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Climate change modeling in the context of urban decarbonization strategy

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Abstract. The anthropogenic influence on the Earth's climate is growing and the risks of the irreversible impacts on ecosystems also increase. This paper is focused on the long-term prediction of the climate change in Kyiv region and decarbonization strategy development. The bcc-csm1-1 and IPSL-CM5A AR 5 climate models were used. It was determined that the average annual temperature in Kyiv region under the RCP 8.5 high-emission future scenario will increase noticeably (up to 23.8 °C according to the IPSL-CM5A model) while at the RCP 2.6 low-emission future scenario it won't change significantly (maximum value of 11.5 °C according to the IPSL-CM5A model). So, the research recommendations were organized in order to develop decarbonization strategy for Ukraine that will help to reduce emission levels and reach the RCP 2.6 scenario. The practical and scientific value of the work is specified by the fact that obtained results take into account updated information about climate changes and can be used to increase the awareness of citizens about it. The results of the study confirm the existence and danger of the problem of climate change and show how GHG emissions can affect the ecological balance of the urbanized ecosystem. The risks of the certain natural disasters occurrence were also considered. It was found that amplification of the natural hazards is one of the main dangers of the RCP 8.5 scenario for the world, Ukraine and Kyiv region.

Keywords: climate modeling, global warming, decarbonization, climate change, natural hazards.

1 Introduction

In 2014 the Intergovernmental Panel on Climate Change (IPCC) that was created by UNEP and WMO has published the most recent Fifth Assessment Report (AR 5) with the newest information about climate changes and global warming (GW) [1]. The IPCC Synthesis Report confirms that anthropogenic influence on the Earth's climate is growing and the consequences can be observed across all continents and oceans on the planet. So, the risks of the irreversible impacts on ecosystems also increase [2].

Ukrainian industrial and transport complexes consume too much fossil fuel which leads to the significant emissions. According to the State Statistics Service of Ukraine, in 2016 carbon dioxide emissions to the atmosphere from the stationary pollution sources reached 150581.0 thous. t, which is 8.4 % more than in 2015. At the same time, the total amount of all other pollutants and greenhouse gases (GHG) emissions from stationary sources reached 3078.1 thous. t, which is 7.7 % more than in 2015. Pollution from the mobile sources is also considerable – carbon dioxide emissions into the atmosphere in 2015 reached 23139.8 thous. t while emissions of all other pollutants and GHG from mobile sources reached 1663.9 thousand tons [3].

Thus, to prevent climate changes it is important to reduce the usage of fossil fuels. But today they are the key energy source for our country and it is too hard to abandon them instantly. So, it is essential to develop a governmental decarbonization strategy in order to reduce the percentage of fossil fuel usage and, in turn, increase the percentage of alternative energy, such as wind or solar energy, biofuels, etc.

2 Literature Review

Mathematical modeling is widely used in GW and climate change assessment. In particular, in [4] BCC_CSM1.1 climate model was used to make predictions for East Asia under various RCP (Representative Concentration Pathways). In [5] Earth system models were used to assess the sensitivity of surface warming to carbon emissions from fossil fuel; in [6] − global TIMES model was used to estimate the impacts of technology influence on various aspects including CO_2 emissions. In [7] the analysis of the surface temperature modeling data from global climate models, CRU and regional climate model REMO was conducted.

It was found that considered models take into account different sets of factors affecting the climate and in different ways. The choice of the factors depends on the purposes of the model developers. The scale (global or regional) is also an important aspect because it is equally important to describe changes at the planetary level and to provide a clear understanding of the consequences for specific regions. It was also discovered that models have different simulation periods and their predictive capabilities are not limited by surface temperature – the distribution of precipitation, humidity, snow and plant cover, etc. around the world can be also forecasted.

According to [8], in comparison with the previous model generation, IPCC AR 5 climate models have an improved ability to simulate surface temperature and can predict a climate state that significantly differs from the present one. AR 5 models take into account the more rapid warming in the second half of the 20 century and the cooling following large-scale volcanic eruptions. To provide climate information at the smaller scales, regional downscaling methods are used in AR 5 models. Thus, their usage is considered appropriate for the study.

Today the main unsolved problem is climate change itself. And although the creation of new models and the improvement of the existing ones can't solve it, more accurate modeling results provide an opportunity to understand how specific measures will affect the state of the environment. At the same time, the increased accuracy of models increases the probability of making the right and economically reasonable decision during the development and implementation of the decarbonization strategy.

Despite the fact that climate modeling is often discussed in the literature, currently, this issue is not fully covered. First of all, it is more often considered in a global context, while changes of the specific urbanized ecosystems are not taken into account. In addition, with the development of science and new data appearance, new opportunities arise and more factors can be taken into account. Consequently, improved models provide more accurate results.

3 Research Methodology

The paper is focused on the long-term prediction of the climate change in Kyiv region and decarbonization strategy development. To achieve the aim of the research, the following tasks have been set:

– estimate the surface annual mean temperature changes in the world in general by the bcc-csm1-1 AR 5 model;

– by the bcc-csm1-1 and IPSL-CM5A AR 5 climate models predict the average annual temperature changes in Kyiv region for the long-term period;

– analyze possible consequences of the climate change in Kyiv region and Ukraine for the environment, economy and humans;

– consider international experience due to the decarbonization strategy and give recommendations for Ukraine.

The study is based on the most recent and improved IPCC AR 5 climate models. Two key software instruments were used in the investigation – AR 5 Climate Model Mapper (CMM) [9] and Climate Time Series Browser (CTSB) [10] provided by The University of Chicago. AR 5 CMM is a map making online software and analysis system. It is based on the limited set of the AR 5 models output archive and can be used in order to examine predictions about surface and atmospheric temperatures, specific humidity, precipitation, leaf area index, snow cover etc. in the world [9].

In turn, CTSB collects data about monthly mean temperature records from the NOAA National Climatic Data Center from 7169 weather stations around the world (26 stations in Ukraine, one in Kyiv). These data can be compared with the AR 5 climate model results, obtained from computational grids in order to correspond closely to the meteorological stations [10]. So, CTSB gives an opportunity to analyze four climate scenarios:

– "human and natural so far" – models data since 1850 taking into account natural changes such as solar intensity and volcanic eruptions, as well as anthropogenic impact;

– "natural only so far" – considers only non-anthropogenic impacts;

– "low-emission future" – is the RCP 2.6 scenario which pays attention to the existing climate changes without further emissions of GHG;

– "high-emission future" – the RCP 8.5 scenario which examines the situation with high-level emissions [10].

4 Results

At the first stage of the study, the CMM was used. The bcc-csm1-1 AR 5 model was chosen. The modeling results are shown in the Figure 1 for 2 100, 2 200 and 2 300 years. It was found that the surface temperature in most regions of the world will rise significantly leading to the changes in climate. These processes will affect Ukraine.

In the second part of the study bcc-csm1-1 and IPSL-CM5A AR 5 models have been chosen to estimate future climate changes in Kyiv region. These models can make predictions up to the 2299 year for the place of interest and cover two different but overlapping regions on the basis of the Kyiv station (Figure 2). In particular, these models are representative because modeled under the human and natural so far scenario historical data and the real data from the meteorological station are closely related (Figures 3, 4).

As can be seen from the Figure 3, according to the bcc-csm1-1 AR 5 model, at a high-emission future RCP 8.5 scenario, the average annual temperature in the area (1) around Kyiv meteorological station (Figure 2) will rise rapidly from 9.5 °C in 2016 and reach the value of 12.7 °C in 2100, 17.2 °C in 2200 and then reach the maximum value of 19.1 °C in 2259. Then there will be a slight decrease but in general, the temperature will remain at approximately the same level from 2200 to 2299 with the value of 16.9 °C in 2299. But at a low-emission future RCP 2.6 scenario, the temperature in the investigated region won't change significantly from 2016 and will reach the maximum value of 10.5 °C in 2116.

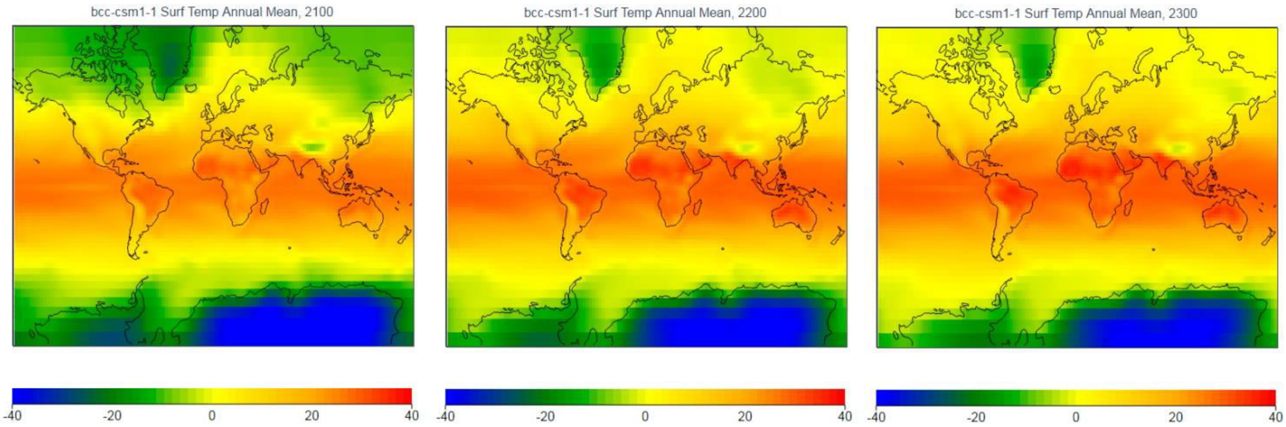

Figure 1 – World maps displaying the surface annual mean temperature in 2100, 2200 and 2300 as a result of the GW and climate changes under the bcc-csm1-1 AR 5 model, obtained by the author on the CMM

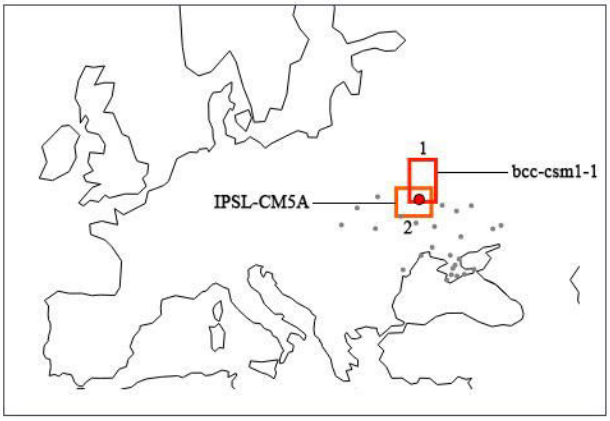

Figure 2 – The map that indicates the areas for which obtained results are representative (by the author on the CTSB)

The modeling results of the average annual temperature in the area (2) (Figure 2) obtained by the IPSL-CM5A model are shown on the Fig. 4. It was found that in the case of the high-emission future RCP 8.5 scenario, the temperature will reach the maximum value of 23.8 °C in 2267 and 2291. In 2100 the predicted temperature will be 13.9 °C, in 2200 it will be 22.1 °C and in 2299 it will be 22.8 °C. But at a low-emission future RCP 2.6 scenario, the temperature in Kyiv region will stay almost the same with a maximum in 2085 (11.5 °C).

So, according to the Figures 3–4, the only way to reach sustainability in Kyiv, Ukraine and other parts of the world is to reduce GHG and pollutant emission levels to reach the low-emission future scenario. And even taking into account the fact that preventing environmental degradation is not the problem that can be solved by a single city or country, all contributions are important. Otherwise, the consequences can lead to a significant aggravation of the ecological crisis.

One of the dangers of the high-emission future scenario is that the temperature isn't going to change in all parts of the world equally. Some places will be affected more than others and it will lead to aggravation of natural disasters such as droughts, floods, fires, and hurricanes. The places that are dry today will become dryer; areas that suffer from disasters now will suffer even more. Dangerous natural phenomena are going to affect areas where they were not seen before. So, the climate will become weirder around the world.

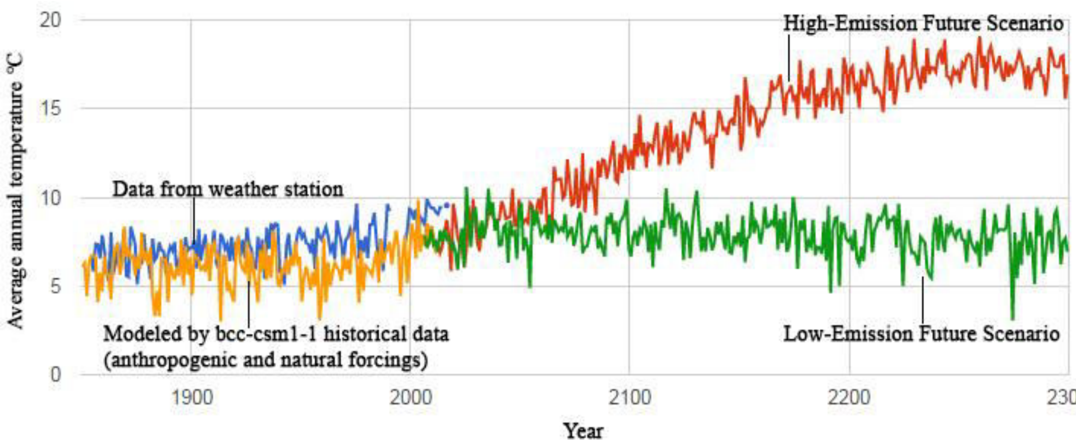

Figure 3 – Average annual temperature modeling results for Kyiv region by the bcc-csm1-1 AR 5 model at RCP 2.6 and RCP 8.5 scenarios, obtained by the author on the CTSB

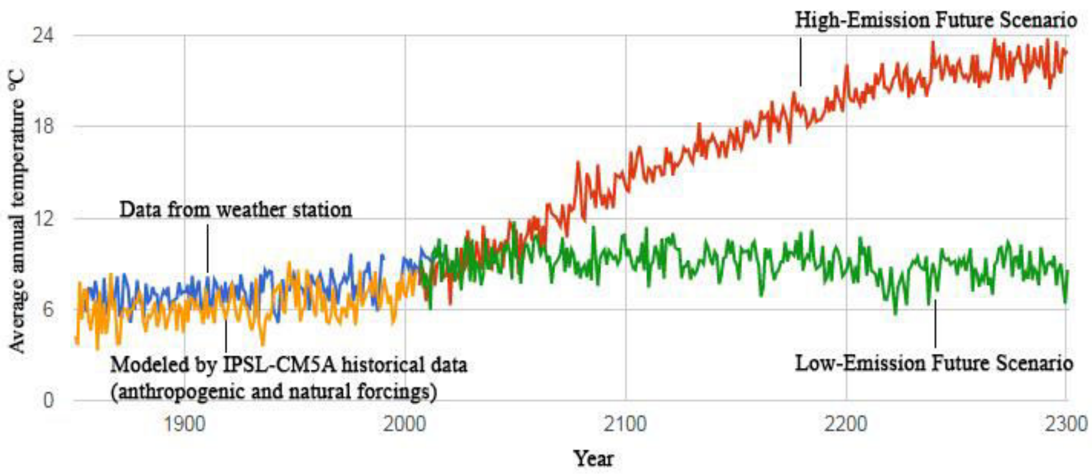

Figure 4 – Average annual temperature modeling results for Kyiv region by the IPSL-CM5A AR 5 model at RCP 2.6 and RCP 8.5 scenarios , obtained by the author on the CTSB

The consequences of such "weirding" have been already observed in 2016 and 2017. For example, according to [11], in 2017 forest fires in Portugal killed 64 people and destroyed nearly 30 000 ha of forest; Hong Kong was hit by a powerful typhoon [12]; Northern Ireland was affected by heavy rains and storms that caused flood [13]; terrible floods were also observed in India, Nepal and Bangladesh [14]; hurricane Harvey hit Texas [15], etc.

According to The State Emergency Service of Ukraine data [16], only on the time interval from 2010 to 2016 (Figure 5) the overall number of natural hazards in Ukraine reached a value of 540 (89 hazards occurred in 2016). According to the platform PreventionWeb [17] managed by the UN Office for Disaster Risk Reduction, the main natural hazards in Ukraine are droughts, extreme temperatures, floods and storms. As can be seen (Fig. 6), floods are the most common disasters in the country (Figure 6 a, in 51.9 % of cases), while extreme temperatures are the main cause of death (Figure 6 b, in 90 % of cases) and droughts are the key reason of the economic issues among all disasters (Figure 6 c, in 50.5 % of cases). PreventionWeb also highlights climate changes and environmental degradation among the main risk drivers.

So, climate changes can do much harm to Kyiv and Ukraine and it is important to implement “decarbonization” lifestyle. Analysis of the literature sources and experience of the international community has shown that green urban initiatives are an important part of the decarbonization strategy and can make Kyiv eco-friendly, healthy and sustainable city. And it was determined that experience of Scandinavian countries can be especially valuable for Ukraine. For example, the "eco-city" green urban initiative in the Western Harbour in Malmö, Sweden, is the evidence of a possibility of the industrial area transformation into the sustainable urban environment. This "eco-city" has a renewable energy system with wind power plant, solar cells, solar collectors on the roofs & walls, as well as a waste treatment system, green roofs and limited car traffic [18].

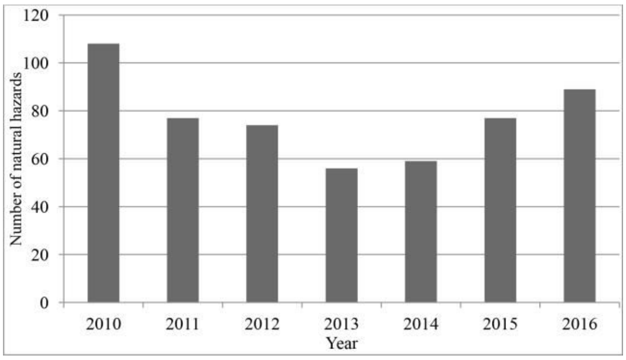

Figure 5 – Number of natural hazards in Ukraine since 2010, created by the author on the bases of the data [16]

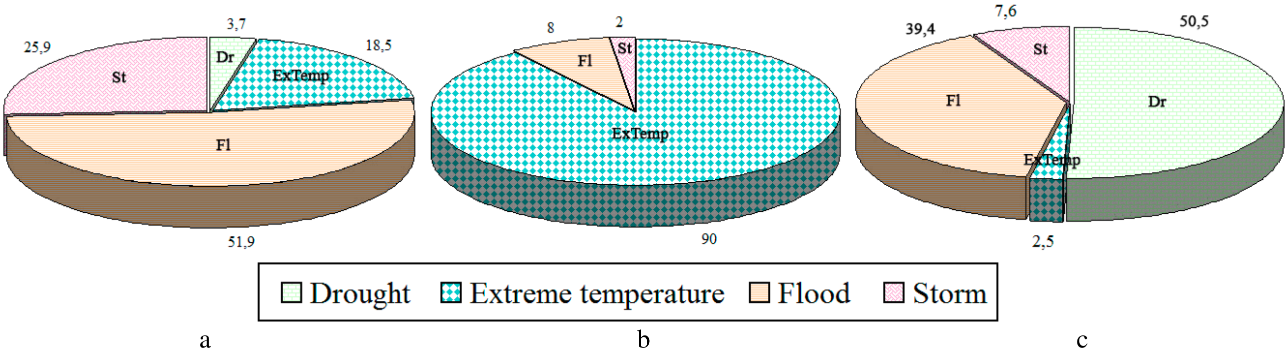

Figure 6 – Distribution of the main natural hazards in Ukraine (%) by frequency (a), mortality (b) and economic issues (c) [17]

Business and universities also play an important role in the sustainability of the country. For example, in 2016 MIT launched startup accelerator "The Engine" in order to help startups with funding of the projects devoted to such areas as clean energy & water, nuclear power, and climate change. And this accelerator is available not only for the MIT students and graduates [19].

5 Conclusions

By the bcc-csm1-1 AR 5 model, it was found that the surface temperature in most regions of the world will rise significantly leading to the changes in climate and these processes will affect our country too. According to investigated bcc-csm1-1 and IPSL-CM5A models, the average annual temperature in Kyiv region under the RCP 8.5 scenario will increase noticeably while at the RCP 2.6 scenario the temperature won't change significantly and will remain almost stable. Thus, the only way to prevent severe consequences for the environment and society is to develop the decarbonization strategy and reduce GHG and pollutant emission levels.

The practical and scientific value of the work is specified by the fact that obtained results take into account updated information about climate change dynamics and consequences and can be used to increase the awareness of citizens about the importance of this problem. The results of the study, obtained by AR 5 models and statistical analysis methods, confirm the existence and danger of the problem of climate change and can be used for the decarbonization strategy development. The results of the study also show how the increase or decrease in GHG emissions from transport and industry can affect the ecological balance of the urbanized ecosystem.

The risks of natural disasters occurrence were also considered. It was determined that climate "weirding" leading to aggravation of natural hazards is one of the main dangers of the RCP 8.5 scenario. Floods, extreme temperatures and droughts are particularly dangerous for Ukraine. All results of the study were evaluated in the context of the author's experience in the field of environmental safety and physical aspects of natural disasters and substantiate the need for the "decarbonization" lifestyle implementation on the basis of the international experience, as well as the interaction between government, business and universities.

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Моделювання зміни клімату відповідно до міської стратегії декарбонізації

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Анотація. Антропогенний вплив на клімат Землі зростає, а також зростає ризик незворотних впливів на екосистеми. Стаття присвячена довгостроковому прогнозуванню кліматичних змін у Київській області та розробці відповідної стратегії декарбонізації із застосуванням моделей клімату bcc-csm1-1 та IPSL-CM5A AR 5. Встановлено, що середньомісячна температура у Київській області за сценарієм високого викиду RCP 8.5 значно збільшиться (до 23,8 °C згідно з моделлю IPSL-CM5A). У той самий час, RCP 2.6 із низьким рівнем викидів не істотного впливатиме (максимальне значення 11,5 °C відповідно до моделі IPSL-CM5A). Таким чином, були запропоновані рекомендації щодо розробки стратегії декарбонізації України, яка допоможе зменшити рівні викидів та досягти сценарію RCP 2.6. Практична та наукова цінність роботи визначається тим, що отримані результати враховують оновлену інформацію щодо змін клімату, які можуть використовуватися для підвищення обізнаності громадян. Результати дослідження підтверджують існування та небезпеку проблеми зміни клімату та показують, як викиди GHG можуть вплинути на екологічний баланс урбанізованої екосистеми. Також були розглянуті ризики виникнення стихійних лих. Виявлено, що посилення природних небезпек є однією з основних небезпек сценарію RCP 8.5 для світу у цілому, а також України та Київської області зокрема.

Ключові слова: моделювання клімату, глобальне потепління, декарбонізація, кліматичні зміни, природні небезпеки.