STUDIA UBB GEOGRAPHIA, LXX, 1, 2025 (p. 9-24)
(RECOMMENDED CITATION)
DOI:10.24193/subbgeogr.2025.1.01

ASSESSMENT OF SOLAR CLIMATE RESOURCES ON THE TERRITORY OF THE REPUBLIC OF MOLDOVA IN THE CONTEXT OF CLIMATE CHANGE

Gherman BEJENARU[1], Vitalie DILAN[2]

ABSTRACT. – Assessment of Solar Climate Resources on the Territory of the Republic of Moldova in the Context of Climate Change. This study evaluates the solar climate resources of the Republic of Moldova in the context of climate change. The analysis covers data from representative meteorological stations for the periods 1961-1990 and 1991-2020. The main focus is on global and direct solar radiation, as well as sunshine duration. Results indicate an increasing trend in solar radiation and sunshine duration, particularly in the northern part of the country. The study also discusses the implications for the use of solar energy in Moldova, highlighting the potential for enhanced heliothermal resources due to climate change. The findings provide a comprehensive understanding of solar climate variations and their impact on renewable energy potential.

Keywords: *Solar radiation, Sunshine duration, Climate change, Renewable energy, Moldova.*

1. INTRODUCTION

Renewable energy sources (wind, solar, hydro, ocean, geothermal, biomass and biofuels) are alternatives to fossil fuels that help reduce greenhouse gas emissions, diversify energy supply and reduce dependence on volatile and uncertain fossil fuel markets, especially oil and gas (Babiker and Ciucci, 2025). Solar energy resources are solar energy resources that can be used to produce electricity.

[1] *National Administration „Apele Moldovei", Water Resources Management Section, 5 Gheorghe Tudor str., Chișinău, Republic of Moldova, gherman.bejenaru@gmail.com*
[2] *„Ion Creangă" State Pedagogical University of Chișinău, Faculty of Geography, 1 Ion Creangă str., Chișinău, Republic of Moldova, dilan.vitalie@upsc.md*

Solar radiation is one of the main renewable energy sources, the use of which is not associated with negative environmental impacts. For these reasons, solar energy fully satisfies the sustainable development of society by ensuring a rational use of natural resources and the development of energy-efficient technologies in the conditions of climate change, and the assessment of solar radiation climate resources is not only fundamental but also of an applied nature.

2. MATERIALS AND METHODS

Observations on solar radiation are performed only at the Chișinău meteorological station, whose data are representative for the whole country. In analysing the duration of sunshine, information from the distributed meteorological stations was used so that the collected data would be representative (table 1).

Table 1. Meteorological stations whose data were used in the study

Station	Observation period, years	Station	Observation period, years
Briceni	1951-2007; 2010-2020	Chișinău	1951-2020
Balti	1958-2007; 2010-2020	Tiraspol	1951-1987; 1989-2020
Râbnița	1964-1986; 1990-2020	Cahul	1956-2007; 201-2013; 2015-2020
Dubăsari	1958-1991		

According to the recommendations of the WMO (World Meteorological Organization), the data analysis and synthesis was carried out for 30-year time intervals, starting from 1961 (WMO, 2017). In case of missing data for some years or months of a year, the method of data restoration was applied by using the arithmetic mean for the analysed period of the string.

Statistical processing and string homogeneity checks, calculation of basic statistical parameters was performed using the Excel formula package. For spatial modelling the spline interpolation method from ArcMap was used. Application of the regression method did not provide satisfactory results.

For illustration, the main specialized indicators of climate resources for the operation of solar power stations and their application diapason in Russia (*Encyclopedia of climatic resources of the Russian Federation*, 2008, p. 63) are presented in table 2.

Table 2. Diagram of the main specialized indicators of helioenergy climate resources

Indicator	Unit of measurement	Minimum	Maxima
1. Annual amount of global radiation on a horizontal surface	MJ/m^2	2659	5019
2. Annual amount of direct radiation on a horizontal surface	MJ/m^2	768	2859
3. Sun's annual sunshine duration	hours	1040	2397
4. Mean annual amount of total nebulosity	grade	5,3	7,4
5. Mean annual amount of lower nebulosity	grade	2,3	5,5
6. Number of days without Sun	days	37	137

The increase of indicators 1-3 (table 2) contributes to the increase of helium-energy resources, and indicators 4-6 - to their decrease (*Encyclopedia of climatic resources of the Russian Federation*, 2008, p. 63). When analysing the combined effect of all these indicators on the value of helioenergy resources, the greatest importance is given to indicators 1-3, the rest are considered complementary (*Encyclopedia of climatic resources of the Russian Federation*, 2008, p. 63).

3. RESULTS AND DISCUSSIONS

Global solar radiation, measured at the Chișinău meteorological station, in the analyzed time intervals evaluated as shown in tab. 3, fig. 1.

Table 3. Global solar radiation recorded at Chișinău meteorological station, MJ/m^2

Observation period	Multiannual average	Average in the warm season (May-September)	Average in the cold season (October-April)
1961-1990	4318	2877	1441
1971-2000	4285	2848	1437
1981-2010	4342	2876	1466
1991-2020	4416	2943	1473

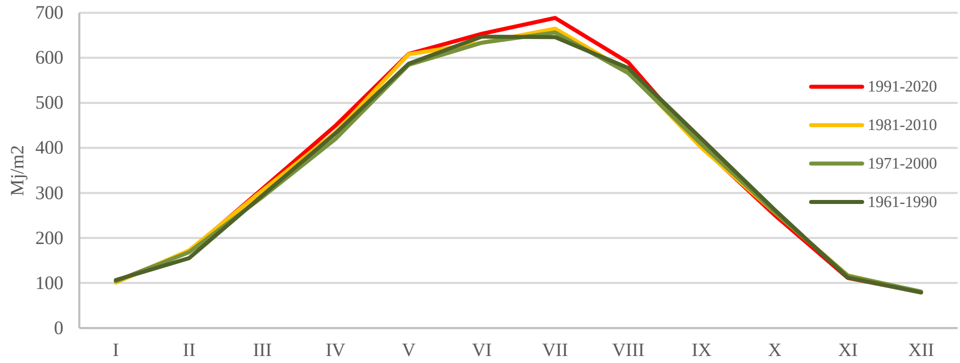


Fig. 1. Average monthly variation of global solar radiation for different periods

The difference between the average values of the period 1991-2020 and those of 1971-2000 increased by 131 MJ/m^2 (3,1%), and for the warm and cold periods of the year - by 95 (3,3%) and 36 (2,5%) MJ/m^2 respectively.

The period 1961-1990 is described by a lower global radiation, but due to the lack of previous observational data we cannot point to any finite cycle, which is also confirmed by the general plot of the parameter time evolution for the whole period of available data 1954-2021 (fig. 2).

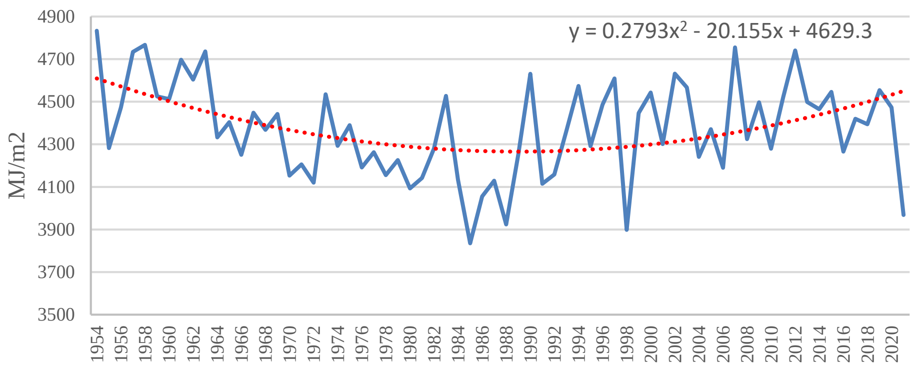


Fig. 2. Global annual mean solar radiation dynamics at Chișinău meteorological station (1954-2021)

Thus, the multiannual average value for the observation period 1961-2020 is 4355 MJ/m^2, and from the last analyzed reference interval 1991-2020 - 4416 MJ/m^2. The same trends are observed in the time distribution of direct solar radiation values, tab. 4, fig. 3.

Table 4. Direct solar radiation recorded at Chișinău meteorological station, MJ/m²

Observation period	Multiannual average	Average in the warm season (May-September)	Average in the cold season (October-April)
1961-1990	2204	1583	621
1971-2000	2169	1557	612
1981-2010	2281	1639	642
1991-2020	2501	1806	696

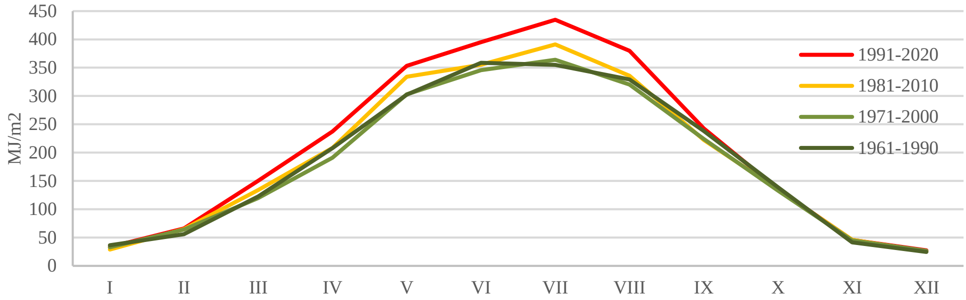


Fig. 3. Average monthly variation of direct solar radiation for different periods

Similar to global solar radiation, direct radiation has been increasing since the 1980s - the difference between the values for the period 1991-2020 compared to 1971-2000 is 333 (15,3%) MJ/m², and for the warm and cold periods 249 (16,0%) and 84 (13,7%) MJ/m², respectively.

In the case of direct solar radiation, the phase of increasing values since the 1990s is even better expressed, but due to the lack of observational data prior to the 1960s, we cannot point to a certain finite cycle (fig. 4).

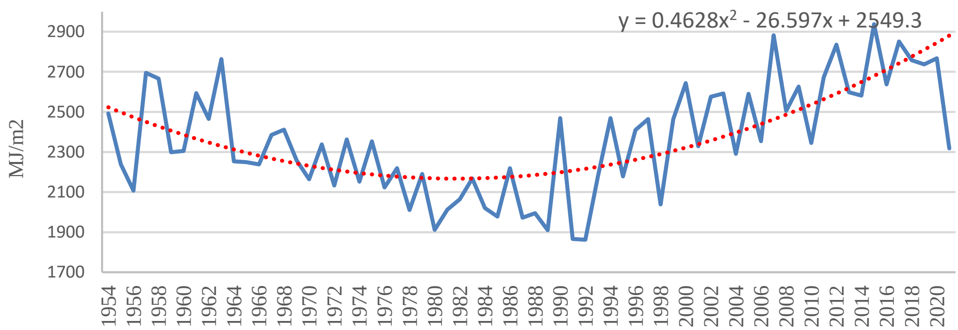


Fig. 4. Annual mean direct solar radiation dynamics at Chișinău meteorological station (1954-2021)

Global radiation and direct radiation during the warm period of the year also increased significantly. The minimum mean annual average value of global solar radiation was registered in 1985 - 3855 MJ/m² (12,6% below the average for the period, a questionable value since several months of that year had no data and their values were restored). The maximum annual average value was recorded in 2007 - 4755 MJ/m² (7,1% above the average for that period and note the severe drought in the summer of that year).

The multiannual average minimum value of direct solar radiation was in 1992 - 1862 MJ/m² (25,6% below the average for that period). The maximum multiannual average maximum value was recorded in 2015 - 2937 MJ/m² (17,4% above the average for that period and the drought and severe heatwave in the summer of that year).

It is worth mentioning that the solar radiation, both direct and indirect, recorded at meteorological stations in neighboring countries (Romania and Ukraine) correlates with the data from the Chișinău meteorological station and is in line with the global trends reflected in the literature (Lipinsky, Dyachuk, and Babichenko, 2003; Sandu, Pescaru, and Poiană, 2008; *Encyclopedia of climatic resources of the Russian Federation*, 2008; Ohmura, 2009).

Direct solar radiation (annual average, MJ/m²) can also be evaluated by the sunshine duration (fig. 5), which is expressed by the function $R_d = f(1{,}3269 \cdot n - 546{,}77)$, where n - annual average sunshine duration, in hours. The obtained linear function correlates with data published in regional studies (Păltineanu *et al*, 2002; Suehrcke, Bowden and Hollands, 2013).

The variation of the mean sunshine duration for the analyzed time intervals is shown in table 5, fig. 6.

Table 5. Average sunshine duration at representative meteorological stations

Reference period	Briceni			Chișinău			Cahul		
	Annual	Warm period	Cold period	Annual	Warm period	Cold period	Annual	Warm period	Cold period
1961-1990	1912	1222	690	2122	1354	769	2177	1347	830
1971-2000	1931	1236	695	2134	1349	786	2188	1346	841
1981-2010	1993	1273	721	2194	1388	806	2272	1390	881
1991-2020	2107	1345	762	2271	1439	832	2328	1430	898

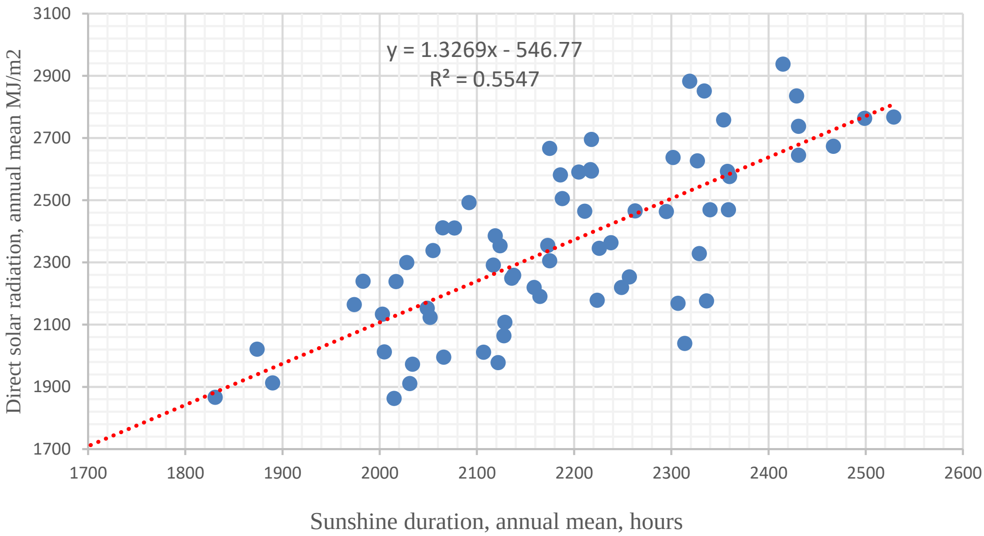


Fig. 5. Correlation of direct solar radiation with sunshine duration at Chișinău meteorological station (annual mean values)

Sunshine duration, as given in table 5 and fig. 6, 7, 8, is increasing for all analyzed periods. In particular, the duration of sunshine increases in the North of Moldova, where the difference between 1961-1990 and 1991-2020 is 195 hours (10,2%), while in Chișinău the same difference is 149 hours (7,0%). The warm period of the year is characterized by a more pronounced increase in the average annual sunshine duration - from 123 hours (10,1%) in the North of the country (Briceni) to 83 hours (6,2%) in the south (Cahul). In the cold period of the year these differences are smaller - 72 hours (10.4%) in Briceni and 68 hours (8,2%) in Cahul, but the upward trend is evident.

The spatial analysis of sunshine duration for the proposed time intervals is shown in fig. 7. Obviously, the lack of interpolation reference points outside the analyzed territory leaves its mark on the quality of the models, particularly at the periphery of the analyzed area, but the proposed goal is the general spatial highlighting of the evolution of the sunshine at different time intervals on the territory of the Republic of Moldova.

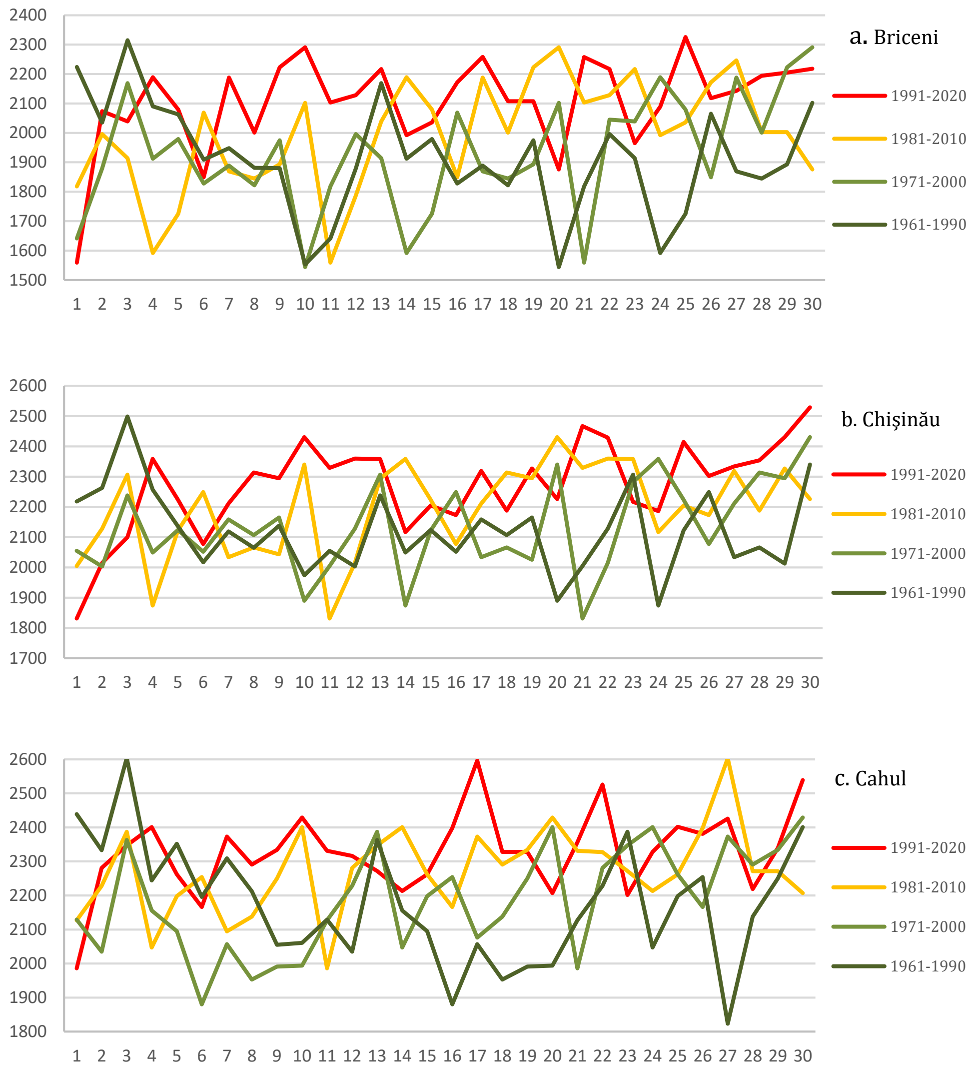
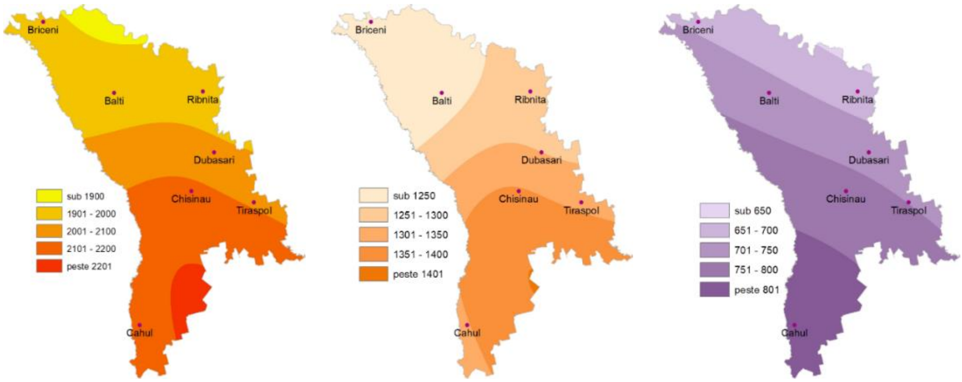


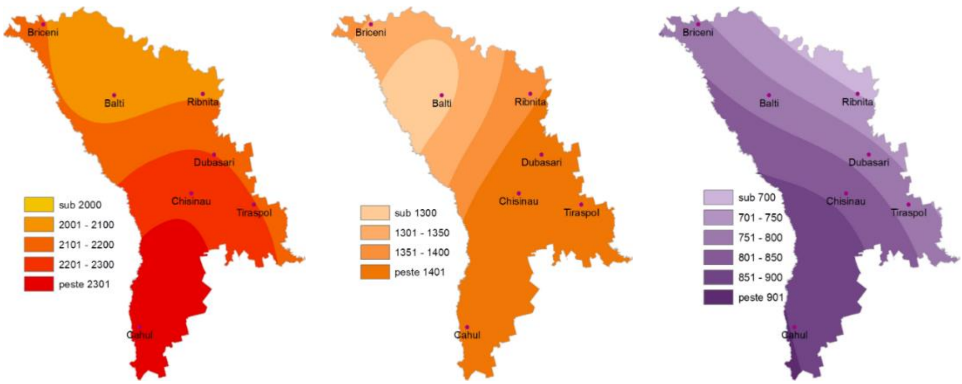
Fig. 6. Variation of mean annual sunshine duration (hours) for different time intervals at meteorological stations:
a - Briceni; b - Chișinău; c - Cahul

1961-1990



a) ***b)*** ***c)***

1991-2020



a) ***b)*** ***c)***

Fig. 7. Spatial assessment of sunshine duration (hours): a) annual average, b) in the warm period and c) in the cold period of the year, for the years: 1961-1990 and 1991-2020

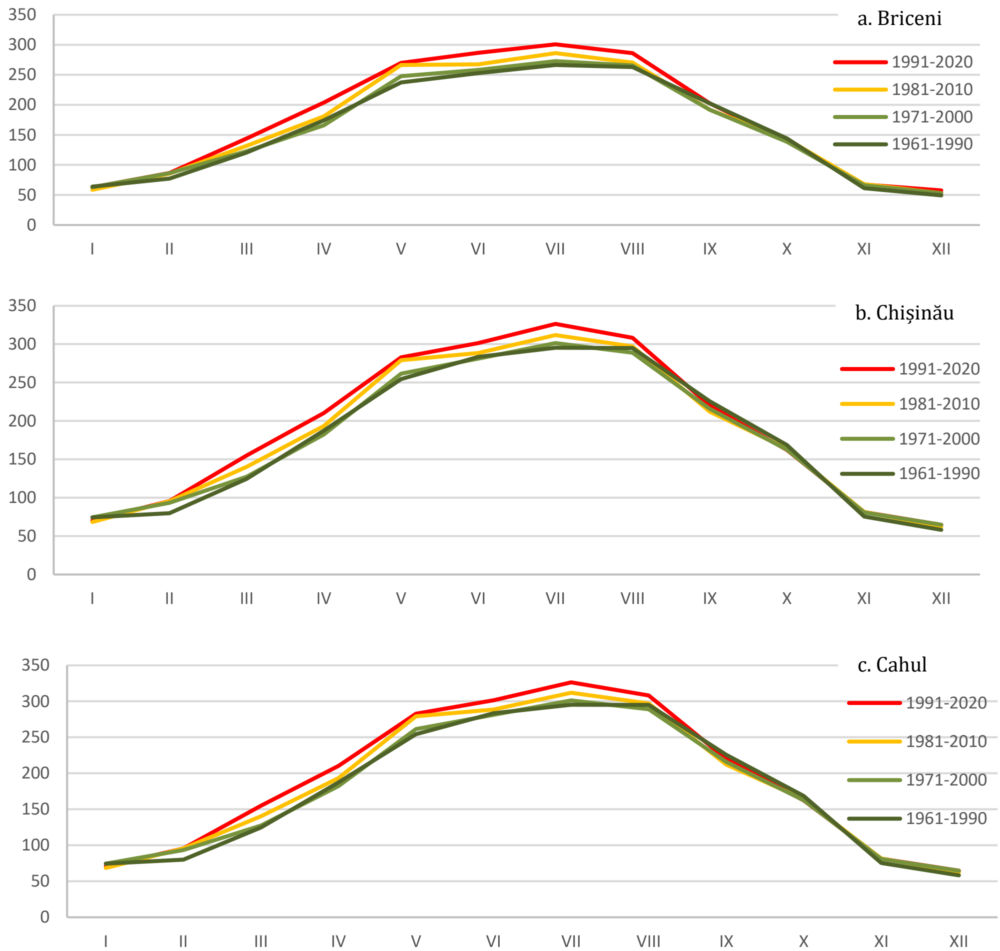


Fig. 8. Average monthly variation of sunshine duration (hours) for different time periods at meteorological stations:
a - Briceni; b - Chişinău; c - Cahul

In the case of the evaluation of the average monthly sunshine duration, the same trends of increase in the number of hours of sunshine are preserved for all months (fig. 8), but the most pronounced increase is in spring and summer months (table 6). Note that in the North of the country the average monthly sunshine duration increased more than in the South. Thus, at Briceni meteorological station, the maximum increase in June and July was recorded with 34 hours in the years 1991-2020 compared to 1961-1990, while at the Cahul meteorological station - the maximum gap is 27 hours in August.

In winter, in January, large variations are not registered, in the North and center there is even a small decrease in the average sunshine duration. December and February are characterized by an increase in the average sunshine duration, but inversely - more pronounced in the South. Thus, in December and February in Cahul the average sunshine duration increased by 12 and 24 hours, while in Briceni only by 8 and 9 hours (table 6).

Table 6. Difference between average monthly sunshine duration (hours) in the years 1991-2020 and 1961-1990

Station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Briceni	-1	9	24	30	33	34	34	23	0	-4	6	8
Chișinău	-4	16	30	23	28	18	31	13	-6	-6	6	6
Cahul	4	24	21	17	20	17	27	15	-5	-16	6	12

The variation of the monthly mean sunshine duration for a sunny day calculated for different time intervals is shown in fig. 9, and the differences between 1991-2020 and 1961-1990 - in table 7.

Table7. Difference between monthly average sunshine duration (hours) for a sunny day in the years 1991-2020 and 1961-1991

Station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	An
Briceni	0.06	0.95	0.24	1.28	1.05	1.43	1.05	0.79	0.35	0.18	0.52	0.30	8.20
Chișinău	-0.23	0.90	0.28	0.82	0.67	0.98	0.88	0.29	0.27	-0.03	0.63	0.27	5.72
Cahul	0.15	0.98	0.44	0.67	0.40	0.85	0.79	0.49	0.07	-0.19	0.68	0.41	5.74

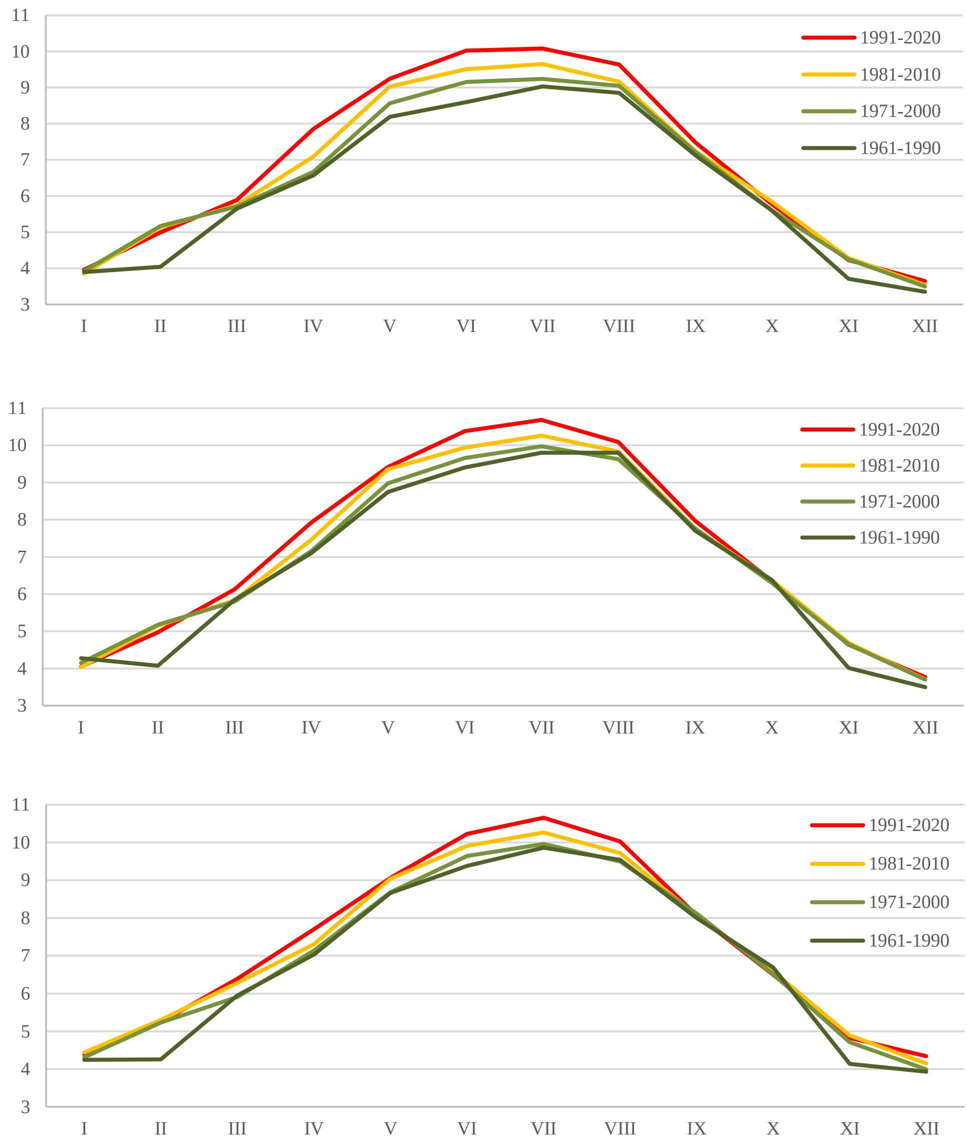
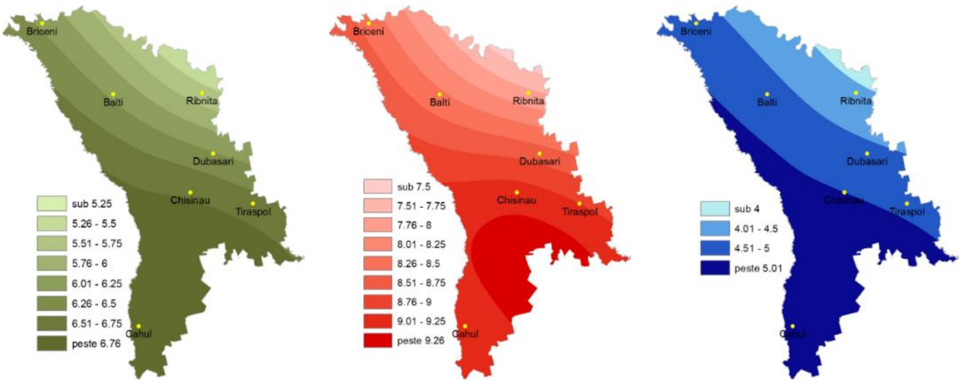


Fig. 9. Average monthly sunshine duration (hours) for a sunny day calculated for different time intervals

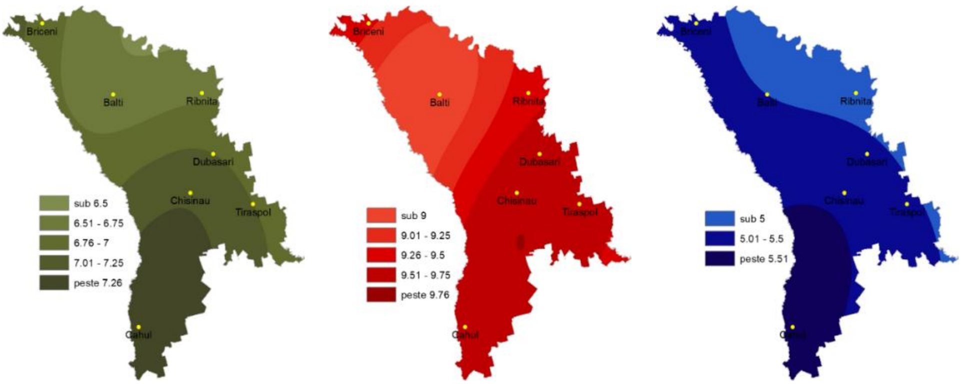
As with the monthly average sunshine duration, the monthly average sunshine duration on a sunny day is increasing. The general spatial assessment of the evolution of the sunshine duration on a sunny day in different time intervals over the territory of the Republic of Moldova is presented in Fig. 10.

1961-1990



a) *b)* *c)*

1991-2020



a) *b)* *c)*

Fig. 10. Spatial evaluation of the average sunshine duration (hours) on a sunny day:
a) annual average, b) in the warm period and c) in the cold period of the year,
b) for the years: 1961-1990 and 1991-2020

The increase in the duration of sunshine on a sunny day is more pronounced in the North of the country, where in summer the values for 1991-2020 are 1.43 hours (June, Briceni) compared to 0.85 in the South (June, Cahul) higher than in 1961-1990. In winter, the increasing trend is less expressed, but here the reverse is true - in the South the values are slightly more increasing than in the North: Briceni - in January the difference is 0.06 hours and in Cahul – 0.15.

Another important indicator, which characterizes the radiative regime and complements the present analysis is the number of days without sunshine for a time interval, table 8.

Table 8. Average number of days without sunshine at representative weather stations

Reference period	Briceni			Chișinău			Cahul		
	Annual	Warm period	Cold period	Annual	Warm period	Cold period	Annual	Warm period	Cold period
1961-1990	87	9	78	78	7	71	71	6	64
1971-2000	88	11	78	75	7	68	69	7	62
1981-2010	87	10	76	73	7	67	65	6	59
1991-2020	82	9	73	70	6	64	63	5	58

Thus, the average number of days without sunshine is decreasing in the annual aspect and in the cold period of the year, depending on the time interval analyzed. Also, this indicator is decreasing also in latitude - from North to South. At Briceni meteorological station, there are now on average 5 fewer days without sunshine each year than in the 1961-1990 period; in Cahul - 8 days. In the cold period of the year this difference is 5 days in Briceni and 6 days in Cahul. The change is not so obvious during the warm period of the year.

4. CONCLUSIONS

1. The upward trend in solar radiation (direct and global), which has been observed since the 1980s of the last century, is characterized by an increase in solar radiation (direct and global) up to the present, amplifying climate change in the study area. Thus, the difference between the annual average values of global radiation in 1991-2020 and 1971-2000 has increased by 131 MJ/m^2 (3,1%), and for the warm and cold periods of the year - by 95 (3,3%) and 36 (2,5%) MJ/m^2, respectively;

2. Average annual sunshine duration is increasing for all analysed periods. In particular, the sunshine duration increases in the North of the country, where the difference between the years 1961-1990 and 1991-2020 is 196 hours. The warm period of the year is characterized by a more pronounced increase in the average annual sunshine duration - from 124 hours in the North of the country (Briceni) to 83 hours in the South (Cahul). In the cold period of the year these differences are smaller - 72 hours in Briceni and 68 hours in Cahul;

3. The duration of sunshine on a sunny day is increasing and is more pronounced in the North of the country, where in summer the values for 1991-2020 are 1.43 hours (June, Briceni) compared to 0.85 in the South (June, Cahul) higher than in 1961-1990. In winter, the increasing trend is less obvious, but here the reverse is true - in the South the values are slightly more increasing than in the North: Briceni - in January the difference is 0.06 hours and in Cahul – 0.15.

4. The average number of days without sunshine is decreasing annually and in the cold period of the year. At Briceni meteorological station, there are now on average 5 fewer days without sunshine each year compared to the 1961-1990 period; and in Cahul - 8 days. In the cold period of the year this difference is 5 days in Briceni and 6 days in Cahul. The change is not so obvious during the warm period of the year.

5. The amplification of climate change since the 1980s of the last century is expressed by an increase in the amount of direct and global solar radiation, accompanied by an increase in the duration of sunshine, an increase in the duration of sunshine on a sunny day and a decrease in the number of days without sunshine. These trends favor the contemporary solar energy potential of the Republic of Moldova.

R E F E R E NC E S

1. Babiker, D., Ciucci, M. (2025), Factsheets on the European Union. European Parliament. Renewable energy, https://www.europarl.europa.eu/factsheets/ro/sheet/70/energia-din-surse-regenerabile
2. Lipinsky, V.M., Dyachuk, V.I., Babichenko, V.M. (2003), The climate of Ukraine, Raevski Publishing House, Kyiv (Климат України. Київ, Видавництво Раевського), 343 p.
3. Ohmura, A. (2009), Observed decadal variations in surface solar radiation and their causes, Journal of Geophysical Research. Atmospheres, 114, D10, doi:10.1029/2008JD011290.

4. Păltineanu, Cr., Mihăilescu, I.F., Torica, V., Albu, A.N. (2002), Correlation between sunshine duration and global solar radiation in south-eastern Romania, International Agrophysics, 16 (2), p. 139-145.
5. Sandu, I., Pescaru, V.I., Poiană, I. (2008), Clima României, Administrația Națională de Meteorologie, Romanian Academy Publishing House, Bucharest, 365 p.
6. Suehrcke, H., Bowden, R.S., Hollands, K.G.T. (2013), Relationship between sunshine duration and solar radiation, Solar Energy, 92, p. 160-171.
7. WMO (2017), WMO Guidelines on the Calculation of Climate Normals, 2017 edition, 29 p., https://library.wmo.int/doc_num.php?explnum_id=4166
8. *** (2008), Encyclopedia of climatic resources of the Russian Federation, Saint Petersburg (Энницикиклопеедия климатических ресурсов Росссийской Федерациии. Санкт-Петербург), Hidrometeoizdat (Гидрометеоизддат), 320 p.