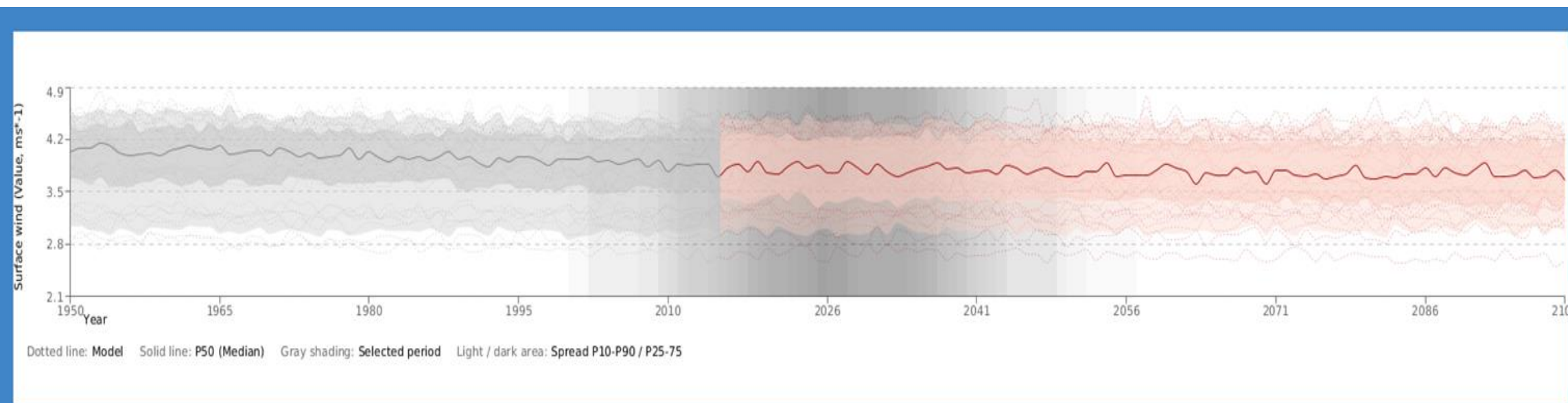
SSP5-8.5 (rel. to 1850-1900)

Regions: Western and Central Europe

Period	Scenario	Median (ms*-1)	P25 P75	P10 P90	P5 P95
Warming 1.5°C	SSP5-8.5	2.6	2.2 2.9	1.8 3.1	1.6 3.5
Warming 2°C	SSP5-8.5	2.6	2.2 2.9	1.8 3.1	1.7 3.5
Warming 3°C	SSP5-8.5	2.5	2.2 2.8	1.7 3.0	1.7 3.5
Warming 4°C	SSP5-8.5	2.3	1.9 2.6	1.7 2.8	1.7 2.9

Time Series

CMIP6 - Surface wind ms^{-1} - Warming 1.5°C - SSP5-8.5 (rel. to 1850-1900) - Annual (31 models)
Regions: Western and Central Europe

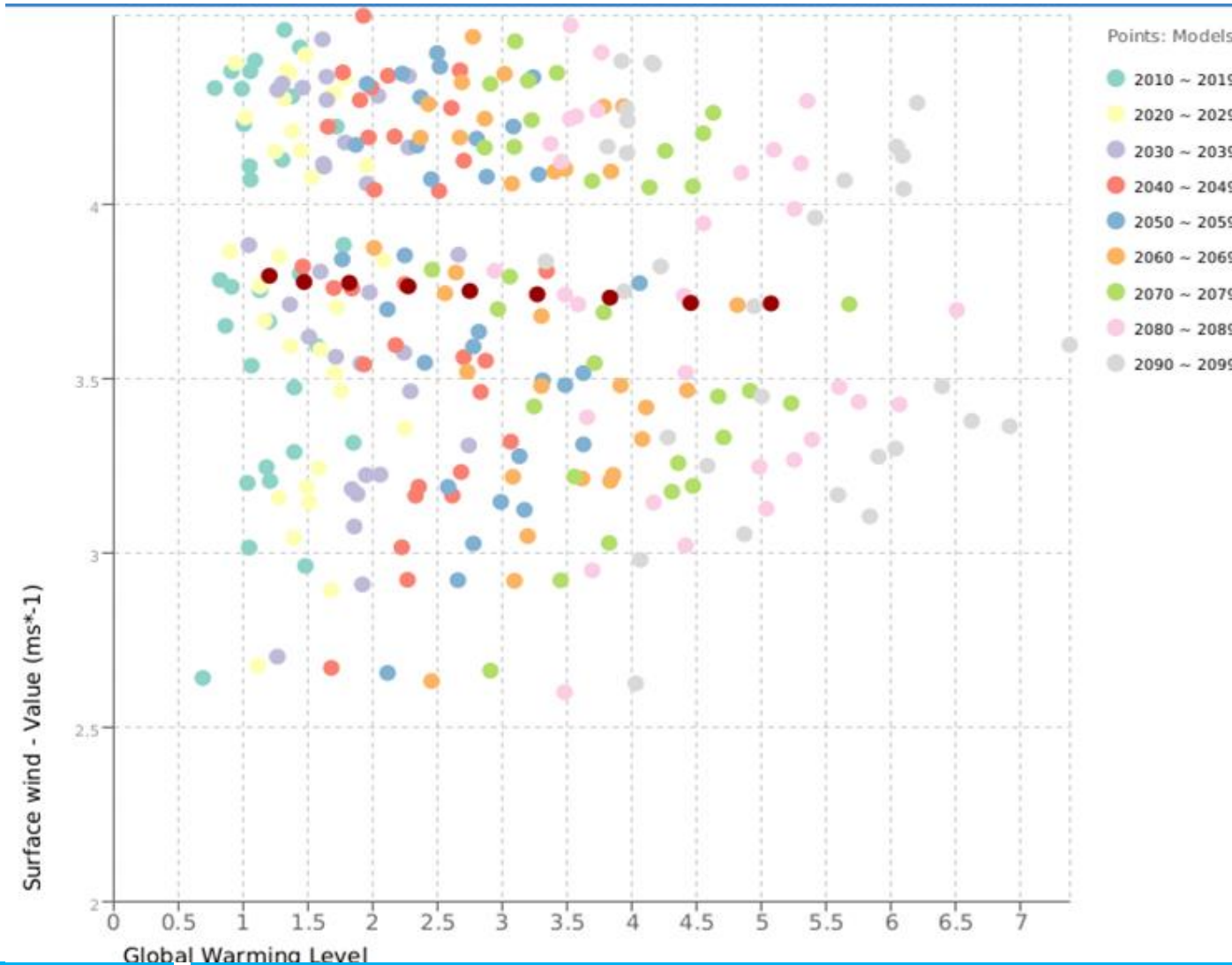


Surface wind - (ms^{-1})

Warming 1.5°C (SSP5-8.5) (rel. to 1850-1900)

CMIP6 - Annual (31 models)-Western and Central Europe

Climatic projections: near-surface wind speed (ms^{-1})



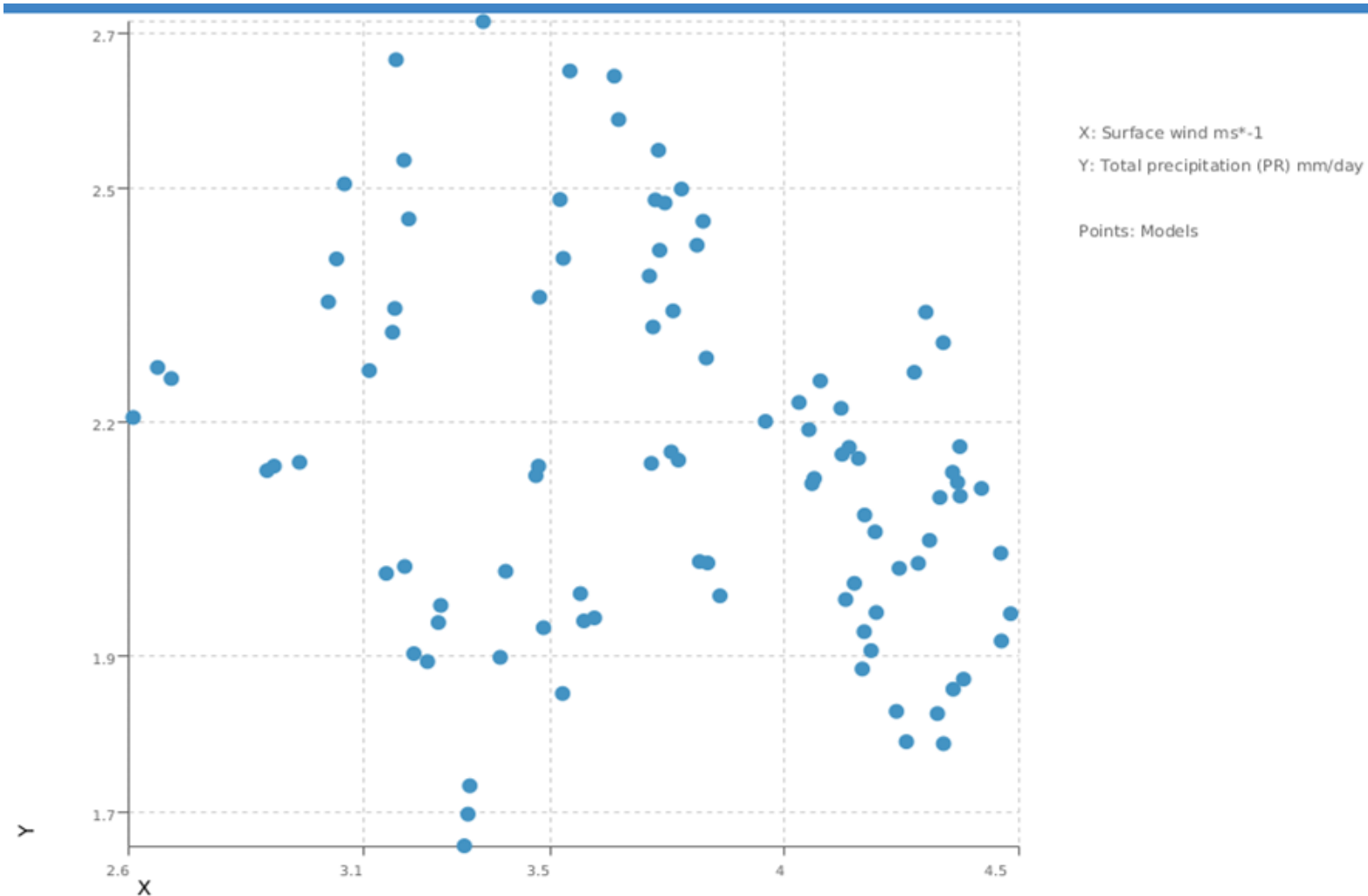
Surface wind ms^{-1}

SSP5-8.5 (rel. to 1850-1900)

CMIP6 - Annual (31 models)

Regions: Western and Central Europe

Climatic projections: daily precipitation vs. near-surface wind speed (ms^{-1})



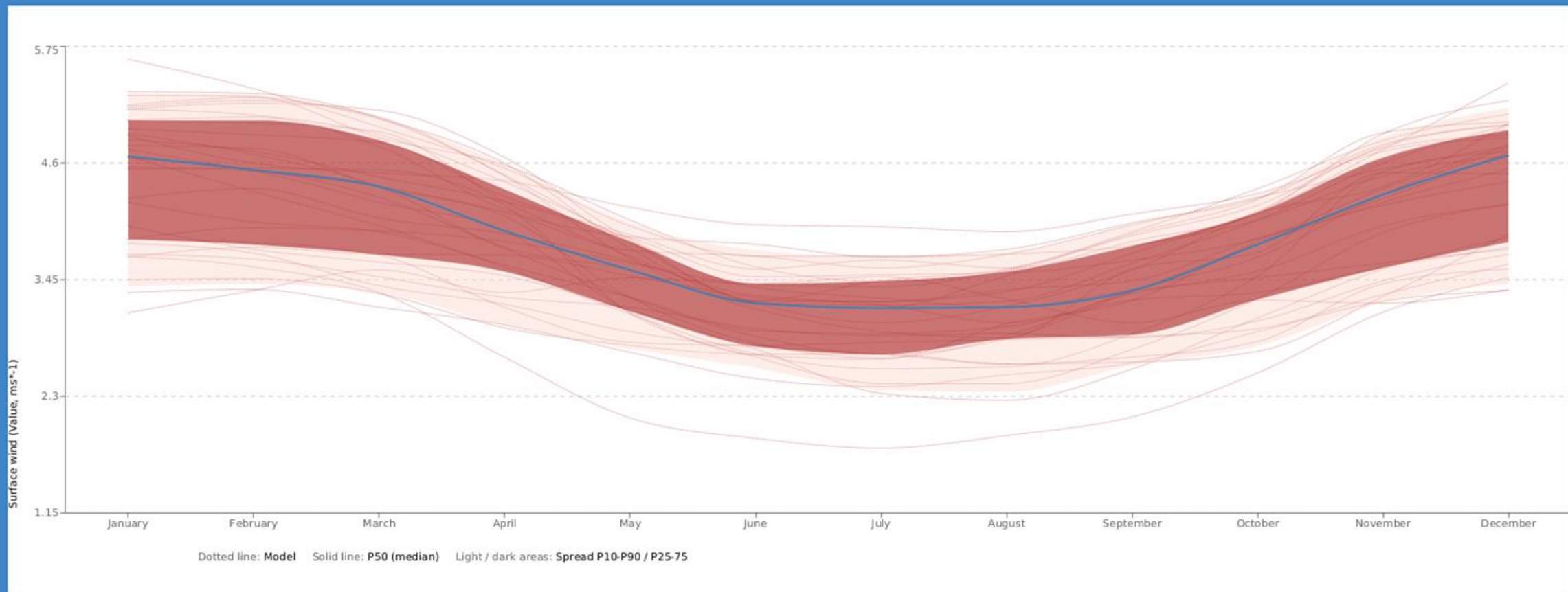
Surface wind ms^{-1}

SSP5-8.5 (rel. to 1850-1900)

CMIP6 - Annual (31 models)

Regions: Western and Central Europe

Climatic projections: near-surface wind speed (ms^{-1})

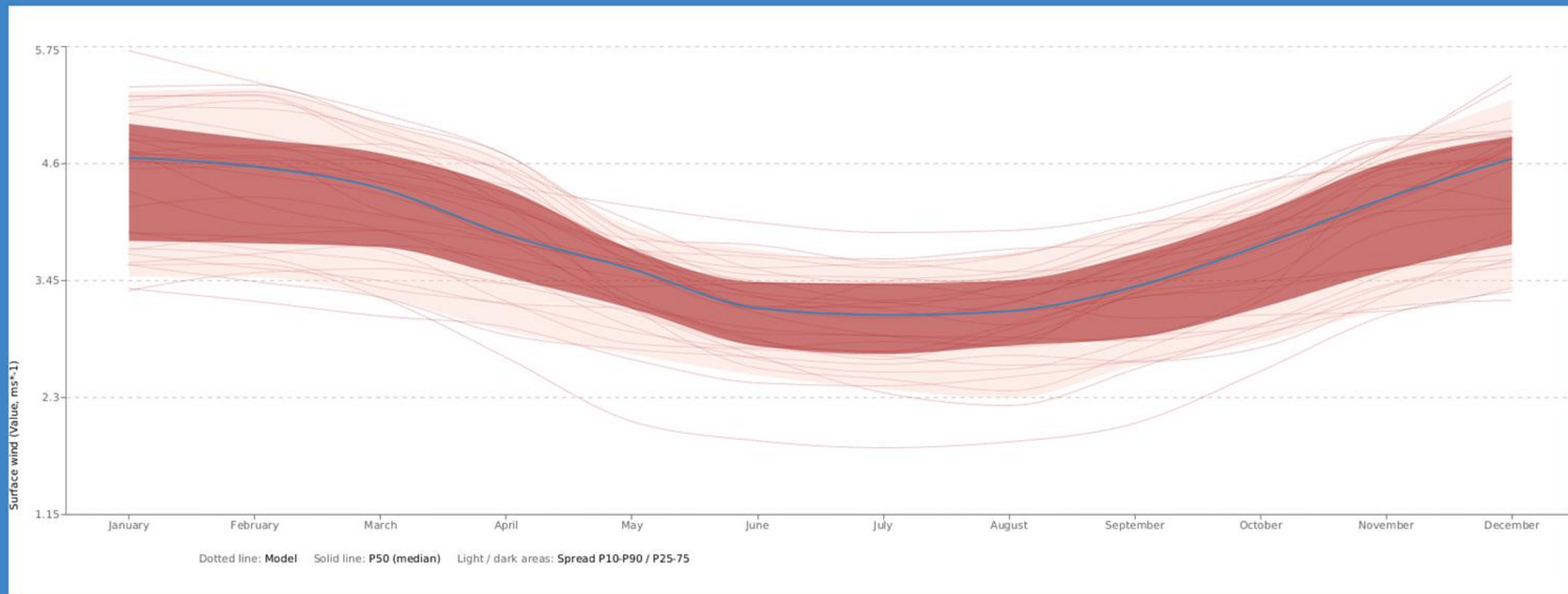


Surface wind - (ms^{-1})

Warming 1.5°C (SSP5-8.5) (rel. to 1850-1900)

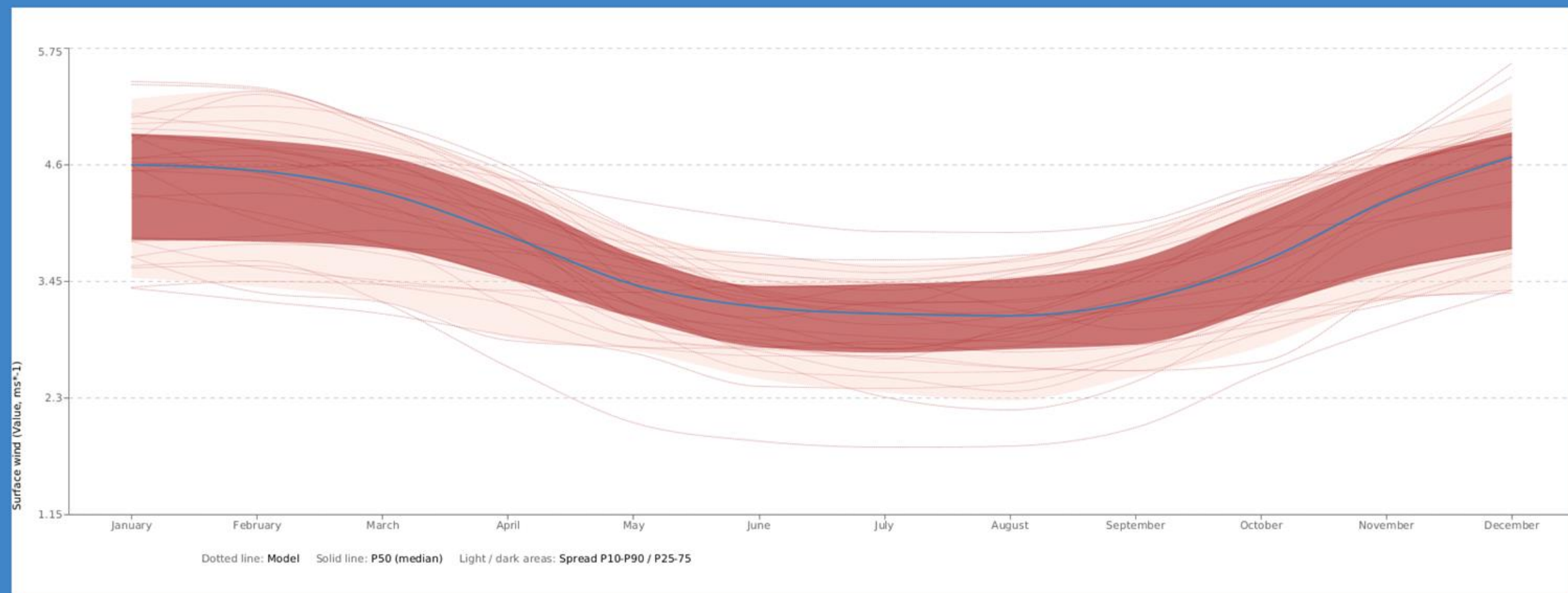
CMIP6 - Annual (31 models)-Western and Central Europe

Climatic projections: near-surface wind speed (ms^{-1})



Surface wind - (ms^{-1})
Warming 2°C (SSP5-8.5) (rel. to 1850-1900)
CMIP6 - Annual (31 models)-Western and Central Europe

Climatic projections: near-surface wind speed (ms^{-1})

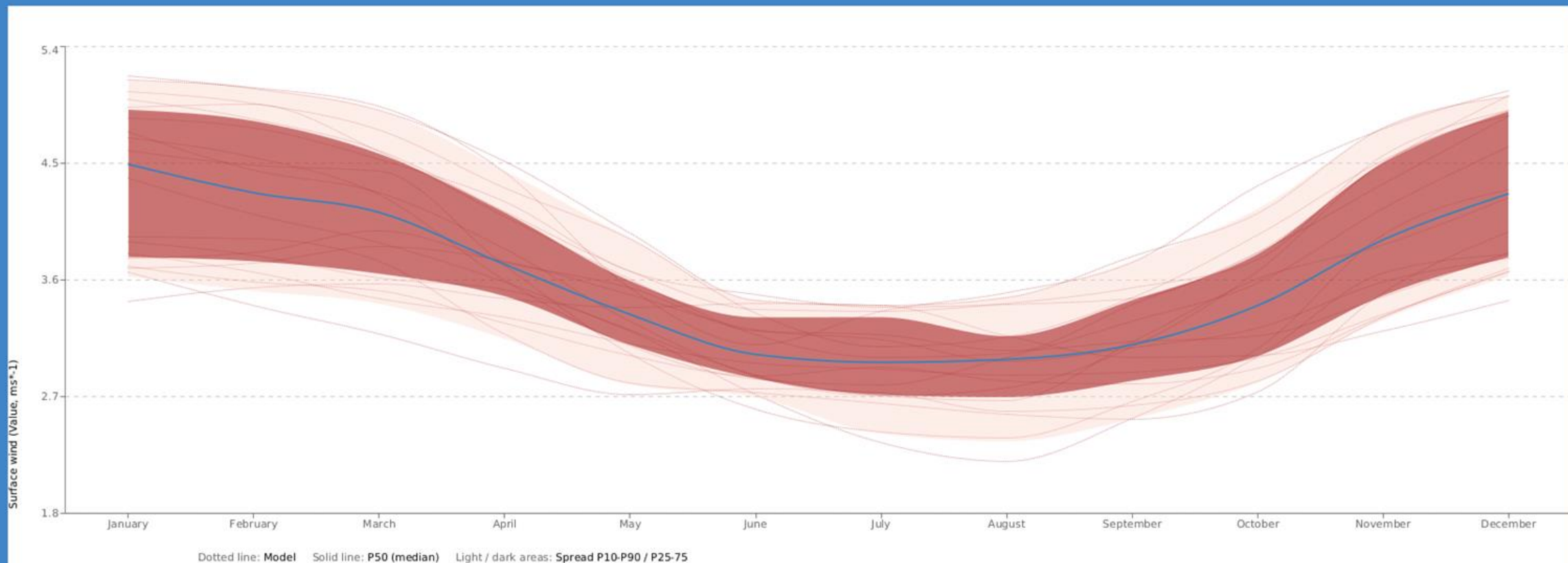


Surface wind - (ms^{-1})

Warming 3°C (SSP5-8.5) (rel. to 1850-1900)

CMIP6 - Annual (31 models)-Western and Central Europe

Climatic projections: near-surface wind speed (ms^{-1})



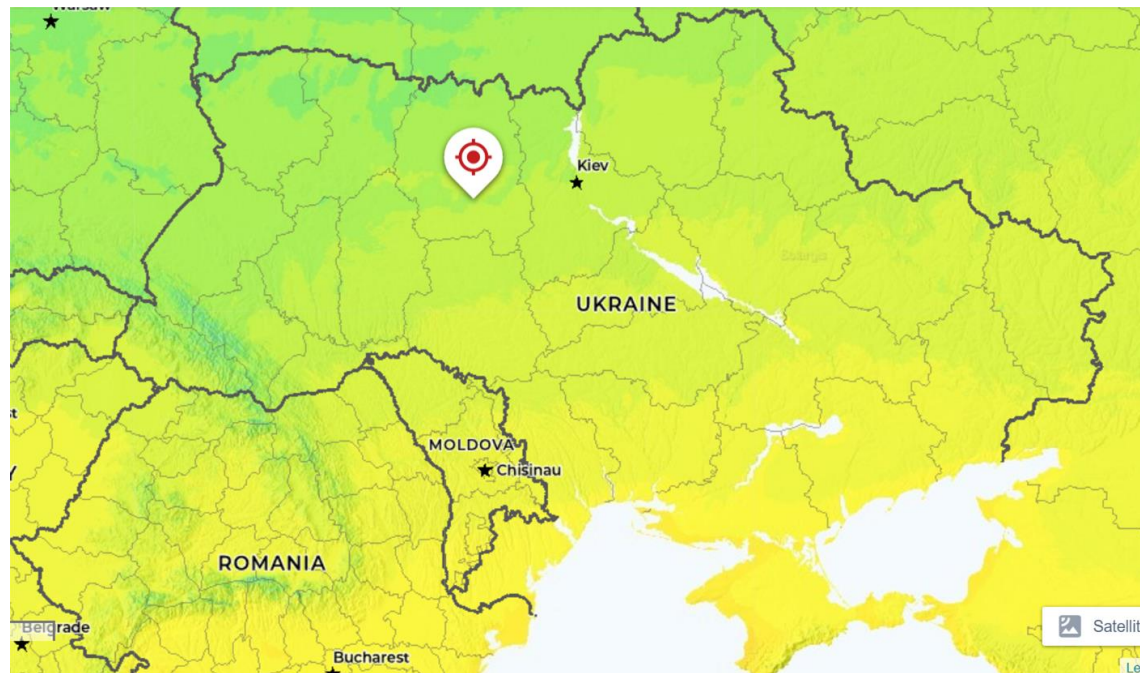
Surface wind - (ms^{-1})

Warming 4°C (SSP5-8.5) (rel. to 1850-1900)

CMIP6 - Annual (18 models)-Western and Central Europe

Solar Potential of Zhytomyr

Map data	Per year
Specific photovoltaic power output	1142.1 kWh/kWp
Direct normal irradiation	1080.6 kWh/m ²
Global horizontal irradiation	1168.5 kWh/m ²
Diffuse horizontal irradiation	575.6 kWh/m ²
Global tilted irradiation at optimum angle	1367.7 kWh/m ²



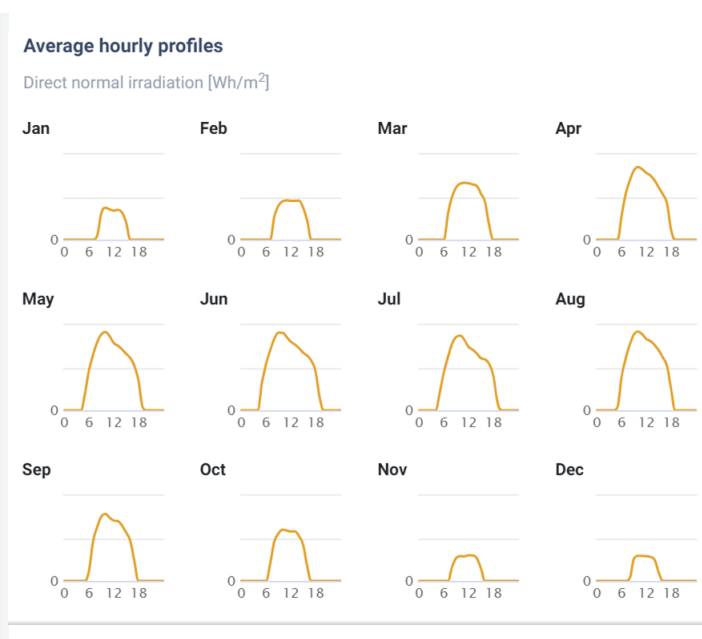
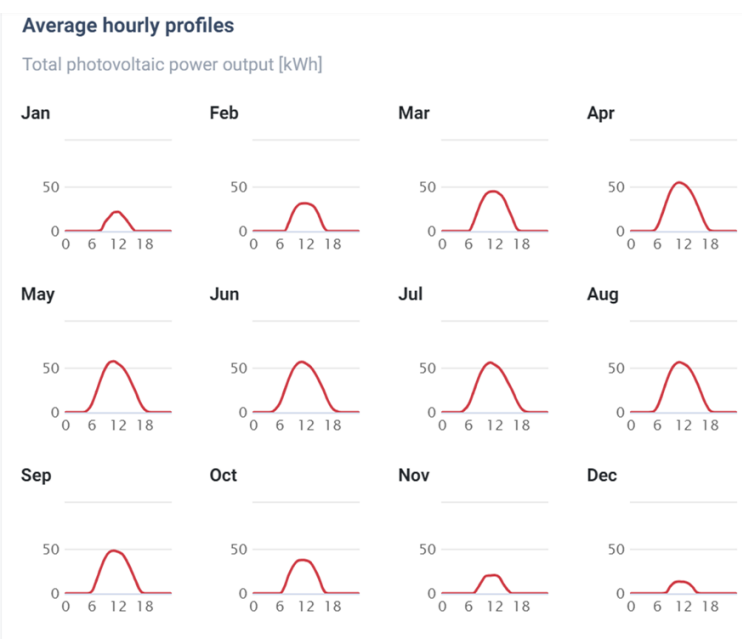
Example:

Pv system: Medium size comercial.

Installed capacity: 100 kWp

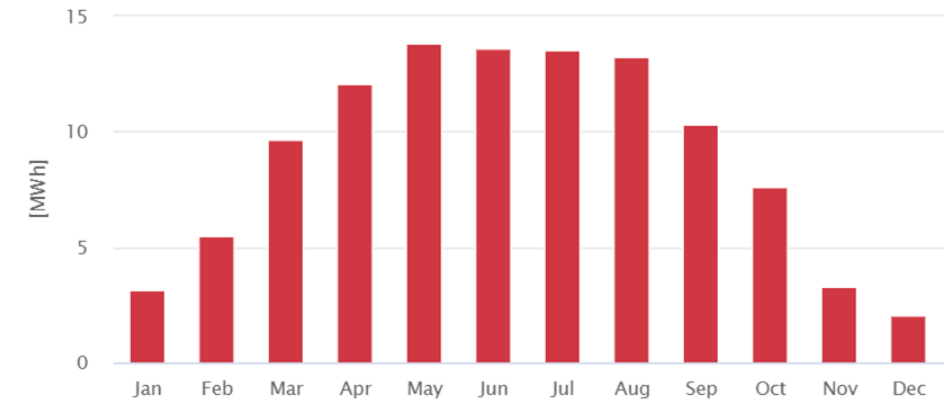
Direct normal irradiation

1098.5 kWh/m² per year



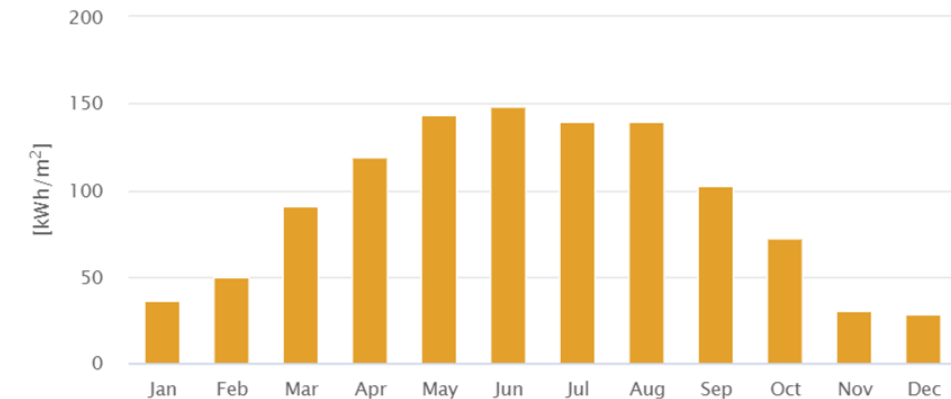
Monthly averages

Total photovoltaic power output



Monthly averages

Direct normal irradiation



Solar Potential of Zhytomyr

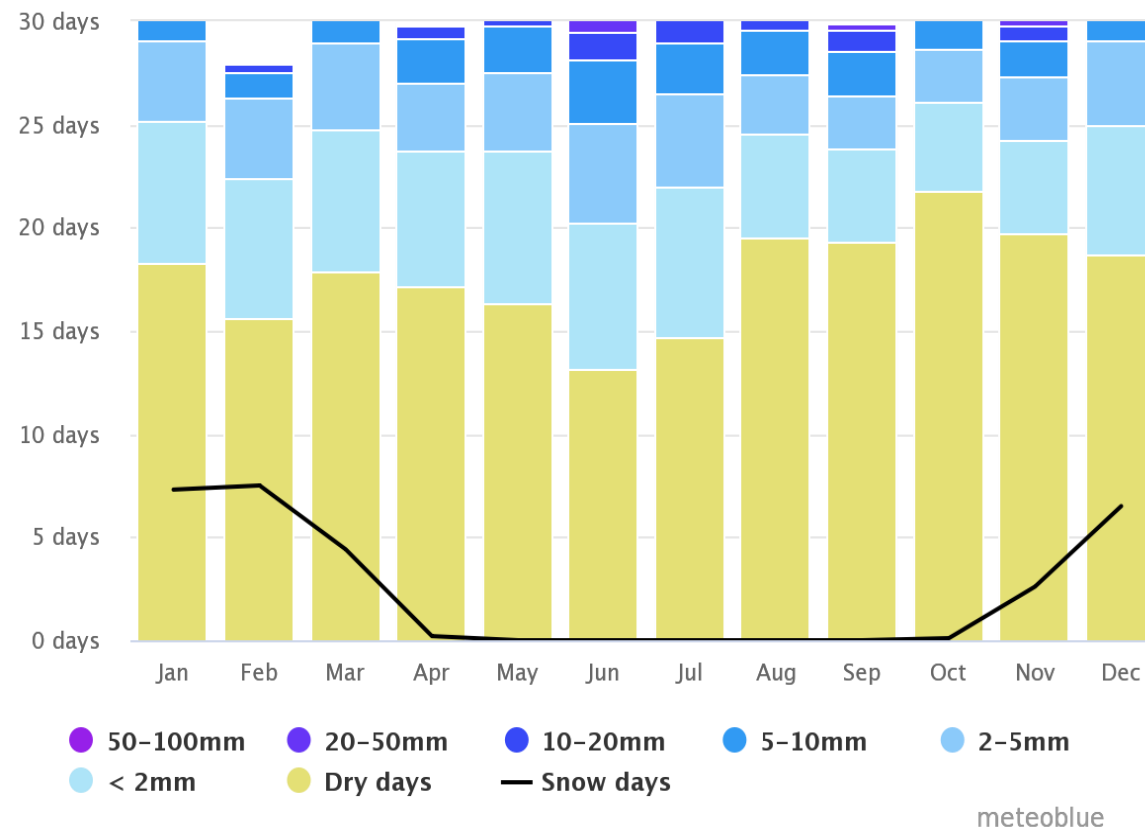
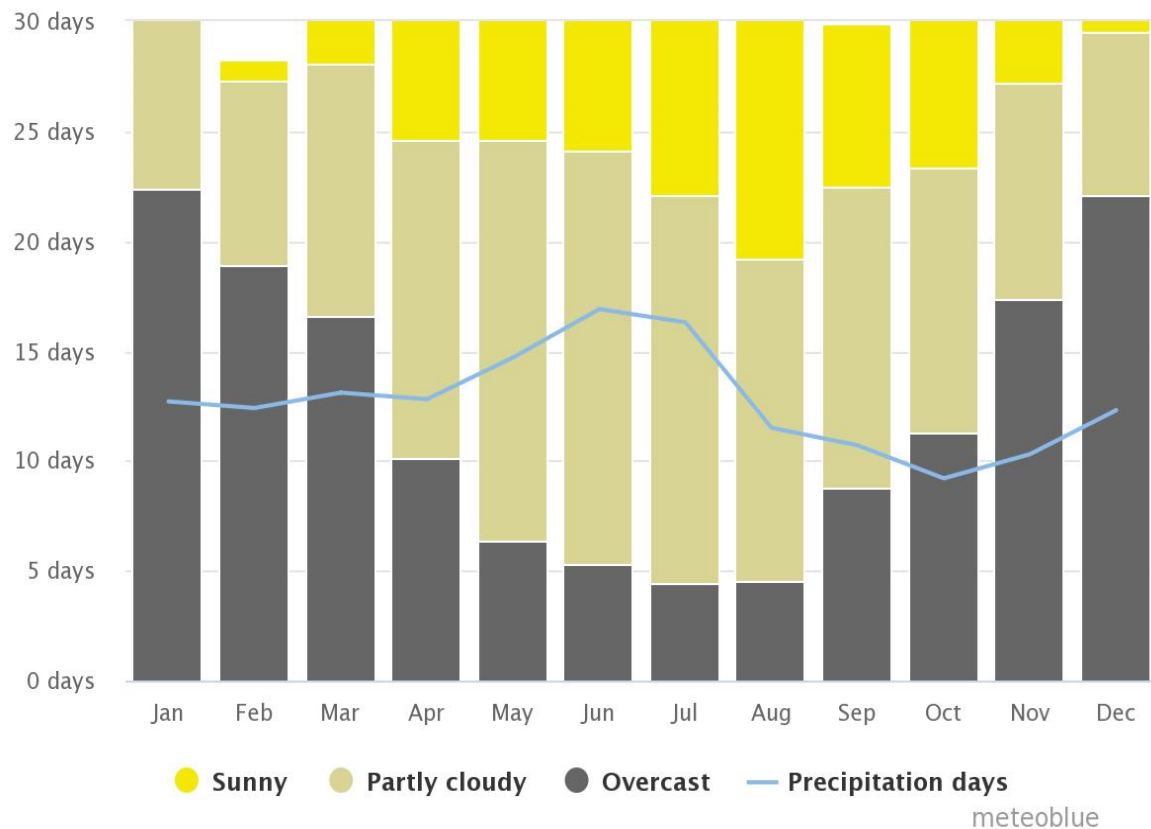


The scenario of energy transition №2 implies that installed capacity of rooftop solar power plants in **2050 will reach 421.4 MW.**

This means annual production can achieve **472,810.8 MW.**

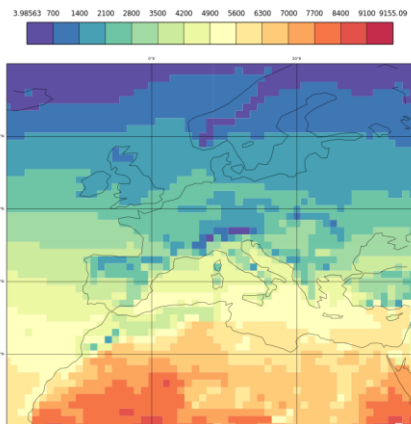
As calculated by the energy modeling according to the scenario 2 for Zhytomyr, they will need **387,800 MW.**

Solar Potential of Zhytomyr: Sunny and cloudless days

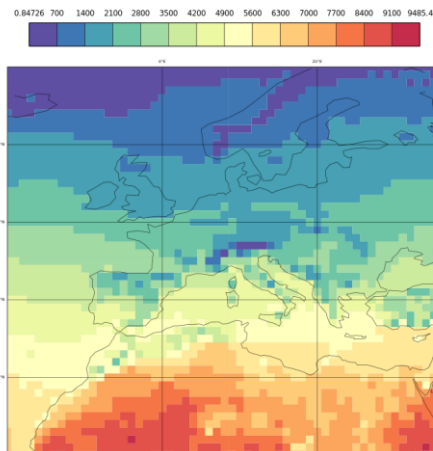


Zhytomyr region: Potential for bioenergy crops production

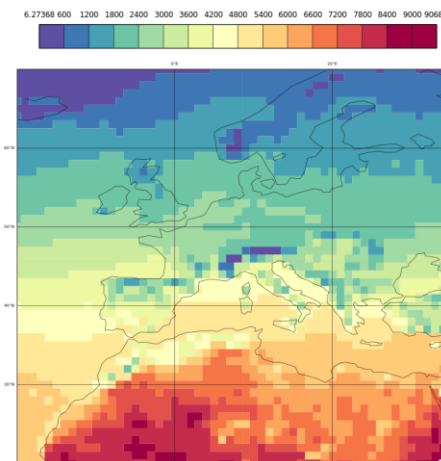
Growing Degree Days 2008 (above 5°C)



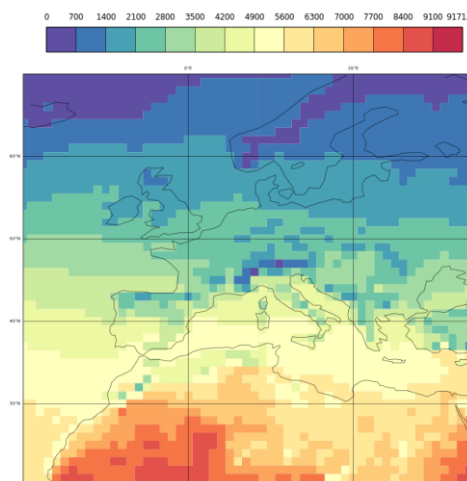
Growing Degree Days 2010 (above 5°C)



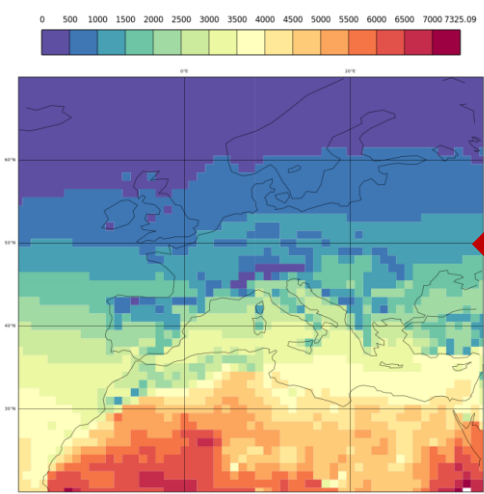
Growing Degree Days 2014 (above 5°C)



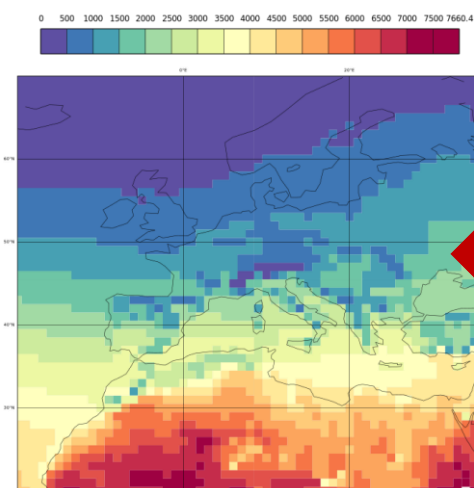
Growing Degree Days 2017 (above 5°C)



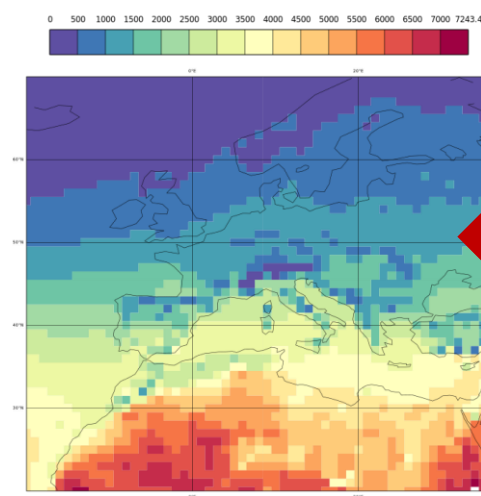
Growing Degree Days 2008 (above 10°C)



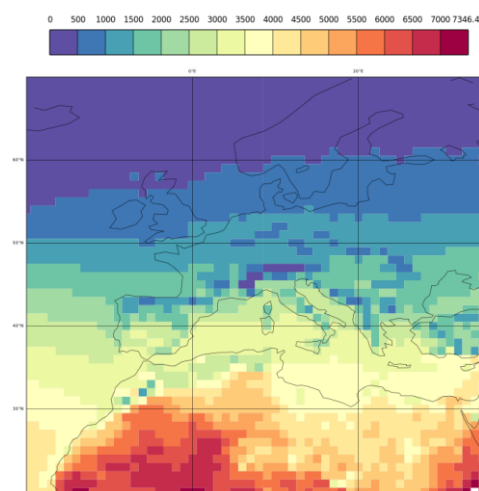
Growing Degree Days 2010 (above 10°C)



Growing Degree Days 2014 (above 10°C)



Growing Degree Days 2017 (above 10°C)



Zhytomyr region: Potential for selected crops and coppice production

Common name	Latin name	Number of growing degree days baseline 10 °C	GDD Threshold	min GDD 2008	min GDD 2010	min GDD 2014	min GDD 2017
Norway maple	Acer platanoides	begins flowering at 30-50 GDD	30	1500	1500	1500	1000
White ash	Fraxinus americana	begins flowering at 30-50 GDD	30	1500	1500	1500	1000
Black locust	Robinia pseudoacacia	begins flowering at 140-160 GDD	140	1500	1500	1500	1000
Corn (maize)	Zea mays	800 to 2700 GDD to crop maturity	800	1500	1500	1500	1000
Soybeans	Glycine max	1100-1300 GDD to maturity depending on cultivar and soil conditions	1100	1500	1500	1500	1000
Sugar beet	Beta vulgaris	130 GDD to emergence and 1400- 1500 GDD to maturity	1400	1500	1500	1500	1000
Barley	Hordeum vulgare	125-162 GDD to emergence and 1290-1540 GDD to maturity	1290	1500	1500	1500	1000
Wheat (hard red)	Triticum aestivum	143-178 GDD to emergence and 1550-1680 GDD to maturity	1550	1500	1500	1500	1000
Oats	Avena sativa	1500-1750 GDD to maturity	1500	1500	1500	1500	1000

Note: **Crops unsuitable for cultivation**

Conclusions

- Recent climatic trends in the city of Zhytomyr and its region show increase in mean annual temperature at 0.04-0.06 K per year with simultaneous decrease in total amount of precipitation.
- Trends in transition of daily mean temperatures through +8°C over 2008-2021 are unclear, so the urban heat supply systems should be adapted to fluctuations in both onset/offset dates and total duration of heating period
- The city of Zhytomyr's climatic conditions seem suitable for wind energy development in present and in the nearest future
- Based on the results of the analysis of the annual productivity of a commercial-type photovoltaic system that can be installed in Zhitomir, the maximum productivity will be observed from April to September. Direct normal irradiation is 1098.5 kWh/m² per year.
- Current calculations and future projections of Growth Degree Days provide for suitable growing and sustainable production of 'energy' crops typical for temperate climate zones



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Thank you!