The Impact of Climate Change (until 2050) on the potential of renewable energy sources (wind and solar radiation) for the territory of Bulgaria

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Abstract

In this study the regional climate model ALADIN - Climate is used with 10 km resolution for assessment of wind and solar radiation energy potential change over Bulgaria for the period 2021-2050. Annual and seasonal spatial maps of wind and solar radiation change are drawn in percentages (%) according to the reference period 1961-1990. The seasons are defined as winter (DJF) -December, January, February; spring (MAM) – Mart, April, May; summer (JJA) – June, July, August and autumn (SON) -September, October, November. Climate change evaluation on renewable energy sources (wind and solar radiation) is done for the territory of Bulgaria.

Assessment of climate change impacts on wind energy resource over Bulgaria for the period 2021-2050

There are different approaches to assess the changes of the wind energy potential. In [9] is used directly energy density. We will apply a different approach. In order to have more practical importance the assessment of wind energy potential change is necessary to comply with the technical and theoretical limits of electricity obtaining from wind energy. Such a restriction is **Betz Equation** [6]. It expresses the theoretical impossibility to extract all wind energy. In other words it is an analogue of Carnot's cycle. Thus each turbine has a coefficient of efficiency which does not allow extracting energy proportional to the wind speed in a wide range. It is specified as so-called **power curve.** It was introduced by the International Electrotechnical Commission (IEC) as an international standard IEC. Another evaluation is so-called **Langevin equation** [7]. In the figure below (Fig. 1) the normalized curves of IEC and Langevin are shown.

It is clear that the effective values for a non-turbulent (without strong gusts of wind) wind begin at speeds of 3-5 m/s and they are up to 15 m/sec. In our conditions wind speeds above 15 m/s cause strong wind gusts and for security reasons wind turbines should be turned off. For assessment of the climate change of wind energy potential from this curve is calculated rated power P/ Pr from accumulated nominal capacities during the reference period and the future period (2021-2050). After that the changes are calculated in percentages by seasons and years. The assessment is done for a **100 meters wind turbine tower.**

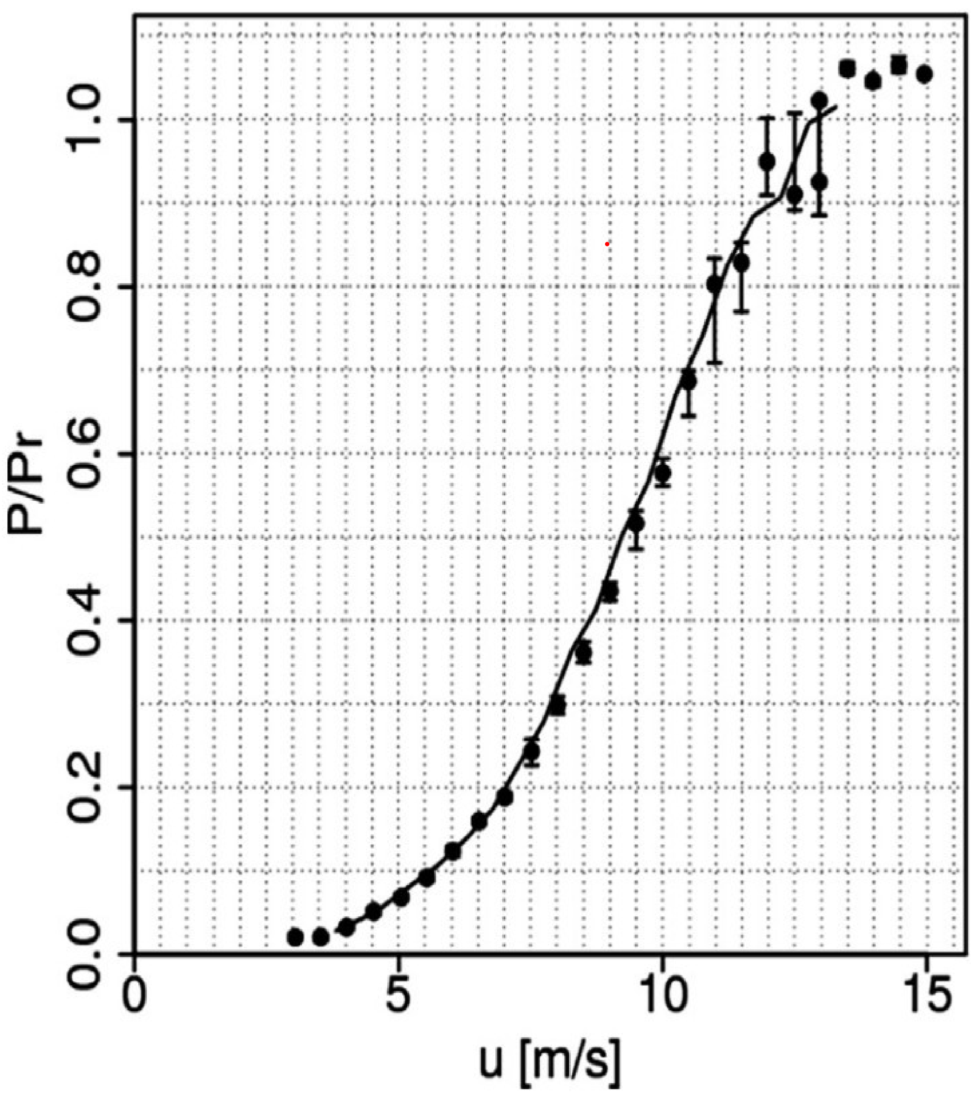

Fig. 1: Normalized power curve under [7]. The solid line represents the IEC power curve and the points and intervals represent the area of efficiency of Langevin. The power output is normalized by its rated value Pr.

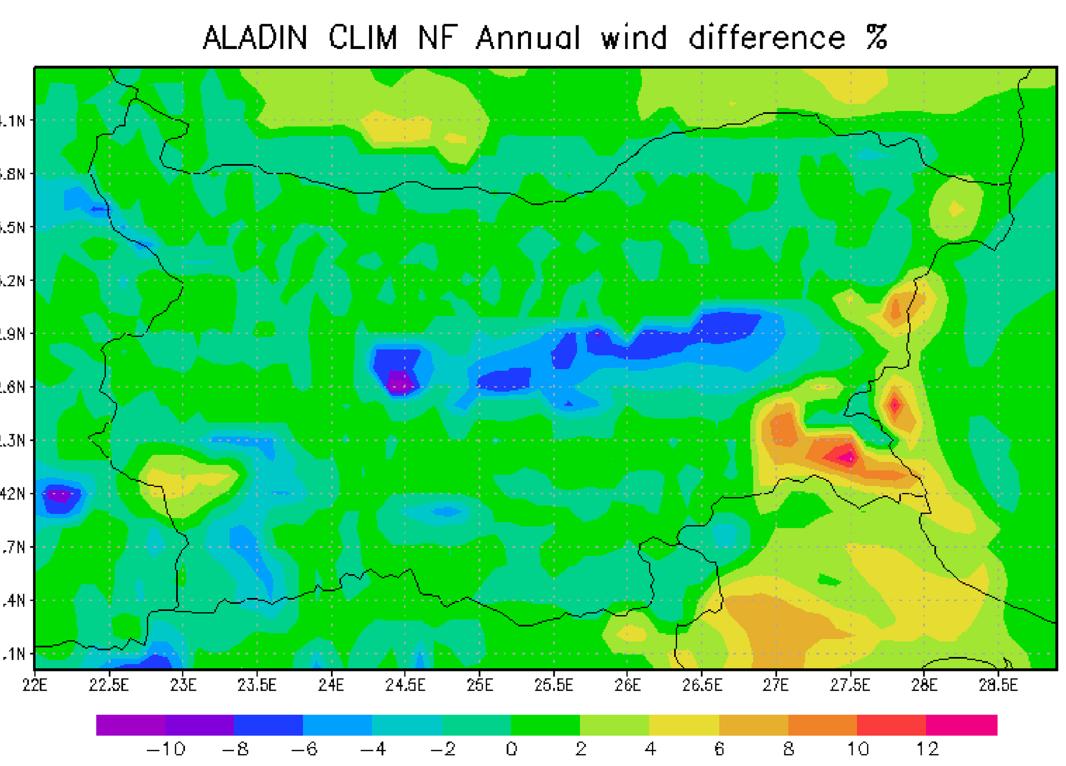

Fig. 2. Expected changes (in percentages, %) for the period 2021-2050 compared to the reference period in annual wind energy potential over Bulgaria.

The change of wing energy ranges from -12 (decrease with 12 %) to + 14 (increase with 12 %) percentages. The most significant increase of wind energy can be expected in eastern and south-eastern Bulgaria with 8 to 14 %. In central and south-western Bulgaria wind energy potential will decrease with 8-12 % and 4-6% respectively. In other parts of the country annual wind energy ranges from - 2 to + 2%.

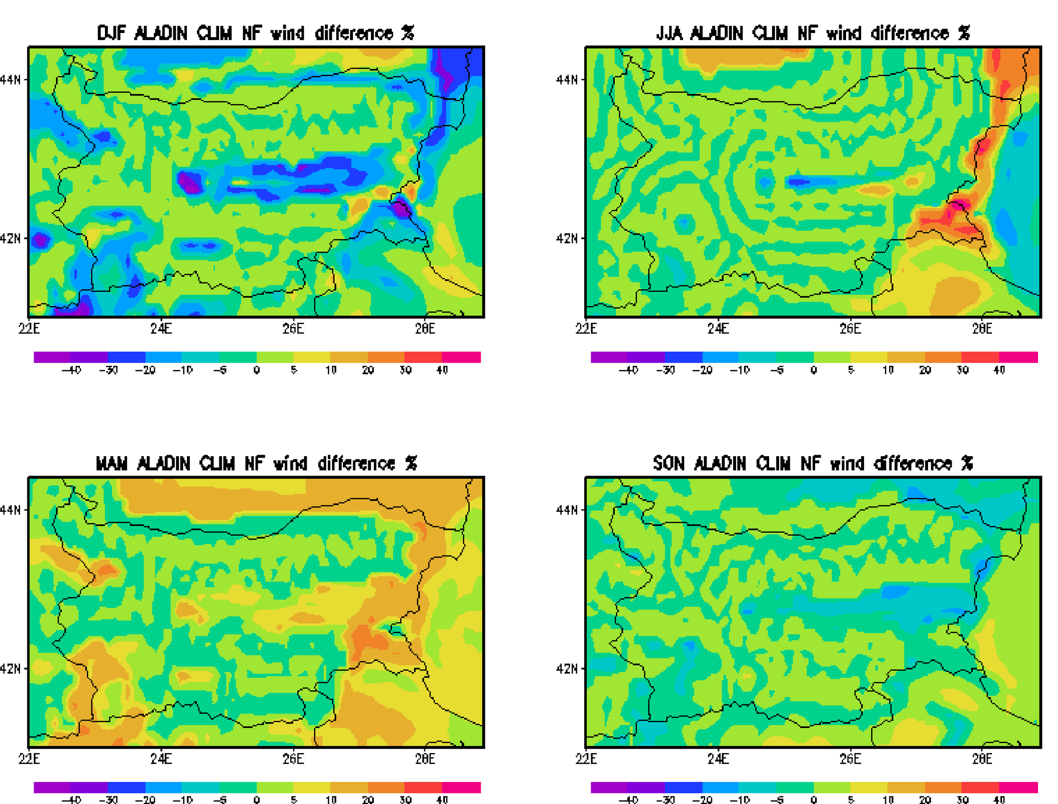

Fig. 3. Expected changes (in percentages, %) for the period 2021-2050 compared to the reference period in wind energy potential by seasons: DJF - winter (top left), MAM - spring (bottom left), JJA - summer (above right) SON - autumn (bottom right) for the territory of Bulgaria.

The wind energy change ranges from -50% to +50%. In winter (top left) changes in wind energy potential range from -50 to +20%. In this season we expect the largest reduction of wind power compared to the other seasons mostly in central and south-western Bulgaria as well as in coastal areas with values between -10 and -50 %. Similar trends are shown in autumn (bottom right), but the values are smaller from -16 to +8%. In summer (above right) wind power ranges from -20 to +50%. The increase of wind energy is the greatest in coastal areas and south-western Bulgaria (30 – 50%). In spring (below left) expected change ranges from -5 to +30% as the largest increase of wind energy potential is shown in the eastern and south-western Bulgaria with 10 to 30%.

Introduction

The changes in temperature and precipitation are the main focus in most studies of climate change. They are caused by changes in atmospheric circulation and cloud regimes. Therefore it is logical to expect changes in wind energy and solar radiation distribution. Wind and solar power use as renewable energy sources will increase in the medium term and for the already installed capacities will start renovation, relocation or replacement of one kind by another. In order to plan a strategy for development and use of renewable energy sources it is necessary to take into account expected changes in energy potential of different energy sources in 2050 as a result of climate change.

In recent years, research on impact of climate change on renewable energy and particular on wind and solar energy increased considerably. As far as these studies are based on simulations with global climate models (GCM) the surveyed areas are continental scaled [8]. The reason is GCM resolution, which is 150-200 km and prevents detailed study of the trends. For example, the topography is important for both wind and mode of clouds which actually determine the changes in reaching surface solar radiation and wind energy. Reporting the breeze effects and other local features is impossible with low resolution climate models. To avoid this disadvantage regional climate models (RCM) are used. They are "fed" by the boundary conditions of GCM, but having better resolution allow to show more details for a regions of interest. The research here is based on simulations with regional climate model ALADIN, successfully used in the project CECILIA of the 6th Framework Programme [1], [2], [3], [4].

Method of research

The climate experiment (simulation) is continuously integrating of climate model to establish a stable mode of changes in atmospheric circulation, which is expected to happen over a period of 30 years. The changes in atmospheric circulation are considered as changes in occurrence and development of cyclones and anticyclones leading to typical winter-summer periods. Moreover, we implicitly assume ergodicity of models. In other words, if no external parameters change, including greenhouse gases during a defined long period of integration, the weather that has to occur will occur in this 30-year period. Continuing the integration period will not lead to anything new. To assess the effect of climate change for a future period this changes are compared with the simulations for the so-called "reference period" presenting the present state of climate. The reference period is 1961–1990. That is conditionally, as far as the simulation depends on the underlying greenhouse gases rather than initial conditions. In practice global concentration values, measured around and after 2000 are used. In other words, the reference period is a simulation of current climatic period.

The climate change scenarios are determined by assuming different development of human activity and different release of greenhouse gases. They are developed by IPCC (The Intergovernmental Panel on Climate Change).In practice, up to 2050 different scenarios are statistically indistinguishable. In resent simulations A1B scenario is used, which is considered as the most likely scenario, but the conclusions are equally statistically significant for all scenarios until this period.

Assessment of climate change impacts on solar energy resource over Bulgaria for the period 2021-2050

From the whole spectrum of sun radiation it is important only short-wave radiation for electricity production. It is calculated in the model and similar to the wind energy radiation can be calculated in the future period and compared with the reference period.

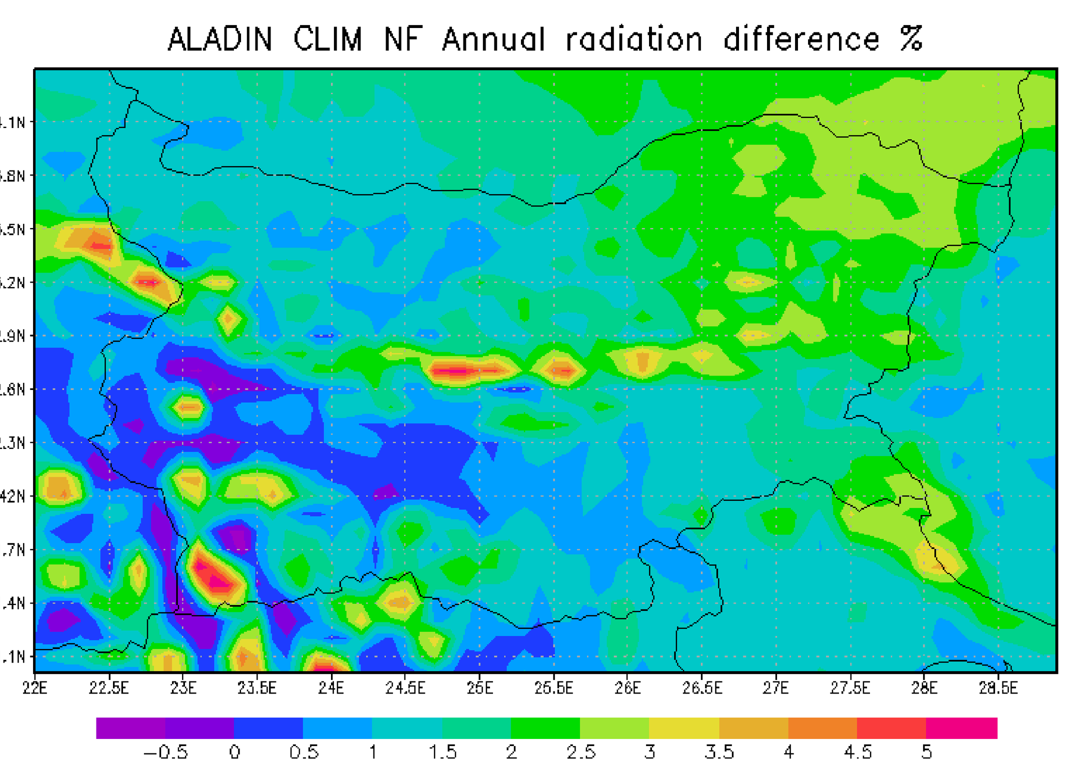

Fig. 4. Expected changes (in percentages, %) in annual energy potential of solar radiation on the territory of Bulgaria for the period 2021-2050.

The change ranges from -1 to +6%. Solar energy will increase in north-eastern Bulgaria with 2 - 3.5% and also in mountains areas (Balkan and Pirin Mountains) with 2-6%. In the other parts of the country - with 0 - 2% . A slightly decrease of solar energy is expected in south-west Bulgaria (- 0.5%), but there is also the maximum of solar radiation increase (4 - 6%).

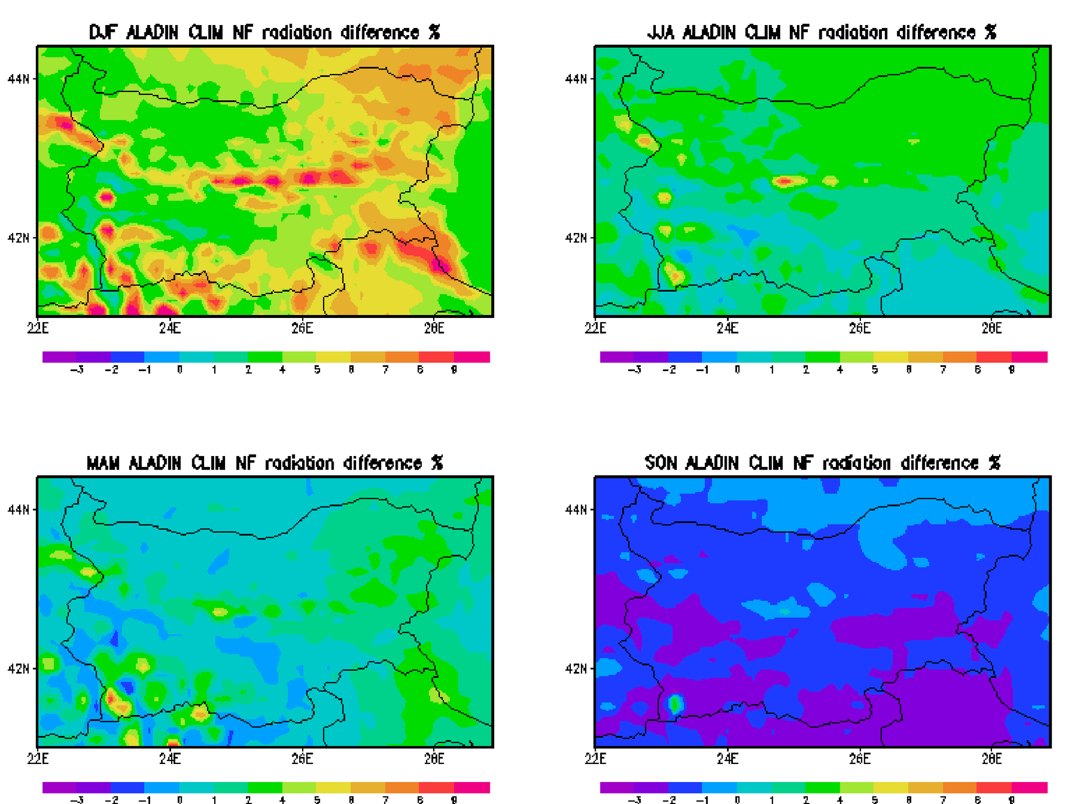

Fig. 5. Expected changes (in percentages, %) in seasonal solar radiation energy potential for the territory of Bulgaria for the period 2021-2050. Seasons are defined as: DJF – winter (top left), MAM - spring (bottom left), JJA - summer (above right) , SON - autumn (bottom right).

In winter (top left) solar radiation will increase in the whole country especially in central and north-eastern parts (8-10%) and mountain areas (Rila, Pirin and Balkan Mountain). In summer (top right) can be expected increase of solar radiation in northern part of the country (2 to 4%) as well as in southern Bulgaria (0 to 2%). In spring (below left) the most significant increase is shown in north-eastern Bulgaria and high mountains about 2 to 4%. In the autumn (bottom right) solar energy is reduced in the whole country and the most significant decrease can be expected in the southern parts of the country (from -2 to -4%).

Seasonal mean temperature increase with 1 to 4 degrees in the whole country. In winter (top left) temperature rising is smaller compared to the other seasons (1-2 ° C). In spring (bottom left) and autumn (bottom right) temperature increase is bigger in eastern Bulgaria (2 -2.5 ° C) and less in western Bulgaria (1.5 - 2 ° C). The greatest increase in temperature can be expected in summer season with 3-4 ° C. It is known that the temperature influences on the photo-voltaic (PV) efficiency [10]. It is important to notice that PV productivity decrease with 1 % for each 2 degrees above 25° C. The assessment depends on the type of PV. In this particular future period increases above 2 degrees are expected. **So, it is important to take into account PV energy decrease in summer season where solar radiation increase will be balanced by the temperature increase.**

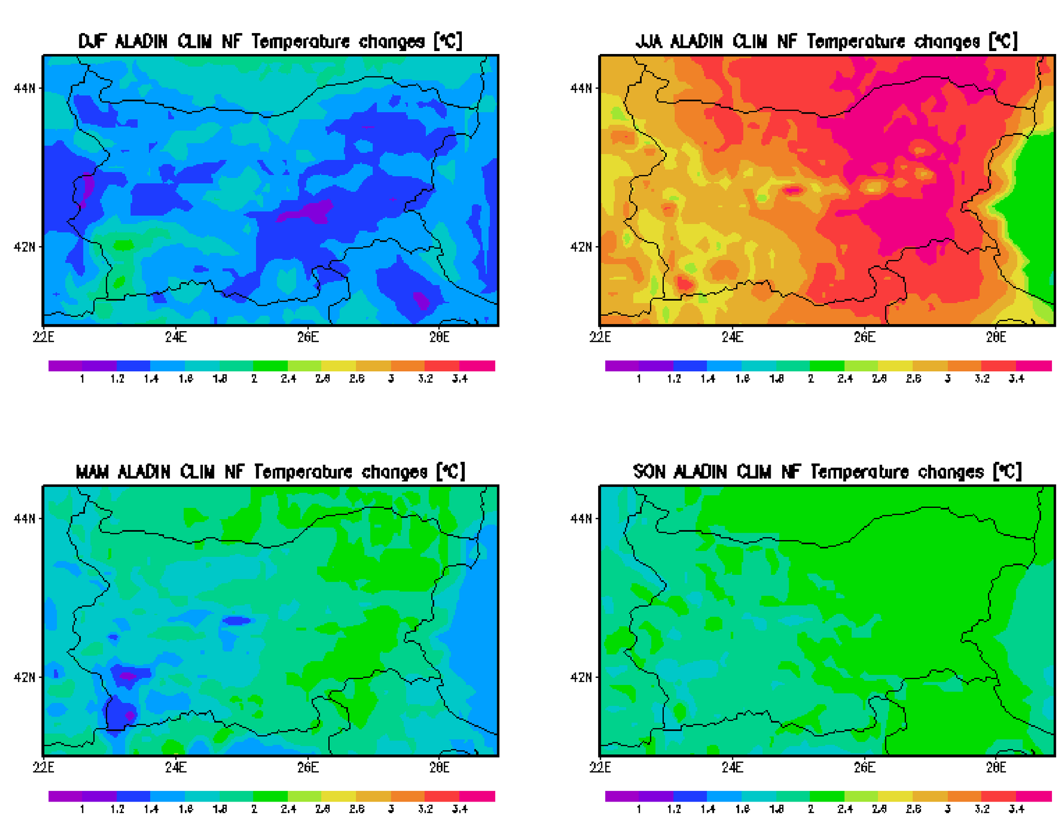

Fig. 6. Expected changes (in degrees Celsius, °C) for the period 2021-2050 in mean temperature according to the reference period for the territory of Bulgaria by seasons: DJF – winter (top left), MAM - spring (bottom left), JJA - summer (top right), SON - autumn (bottom right).

Summary

Annual and seasonal spatial maps of wind and solar radiation change are drawn up to 2050 as well as seasonal maps of temperature change. The most significant increases of annual wind energy can be expected in the south-eastern Bulgaria (up to 14 %) while the most significant decrease - in central Bulgaria with 12 %. Annual solar radiation will increase in south-eastern Bulgaria with 2 to 3.5% and parts of higher areas of the Balkan and Pirin Mountains - up to 6%. In some parts of south-western Bulgaria solar energy will decrease with 1%. Wind energy potential will decrease in winter (10-30%) in central and south-western Bulgaria and will increase in spring (10 -30 %) and summer (up to 50 %) in south-eastern Bulgaria and coastal area. Solar energy increase in winter in the whole country with 1 to 10 % and decrease in autumn in southern parts of the country with 2 to 4 %. In summer season solar radiation energy will increase in south-eastern Bulgaria with 2 to 4%.

These assessments of expected distribution change in wind and solar radiation energy potential due to climate change can be used for proper planning of strategies for development and use of renewable energy on the territory of Bulgaria.

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