EFFECTS OF FUTURE CLIMATE CHANGE ON TRANSPORTATION INDUSTRY OF UKRAINE

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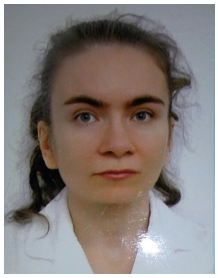

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Summary. In the study impact of climate change on operation of road transport in Ukraine are analyzed on the basis of RCP 4.5 and RCP 8.5 scenarios for two highways. Data contains series of daily value of meteorological variables for the 2011-2050 period. Changes of climate conditions along two highways are received and compared with values of the 1961-1990 WMO normal period.

Social and economic risks to the road transport network are assessed.

Keywords: RCP scenarios, transportation system, social and economic risks

Transportation not only affects climate, but are strongly influenced with the climate conditions, and key hubs of the transportation sector are cities.

Transportation professionals are keenly aware of the effects of weather on system performance. Transportation infrastructure was designed for typical weather patterns, reflecting local climate and incorporating assumptions about a reasonable range of temperatures and precipitation levels.

Climate change will affect transportation primarily through increases in several types of weather and climate extremes, such as very hot days; intense precipitation events; intense hurricanes; drought; and rising sea levels, coupled with storm surges and land subsidence. The impacts will vary by mode of transportation and region of the country, but they will be widespread and costly in both human and economic terms and will require significant changes in the planning, design, construction, operation, and maintenance of transportation systems [2].

Owing to development of emission scenarios transportation decision makers have an opportunity now to prepare for projected climate changes.

The IPCC report defines four timeline scenarios (Representative Concentration Pathways or RCPs) plotting amounts of carbon burned and resulting global average temperatures, depending on when global greenhouse gas emissions (GHG) peak and then decline (fig. 1). The IPCC chose to plot the "business as usual" scenario (RCP 8.5 – continued increase in GHG emissions), then scenarios for global GHG emission peaks in the year 2080 (RCP 6.0), 2040-2050 (RCP 4.5), and 2020 (RCP 2.6) [1].

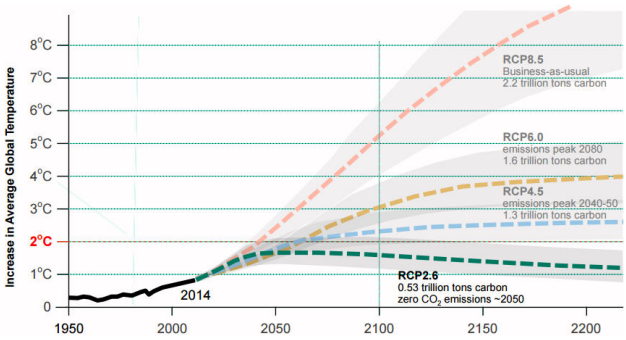

Figure 1. - Global Temperature Projections for various RCP Scenarios [1].

In the study impact of climate change on operation of road transport along two highways are analyzed on the basis of two emission scenarios – RCP4.5 (low) and RCP8.5 (high) ones.

Data contains climate norms [4] and series of daily mean, maximum and minimum near-surface air temperature, daily liquid (or mixed) and solid precipitation, near-surface relative humidity, near-surface wind speed and daily maximum near-surface wind speed, obtained for the period of 2011 to 2050 for 8 cities (Dnipropetrovsk, Khmelnytskyi, Kirovohrad, Kharkiv, Odesa, Ternopil, Vinnytsia and Voznesensk) situated down the highways. The highways of 'Odesa – Voznesensk – Dnipropetrovsk – Kharkiv' and 'Dnipropetrovsk – Kirovohrad – Vinnytsia – Khmelnytskyi – Ternopil' are considered (fig. 2).

The first highway goes across the Black Sea Lowland, the Dnieper Upland and Dnieper Lowland, the other passes through the Dnieper and Volhynia-

Podillia Uplands. The both highways are situated in steppe and forest-steppe native zones.

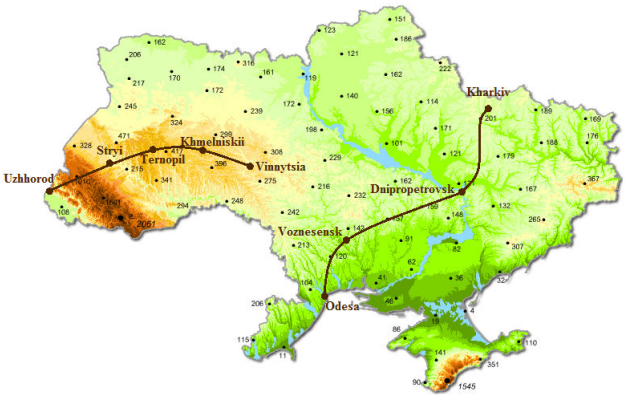

Figure 2. – Two highways are considered in the paper (numerals in the figure shows height above sea level)

Results show that for both scenarios and for both highways mean temperature is rising (fig. 3, 4).

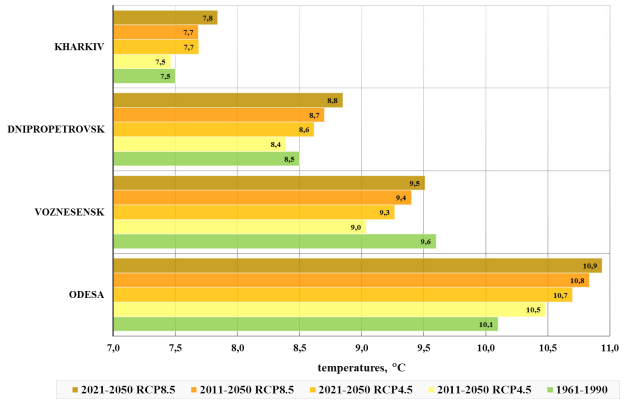

Figure 3. - Average temperature for 1961-1990, 2011-2050 and 2021-2050 periods for the RCP4.5 and RCP8.5 scenarios for the Odesa – Voznesensk – Dnipropetrovsk–Kharkiv highway

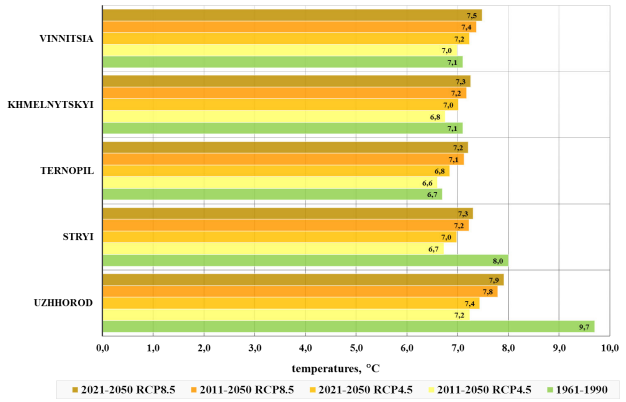

Figure 4. - Changes in mean air temperatures along the Vinnytsia – Khmelnytskyi – Ternopil – Stryi – Uzhhorod highway

It is obtained that in comparison with the climate norm in Odesa city significant increase of average temperature by 2-3°C is observed, in Kharkiv, Dnipro, Vinnitsia, Khmelnytskyi and Ternopil slight growth of temperatures takes place and in Voznesensk, Uzhhorod and Stryi cities temperatures is rising, but don't exceed the climate norm. There temperatures are below than the climate norm values by 0,7 – 1,8°C. More rapid growth in temperature are observed for the high scenario for the highways in question.

For all cities, except Uzhhorod, median values of temperature will increase in January and decrease in July. More rapid rise in median values is observed for the low scenario.

Magnitude of change in mean temperatures will increase, it means that increase in inter-annual variability and changes in cold and warm extremes larger and faster than the corresponding changes in mean.

For the both scenarios maximum temperatures will significantly grow for both highways.

Number of days with maximum temperatures equal or higher than 30, 35 and 40ºC will also increase along the Odesa–Voznesensk–Dnipropetrovsk–Kharkiv highway except Dnipropetrovsk where a decrease in frequency of such days will be observed (fig. 5).

For the 1961-1990 period there were not days with temperatures ≥40ºC in all cities, but for scenarios RCP4.5 such days will occur with probability 0,07 and 0,03 in Odessa and Dnipropetrovsk respectively and for scenarios RCP8.5 with probability 0,07 – in Voznesensk and Dnipropetorvsk.

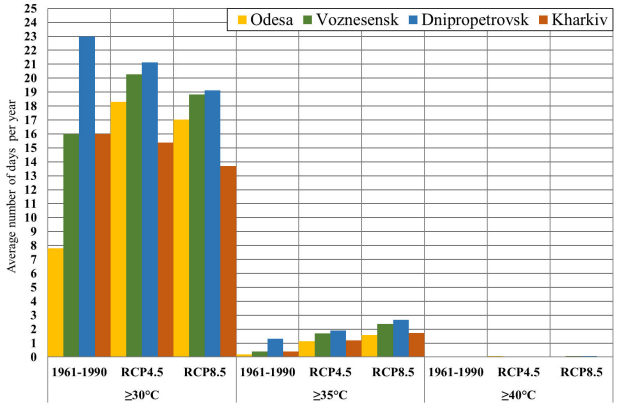

Figure 5. - Average number of days with different maximum temperatures per year for 1961-1990, the RCP4.5 and RCP8.5 scenarios for the Odesa–Voznesensk – Dnipropetrovsk – Kharkiv highway

Along the other highway (fig. 6) number of days with high maximum temperatures will unevenly decrease.

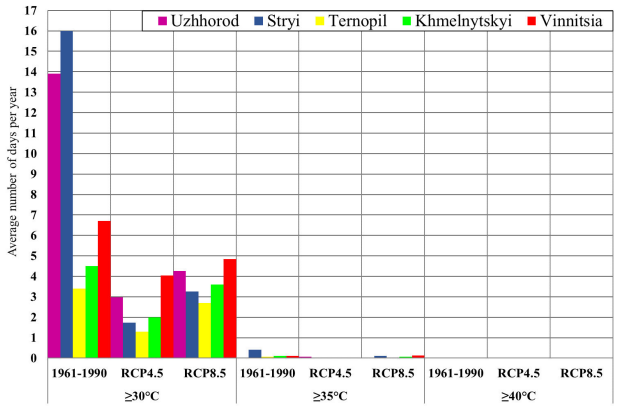

Figure 6. - Average number of days with different maximum temperatures per year for 1961-1990, the RCP4.5 and RCP8.5 scenarios for the Vinnytsia – Khmelnytskyi – Ternopil – Stryi – Uzhhorod highway

Number of days with temperatures with ≥30ºC will be several times lower than for climate norms. Number of such days will be sharply reduced particularly in the western regions of Ukraine, in stations located on the foothills of the Carpathians.
Days with temperatures ≥40ºC will not be observed same as in the 1961-1990 period.
Number of days with low minimum temperatures decrease for both highways.
For all cities decrease in precipitation amount down to 90% will be observed, except Uzhhorod where strong growth in precipitation amount occurs under scenarios RCP4.5 (fig.7, 8).

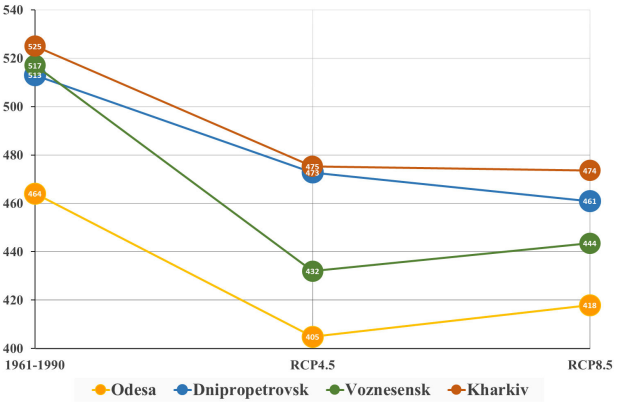

Figure 7. – Average annual precipitation for 1961-1990, the RCP4.5 and RCP8.5 scenarios for the Odesa – Voznesensk – Dnipropetrovsk – Kharkiv highway

Number of days with slight precipitation will grow for all cities. For all cities intensive precipitation decrease, except Uzhhorod for which precipitation amount from 5 to 20 mm increase more than two times. In comparison with the climate norm frequency distribution of precipitation for the Odesa – Voznesensk – Dnipropetrovsk – Kharkiv highway will be same, and for the other highway frequency distribution of precipitation will changed for Uzhhorod and Stryi. In Uzhhorod number of days with various precipitation will increase and in Stryi they will reduce. Difference between two scenarios isn't noticed.

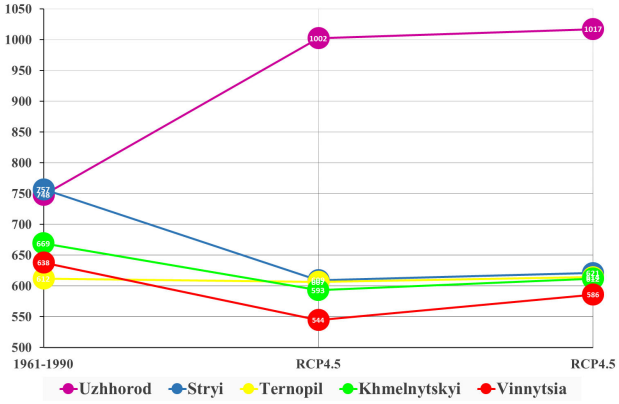

Figure 8. - Average annual precipitation for 1961-1990, the RCP4.5 and RCP8.5 scenarios for the Vinnytsia – Khmelnytskyi – Ternopil – Stryi – Uzhhorod highway

Strong increase in mixed precipitation and significant reduction in ice and liquid precipitation will take place (fig. 9, 10).

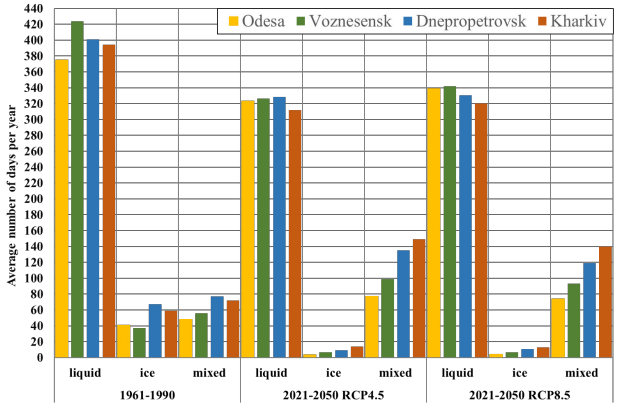

Figure 9. - Yearly average number of rainy, snowy and sleet days for 1961-1990, the RCP4.5 and RCP8.5 scenarios for the Odesa – Voznesensk – Dnipropetrovsk – Kharkiv highway

For the low (RCP4.5) scenario increase in mixed precipitation is more than for the high scenario. The most growth in mixed precipitation will be observed in Uzhhorod that it is explained by increase in total amount of precipitation in this city.
For the high (RCP8.5) liquid precipitation is more than for the low scenario. For both scenarios the ice precipitation is almost disappeared for all cities (about 10 days per year), except Vinnytsia where 48 and 51 days with snow will be recorded per year. In Odessa number of snow days will be reduced down to 4 days per year.

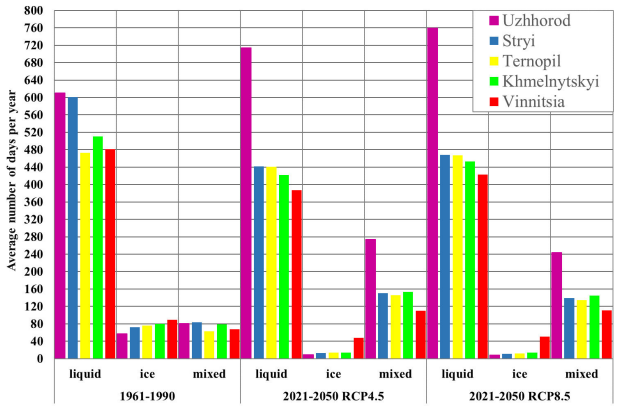

Figure 10. - Yearly average number of rainy, snowy and sleet days for 1961-1990, the RCP4.5 and RCP8.5 scenarios for the Vinnytsia – Khmelnytskyi – Ternopil – Stryi – Uzhhorod highway

Growth in mixed precipitation causes increase in severe weather events such as freezing precipitation, ice-covered ground and snow slippery coat for both highways (fig. 11, 12).

In the paper frequency of such events as freezing precipitation (FP), ice-covered ground (refreezing of melted snow on the road, ICG), ice-covered ground with wind speed ≥10m/s (ICG with V≥10 m/s), ice and snow slippery coat (SSC), slippery wet ground (SWG) and snowstorm are determined. In the brackets abbreviations used in figures 11 and 12 are given. For the 1961-1990 period data on freezing precipitation and snowstorm are available.

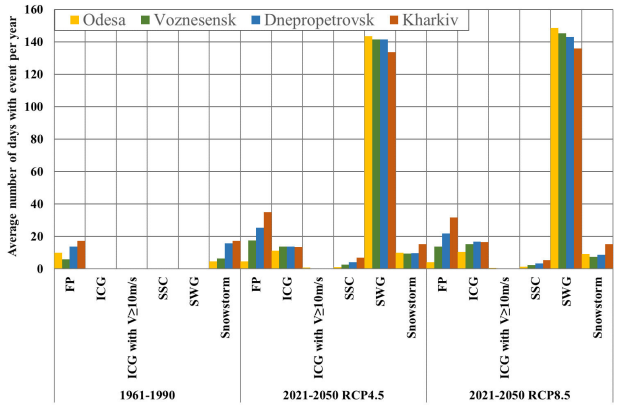

Figure 11. - Yearly average number days with events for 1961-1990, the RCP4.5 and RCP8.5 scenarios for the Odesa – Voznesensk – Dnipropetrovsk –Kharkiv highway

The highest frequency of all meteorological events will be recorded for slippery wet ground. Under both scenarios wet ground will most frequently occur in May and June - about 50% of all days in this period.

In autumn, winter and spring under both scenarios frequency of events that make road surface worse is very high especially in the forest-steppe zone and reaches 60-70%. In the Black Sea Lowland among winter events the frozen snow that had initially melted on a warm road surface is most commonly observed, that is connected with high occurrence of the thaws.

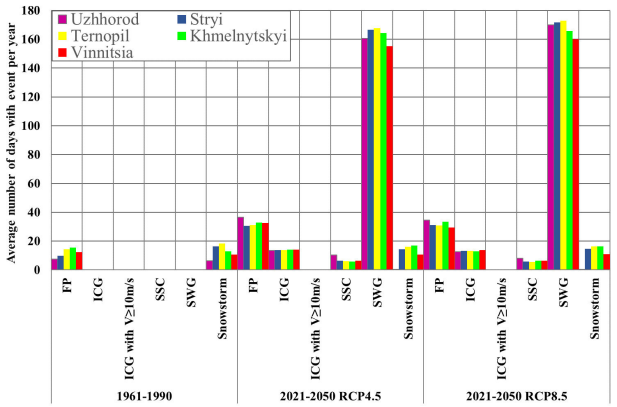

Figure 12. - Yearly average number days with events for 1961-1990, the RCP4.5 and RCP8.5 scenarios for the Vinnytsia – Khmelnytskyi – Ternopil – Stryi – Uzhhorod highway.

Monthly mean wind speed shows that in all cities, except Dnipropetorvsk and Uzhhorod, increase in average monthly and annual average wind speeds are observed, by 0,5-1,5 m/s in comparison with the period of 1961 to 1990. On the contrary, in Dnipropetrovsk, wind speed decreases by 0,7 m/s, and in Uhhorod wind speed almost will not change.

Table. 1-3 presents social and economic risks due to hazards such as heavy rain, strong wind and hot weather heat for Odesa–Voznesensk–Dnipropetrovsk –Kharkiv highway (denoted by #1 in the tables) and Vinnytsia–Khmelnytskyi–Ternopil–Stryi–Uzhhorod highway (denoted by #2 in tables).

Social and economic risks are determined by methods proposed in [3,5].

Table 1 –Social and economic risks for heavy rain for the 2021-2050 period for the RCP4.5 and RCP8.5 scenarios

		# 1	# 2
RCP4.5	P_{social}, thsd. people	12.49	262.83
	P_{econ}, thsd. UAH	66.49	19534.36
RCP8.5	P_{social}, thsd. people	15.14	49.11
	P_{econ}, thsd. UAH	64.53	389.78

Tables 1, 2 and 3 shows that the highway #1 will be mostly influenced by extremely hot weather, but the highway #2 will be frequently flooded. Under scenarios RCP4.5 for Vinnytsia–Khmelnytskyi–Ternopil–Stryi–Uzhhorod highway heavy rain will cause significantly more serious flooding and damages than under scenarios RCP8.5 (table 1). This result may be explained by increase in total amount of precipitation in Uzhhorod.

Table 2 – Social and economic risks for strong wind for the 2021-2050 period for the RCP4.5 and RCP8.5 scenarios

		# 1	# 2
RCP4.5	P_{social}, thsd. people	40.55	11.92
	P_{econ}, thsd. UAH	2.63	0.18
RCP8.5	P_{social}, thsd. people	71.97	9.71
	P_{econ}, thsd. UAH	3.37	0.18

Along the highway #1 same as the highway #2 strong winds will be rarely observed and damages caused by strong wind is low (table 2).

Table 3 – Social and economic risks for extremely hot weather for the 2021-2050 period for the RCP4.5 and RCP8.5 scenarios

		# 1	# 2
RCP4.5	P_{social}, thsd. people	14341.06	1609.63
	P_{econ}, thsd. UAH	148582.32	1606.87
RCP8.5	P_{social}, thsd. people	14283.71	3128.87
	P_{econ}, thsd. UAH	124120.53	5879.76

For hot weather social and economic risks are higher for scenarios RCP8.5 than RCP4.5. It may be explained by more intensive increase in temperature under scenarios RCP8.5.

Conclusions:

For both scenarios, significant climate warming is registered; it is revealed in significant increase of average monthly and annual average temperature by 2-3°C in all cities in questions. Also, significant increase in frequency of days with maximum temperature ≥ +30, 35 and 40°C for Odesa–Voznesensk– Dnipropetrovsk –Kharkiv highway.

For all cities decrease in precipitation amount down to 90% will be observed, except Uzhhorod where strong growth in precipitation amount occurs under scenarios RCP4.5.

Strong increase in mixed precipitation and significant reduction in ice and liquid precipitation will take place.

Growth of mixed precipitation causes increase in severe weather events such as freezing precipitation, ice-covered ground and snow slippery coat that make road surface worse for both highways.

Odesa–Voznesensk– Dnipropetrovsk – Kharkiv highway will be mostly influenced by extremely hot weather, but Vinnytsia–Khmelnytskyi–Ternopil–Stryi–Uzhhorod highway will be frequently flooded.

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