Development of renewable power generation in Russia: opportunities and risks from the climate perspective

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Abstract. The main trends of the renewable generation development are discussed both on the global and national scales. The climate-driven factors of renewable power development are addressed considering the climate change impact. A method of the long-term climate projection assessment is proposed. The forecast estimations of the precipitation amount and the surface wind speed are developed considering a difference between the climate scenarios. The robust output of the fulfilled analysis is a general climate tendency to some improvement of the renewable power operation conditions under all realistic climate projections. The main climate-related negative effect found is a wind speed decrease in the European part of Russia and southern West Siberia, which means that some adaptation measures should be kept in mind when planning renewable power construction in these areas.

1. Introduction
The energy industries are currently undergoing a fundamental transition around the world. Two main factors seem to be governing the progress of this process. The first of them is the implementation of the renewable generation; the second one is connected with development of the novel industrial control technologies.

Renewable power sources were among the drivers of the early industrial development. Nowadays, they are substituting nuclear and fossil-fueled generation. An integration of the constantly increasing renewable power share into the power systems may be possible only with new approaches to flexibly balance the power supply and demand. Such approaches are known under the marketing name of smart grids and include an active role of the power consumers, implementation of the adaptive control measures and creation of the virtual power plants [1].

The data accumulation processes combined with novel data processing techniques and control methods are about to cause a next global lifestyle transition which will be linked with Internet of things, Industry 4.0 and artificial intelligence. It makes sense to remember that all significant shifts of human lifestyle patterns since the Neolithic Revolution were to a certain degree global. A competition nowadays became truly world-wide which means that the global trends have greater impacts on development of national economics than ever.

Russian energy industry is heavily fossil-fuel dependent with highly centralized heat and power generation paradigm which makes an implementation of the renewable technologies very cumbersome even on the moderate scale. Both research and industrial communities are aware of an increasing gap between the Russian energy industry and the best world practices. An expansion of the renewable
generation in Russia is recognized as one of the important means to improve the standards of the national energy industry and ensure a national economical growth during the twenty-first century.

2. State-of-the-art
Renewable energy is being rapidly developed and undoubtedly will be one of the leading generation technologies in just some decades according to the global energy projections [2]. This necessarily means some structural shifts in the energy systems and infrastructure which will be possible under a condition of the appropriate changes in the very organizational principles of the regional energy systems.

2.1. Global picture
The accurate forecasts of the energy-related climate parameters are one of the prerequisites to integrate the expanding renewable power generation into the energy systems. A system approach is becoming today crucially important for the energy policy. Reconciliation of different economic and energy sectors is a key for a strategy intended to ensure adaptation of the energy systems to the new environmental and market conditions [3], [4], [5]. The importance of the environmental factors is increasing for such analyses. The first reason is that energy systems around the world are known to be vulnerable to the climate change. Secondly, the renewable potential is governed by natural conditions, which means in fact that the climate became one of the leading energy resources. And last but not least, the climate factors are strongly connected with energy demand. The system approach is nowadays seen as a key to ensure the energy transition balancing the environmental, economic, social and technological factors.

2.2. Renewable generation in Russia
Implementation of the renewable generation in Russia has almost a century-long history. However, the competition with the cheap fossil energy has resulted in a shrink of all the renewable initiatives in the country. The centralized structure of the energy systems was formed as the most advantageous one to supply concentrated industry consumers with the electricity. The large hydropower plants remained the only renewable energy supplier for some decades.

A new turn of the interest towards the renewable technologies emerged quite recently and is connected with the current energy transition. An increase in the renewable generation is being seen as a one of the measures to increase the general energy efficiency along, e.g. with improvement of the building thermal quality and the use of the local fuels such as byproducts of the oil industry.

The vast majority of renewable energy research in Russia is focused on applications to power supply for the remote communities [6]-[7]. Implementation of the renewable power into centralized power systems is rarely addressed. The work on that subject is focused rather on organizational and economic part neglecting the technological and climate issues.

2.3. Projection of the renewable climate factors Russia
Recent studies have resulted in a conclusion that Russia has enough renewable potential for successful renewable technologies development. However, the long-term trends of the renewable potential were not considered yet, despite of the well-known fact that even the natural long-term climate variability may impact the power industry quite significantly.

The most recent Roshydromet Assesment Report [8] gives a general overview of the long-term climate projections, but does not address the prospects of the renewable power generation under the projected changes. A few comprehensive works [9]-[10] present the results of the forecast estimations of the wind and hydropower, but does not mention an effect of the chosen climate scenario which is one of the main uncertainty sources of the climate projections. The work [11] presents an attempt to assess an impact of the climate scenario selection on the hydrological projection, but is focused on the runoff estimations obtained directly from the global climate models which may be taken only as quite an approximate estimation.
Thus, investigation of the long-term climate trends is still rather incomplete to quantify the impact of climate variability and climate change effect on the renewable power perspectives in Russia. The presented work is intended to contribute in filling this gap. In what follows we will propose a methodology of the long-term projections development, including assessment of the scenario-linked uncertainties, and provide some results of the climate projections.

3. Assessment of the long-term trends of the renewable energy sources in Russia

3.1. Methods

The global climate models are known for their ability to represent properly the general features of the climatic processes. However, the uncertainties of regional estimations are still significant for each specific model. One of the most effective strategies to overcome these difficulties is an ensemble approach which implies averaging of the simulation results by a variety of the models [9].

The development of the ensemble estimation basically consists of processing the gridded computational archives. The workflow includes matching up the different simulation calendars, re-interpolation between different spatial grids, as well as temporal and special averaging. An original computational R-toolset was developed to automate the ensemble calculations. The aim of the developed concept was to facilitate ensemble calculations and to make assessment of the effect of the scenario and model selection as simple as possible. The details of the implementation may be found elsewhere [12]. The source code of the tool is available under the GPL-3 license via https://github.com/ekatef/CMIP5-ArAvr.

All the available models were employed to obtain the precipitation projections across Russia. The wind projections were constructed using the results of the eight models which demonstrate the best skill for the daily wind speed distributions according to the recommendations [13].

3.2. Data

The data provided by the participants of the Coupled Model Intercomparison Project Phase 5 (CMIP5) were used for calculations. It should be noted that the next phases of the CMIP initiative are in progress. However, the up-to-the-date CMIP5 archive remains the most comprehensive data source on the global climate numerical experiments.

3.3. Results

The optimistic scenario rcp 2.6 and moderate one rcp 4.5 were considered for simulations, as the real climate system is most likely to evolve between these two trajectories [2].

The mid-term time horizon 2045-2054 was taken for calculations. The results of the ensemble calculations are presented in figures 1-2. The precipitation amount demonstrates an increase in the most parts of the country for both of the considered scenarios, which implies that the operation conditions of hydropower plants tend to improve. That is consistent with the results of the earlier works [10], [11] and with the observed pattern of the regional manifestation in the global hydrological cycle under the climate change.

The estimations of the wind speed variation give a robust increase in the wind speed in the Primorye region. That effect is evident for all the considered combinations of the climate scenarios and the ensemble composition. On the contrary, a tendency towards a wind speed decrease is found for the European part of Russia and south of West Siberia. The absolute values of the wind speed changes are quite low; however, it has been found recently [16] that the general climate model tends to underestimate the decrease in the wind speed which was observed during the last fifty years in the Northern Eurasia.

4. Summary

The change of the precipitation field follows a known pattern “wet getting wetter” which means that wet areas receive more precipitation due to the climate change, whereas dry areas are getting drier
This will likely lead to some increase in runoff and improve conditions of the hydropower operation across Russia which is perfectly consistent with the earlier works.

The obtained wind speed projection fields have a more complicated structure than precipitation ones. The robust finding for the wind speed is the increasing trend in Primorye region. The results for the other parts of the country demonstrate some dependence on the ensemble composition and are quite strongly linked with the considered scenario. However, a tendency to wind speed decrease in the European part of the country and in the southern part of West Siberia may be concluded with a certain confidence. It should be noted also that rather small values of the wind speed changes are very likely underestimated by the global climate models [16] and should be treated as a very initial assessment that should be further improved using some statistic corrections.

![Figure 1](image1.png)

**Figure 1.** Projections of the relative change of the annual precipitation amount in 2045-2054 as compared with 2007-2016: a – optimistic climate scenario rcp 2.6, b – moderate climate scenario rcp 4.5. Authors’ calculations using [14] and [15] data.

The general long-term projection pictures of the both considered climate factors are quite consistent between the considered low and moderate climate scenarios that seem to be the closest to the real evolution of the climate system. The general result of the developed ensemble estimations may
be a conclusion that the anticipated change of the climate conditions is rather favorable for development of the renewable power in Russia.

However, it should be kept in mind that the key to a successful integration of the renewable power into the power systems is a proper assessment of the regional climate dynamics. An increase in the spatial and temporal resolution of the climate projection is a necessary next step which is needed to support development of the renewable generation in Russia.

**Figure 2.** Projections of the relative change of the surface wind speed in 2045-2054 as compared with 2007-2016: a – optimistic climate scenario rcp 2.6, b – moderate climate scenario rcp 4.5.

Authors’ calculations using [14] and [15] data.

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