Economic vulnerability assessment in the water sector with a focus on electricity production in hydropower plants: case of Montenegro

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Abstract. The aim of our paper is economic vulnerability assessment in the water sector of Montenegro, with a focus on electricity production in hydropower plants. The absence of an officially defined methodology in Montenegro, as well as in the region of South-East Europe represents a kind of challenge for research of this type especially for the assessment of economic damage caused by climate change and in the future period. In our paper, we treated negative impacts in the water sector as additional costs for the import of electricity due to reduced electricity production caused by the reduction of water potential due to climate change. After collecting, processing and analyzing data on electricity production in Montenegro, we prepared a projection of this production in the future period for the basic scenario - "without climate change". This was followed by an assessment of the quantitative damage, in accordance with the determined climate scenarios. After analyzing electricity prices in the European market, we defined future unit were defined as a basis for damage assessment. We conclude the paper with the calculation and projection of economic damages caused by climate change in the Montenegrin energy sector. The basic variant of the analysis would be the existing price of electricity imports for 2022, in the amount of 200 EUR per MWh. The other two variants would be one higher and one lower electricity import prices (250 and 150 EUR per MWh, respectively), in order to gain an overview of the future price fluctuations in a certain way.

1 Introduction

Widespread, rapid, and intensifying climate changes accompanied by global warming are among the biggest problems of the planet [1,2], which result in severe changes in the planet's ecological and geological systems [3-6]. As a result of climate change, there are changes in characteristics of precipitation [7,8] and evaporation [9-11], which has implications for the biosphere and people due to changes in water availability [12,13]. Trends in temperature, precipitation or snow cover, as the main climate variables, have a strong influence on groundwater [14], which is why their long-term and continuous monitoring can facilitate the

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assessment of the climate change impact in the future on the availability of the water resources [15]. Certain studies already indicate that clear trends of increasing evapotranspiration and temperature, as well as decreasing precipitation, lead to a continuous trend of decreasing surface water resources, which affects the sustainability of agricultural land use and increases the level of groundwater use [16]. Along with the increase in population on earth, the demand for water increases, and urbanization affects the quality of water [17,18], while some countries are predicted to become water-stressed countries in the near future [19,20]. In addition, there is a decline in economic growth, especially in some developing countries that do not have enough resources to deal with natural disasters [21,22].

Due to its multiple impact on water resources, ecosystems, agriculture, human health, climate change is the concern of hydrologists, ecologists, agronomists, and doctors [23-27]. Climate changes are the result of the combination of two groups of factors, natural and factors related to human activities [28]. However, in the last 50 years most heat can be attributed to human activities [29,30], which has caused numerous environmental problems, including freshwater scarcity [31,32]. At the same time, poor countries, due to their greater dependence on natural resources, are less able to deal with variability and extremes [33,34], which is why solving the problem of degradation of natural resources is urgent [35,36].

As one of the most important natural resources, water is of exceptional importance for economic and overall social activity. The generally accepted and undisputed point of view is that water resources availability and climate change are strongly related to each other [37,38]. Namely, in the IPCC 2014 Report, it is stated that 93% of the impacts related to climate change will be felt in the water sector [39]. At the same time, the results of certain recent research show a future reduction of water resources (up to 40%), with increasingly frequent dry periods [40]. Certain studies warn of the risk of drinking water quality [41], with the influence of extreme events related to climate applications, such as temperature rise, floods, heavy precipitation, red tide, etc.

It has been unequivocally confirmed that climate change has a significant impact on water cycles, which has led to temporal and spatial changes in the distribution of water resources [42,43], reduction of available water resources, and more frequent occurrence of extreme hydrological events. This causally increases the vulnerability of water resources and exerts additional pressure on the security of water supplies. Rapid population growth, urbanization and economic development are exacerbating the impact of climate change, especially in areas where demand for water exceeds scarce supplies. Inadequate adaptation to climate change threatens not only the achievement of SDG6 ("Water goal"), but also threatens other Sustainable Development Goals (SDGs). Studies on the impact of climate change on water resources began in the 1980s, and the World Meteorological Organization (WMO) published an overview of the impact of climate change on water resources and suggested certain methods of impact evaluation, after which it published a report on the sensitivity of the impact of climate change on hydrology and water resources, summarizing this problem for the future and modern climate change [44,45]. In the meantime, WMO and UNEP jointly established the Intergovernmental Panel on Climate Change (IPCC), which specializes in the periodic evaluation of the impact of climate change on water, as the most direct and vulnerable sector [46-48].

With climate change, due to global warming and temperature changes [49-51], as well as changes in precipitation [52,53], hydrological cycles have been altered in many parts of the world [54-57]. According to World Bank [58], global fresh water resources per capita have decreased, from 13,632 m³ in 1961 to 5,555 m³ in 2019. According to WHO forecasts, half of the total population will suffer water stress conditions by 2025 [59]. Al-Zubari et al. [60] showed that residential water demand increases by about 3.8 liters per inhabitant if the temperature increases by 1°C. For these reasons, studies on the impact of climate change on water resources have been updated. Evaluating the Water Crowding Index" (WCI, annual water resources per capita) and "Water Stress Index" (WSI, the ratio of water demands to resources), some of the earlier studies warn that around 35-60% of the global population in the 1990s were under water stress, moderate and severe level, at different spatial scale [13,61,62]. Later numerous studies, focused on the impact of climate change on water resources in the future, concluded that under the influence of socio-economic factors, water stress increases and varies from region to region [63-67]. Consequently, changes in water resources significantly affect agriculture through the quality and quantity of yields, causing problems in the supply of food markets and generating economic difficulties [68].

Climate change has had a significant impact on groundwater contamination, as well as the population life [69-71]. The lack of clean drinking water threatens the sanitary conditions of life [72,73], increasing the risk of disease [71]. Climate variability has a strong impact on public health, and at the same time there is a problem of water-related diseases [74], especially in the conditions of changing climate scenarios –temperature rise [75,76], uneven precipitation temporally and spatially [77-79], flash floods, severe droughts and sea level rise [80-82], heatwaves etc.

Evident changes in the water resources system, under the influence of climate change, have a causal effect on the local climate and to a certain extent have a negative impact on climate change. Therefore, regional and global hydrological models are combined with global climate model projections, in order to assess changes in water resources under the influence of climate change [13,83-85]. Future climate projections models indicate the inevitable consequences of climate change on water resources [2,86,87]. Finally, certain studies warn that, for a number of different reasons, the impact of climate change on the water environment is uncertain [88], and therefore water management in the future is also uncertain.

In general, we notice that the current water management systems are not adapted to these changes, the infrastructure is built for conditions of relatively stable water resources, and urbanization and the increase of irrigated areas have already caused difficulties in water supply. In addition, the limited availability of long-term hydrometeorological records and insufficient efforts to reconstruct historical data lead to the absence of comprehensive studies on changes in hydrometeorological indicators and other relevant indicators, which are a consequence of climate change [89]. Most of the studies are not comprehensive (most often they analyze one hydrometeorological or bio-physical phenomenon), they do not cover the entire nation, which is why a serious and integrated approach to climate change management is missing.

In order to adapt to climate change, some research suggest sustainable development strategies, as well as the integration of environmental education (EE) programs into the education systems of the country in order to raise awareness of climate change and other environmental problems, and make adaptation and mitigation initiatives successful [90-93].

Certain studies [94] focus on the estimation of economic damages from the impact of climate change on water resources. Frederick and Schwarz estimated the annual US cost associated with climate change impacts on water resources in the range of USD 136-327 billion. Furthermore, Hurd et al. [95] estimated the total economic damage (i.e. benefits from avoiding climate change impact) associated with flooding and water quality decline (due to assumed temperature rise and precipitation increase). Unlike some studies that assessed the overall national economic effects of climate change, other studies assessed the effects of specific effects of climate change, such as the impact of drought on the economy [96-98]. Recently, Du et al. [99] showed that climate change in the countries of the Belt and Road Initiative (BRI) will increase the demand for water by about 1.4-2.3% in the countries by 2050, with the consequence of serious water shortages in the countries of Central and Western Asia. The importance of water to other sectors, such as energy, manufacturing and transport [100,101] makes the problem of water supply multi-sectoral and multi-regional, although there is a lack of research on how the economic costs of future water shortages will spread across sectors and regions [102]. Lately, Papakostas et al. [103], conducted for Greece (Athens and Thessaloniki), confirmed the reduced demand for heat energy and the increase in energy consumption for cooling, due to the increase in air temperature. The results of earlier research also warned of the impact of climate change on reducing water availability and increasing water use [104-107]. Lehner et al. [108] pointed to the reduction of water resources in Eastern Europe due to two main causes: trends towards a dry climate and increasing water consumption for human use.

Interestingly, a large number of studies based on projected changes in water availability investigated the impact of climate change on hydropower. A global survey by Vliet et al. [109] projects a decrease in usable capacity by 61-74% for hydroelectric power plants and 81-86% for thermal power plants, worldwide for 2040-2061, due to climate impacts. On the other hand, Vliet et al. [110] pointed out the vulnerability of the European power sector due to hot and dry summers, citing that the increase in water temperatures and the reduced summer flow of rivers, under the influence of climate change, has an impact on hydropower and thermoelectric power in Europe, with significant impacts on electricity prices. At the same time, in some countries there are trends of decreasing hydropower potential, and in some it is maintained at a stable level, with a projection of a drop-in hydropower potential of about 6% by 2070, for the whole of Europe [111]. Schaeffer et al. [112] indicate that energy systems often do not include the effects of future climate variations in their work, so understanding the climate impact on the power system is of key importance for policy makers, in order to overcome the potential bottlenecks of energy systems. At the same time, Turner et al. [113] suggest that the Balkan countries appear to be the most vulnerable to climate change, with losses in total electricity production ranging from 5-20%, depending on the country. Recently, Tobin et al. [114] warns that, under the influence of warming, the production of hydro and thermal energy can be reduced by up to 20%, and that the southern European countries are more sensitive than the northern ones, while the increase of renewable sources could reduce this sensitivity. Solaun and Cerdá [115] suggest a drop-in hydropower production in Spain from 10 to 49% by the end of the century, depending on the plant and scenario, which could threaten future investments in similar projects. Interestingly, Sample et al. [116] forecast climate change is likely to have a weaker impact on the hydropower potential of Scotland than on locations in Mediterranean Europe or basins in the Alps, but higher than in countries such as Norway and Sweden. Wagner et al. [117] forecast that in the period 2031-2050 electricity production will go down by up to 8%, for the entire Appalachian region, compared to the period 1961-1990. On the other hand, some studies somewhat relativize the impact of climate change on hydropower production. Hamududu and Killingtveit [118] showed that climate change will not cause significant changes in global hydropower generation, if the existing hydropower system is taken into consideration. Tarroja et al. [119] suggest that the impact of climate change and increased variability will have some effect on hydropower production, depending on whether there is a longer dry period or a period with extreme rainfall.

Water sector in Montenegro is vulnerable to projected changes in mean climate conditions such as mean temperature and rainfall, projected climate variability (climate variability is expected to increase in a warmer climate), as well as projected changes in the frequency and intensity of extreme weather events and changes in the sea level. Concern about the potential effects of climate change on water resources of Montenegro is growing. Water resources vulnerability is a critical issue to be faced by society in the near future. Current variability and future climate change are affecting water supply and demand over all water-using sectors. Consequently, water scarcity is increasing. Climatic, hydrological, geological and socio-economic factors influencing vulnerability need to be identified and appropriate indicators selected. Exposure, sensitivity, potential impact and adaptive capacity are all considered in the evaluation of vulnerability to a defined climate change stressor such as temperature and precipitation.

The goal of our paper is economic vulnerability assessment in the water sector of Montenegro, with a focus on electricity production in hydropower plants. In Montenegro, as well as in the South-East Europe region, there is no officially defined methodology on the procedure and method of determining damage caused by climate change. The absence of such a methodology also applies to the assessment of economic damage under the influence of climate change in the future as well. Estimates so far were mainly based on a specific assessment of material damage, due to certain extraordinary events that occur under the influence of a changed climate.

The paper is organized as follows. In Introduction, relevant aspects of the problem related to the research objectives of this paper are presented, regarding the impact of climate change on the water sector, which causes economic damage in many sectors, especially in the energy sector. In the second section of the paper, we offer an overview of the national circumstances related to the water sector in Montenegro and the impact of climate change on this sector. The third section of the paper is devoted to economic vulnerability assessment in the water sector of Montenegro, with a focus on electricity production in hydropower plants and economic vulnerability assessment of fluvial floods in Montenegro. Negative impacts of climate change on the water sector in Montenegro are analyzed in the context of additional costs for the import of electricity, due to the reduction of water potential, which is a consequence of climate change. For the basic scenario - "no climate change" scenario, we prepared a projection of hydropower production in Montenegro in the future period, based on which the quantitative damage due to the reduction of production and in accordance with the defined climate scenarios. The assessment of economic damage was preceded by the collection of data related to the amount of hydropower produced in Montenegro, and their further processing and analysis, with the x projections. By including electricity prices in the analysis, we performed the calculation and projection of economic damage caused by climate change in the energy sector. In Section Conclusions, we offer final conclusions and recommendations, but also point to certain limitations of this paper, which can serve as an impulse for future research in this important field.

2 National circumstances relating to water sector and climate change impacts in Montenegro - overview

Montenegro is located in the central part of a moderately warm zone in the Northern Hemisphere (41°52’ and 43°32’ latitude North and 18°26’ and 19°22’ longitude East). Owing to its latitude, i.e. its proximity to the Adriatic and Mediterranean Seas, it has a Mediterranean climate with warm and somewhat dry summers and mild and rather humid winters. The dominant climate types in Montenegro are: Maritime, Continental and Mountainous. 79.23% of the total territory of Montenegro is covered by forests and semi natural areas, 16.09% is agricultural land, 1.9% water bodies and 1.87% is artificial areas.

In the area of Žabljak (1,450 meters above sea level), the average annual air temperature is 5.3°C, and on the coast the average annual temperature is 16.1°C. In the extreme north (municipality of Pljevlja), the average annual rainfall amounts to 790 mm, and about 3,350 mm in the extreme southwest (municipality of Cetinje). The average number of days with precipitation at the level of the year is from 115 to 130 days, while the average number of days in the northern region is 172 days. Snowfall occurs above 400 m above sea level, lasting from 10 days (Kolašin) to 76 days (Žabljak)The hydrography of the municipality of Dojran mainly consists of the Dojran Lake, smaller springs and streams, as well as a few artificial reservoirs. Most of the streams drain into Lake Dojran, and about 1/3 (the western part of Karabalija Mountain) drain to the Vardar River basin via the Luda Mara River.

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Seasonal air temperature data for Montenegro are presented in Table 1.

Table 1. Seasonal average, min-average and max-average temperatures for Montenegro (Prepared by Climatic Research Unit, University of East Aglia, https://www.uea.ac.uk/groups-and-centres/climatic-research-unit)

	1961-1990				1991-2020			
Temperature average values (mean)	**December-January-February**	**March-April-May**	**June-July-August**	**September-October-November**	**December-January-February**	**March-April-May**	**June-July-August**	**September-October-November**
Country:	-0.22	7.89	17.31	9.87	0.66	8.85	19.05	10.64
Highest:	5.95	13.64	23.41	15.9	6.64	14.52	25.09	16.59
Lowest:	-2.31	5.91	15.19	7.85	-1.44	6.85	16.92	8.62
	1961-1990				**1991-2020**			
Temperature average values – min	**December-January-February**	**March-April-May**	**June-July-August**	**September-October-November**	**December-January-February**	**March-April-May**	**June-July-August**	**September-October-November**
Country:	-3.83	3.31	11.82	5.31	-2.9	4.35	13.69	6.27
Highest:	1.93	8.78	17.59	10.97	2.69	9.77	19.46	11.91
Lowest:	-5.87	1.45	9.74	3.34	-4.95	2.47	11.58	4.32
	1961-1990				**1991-2020**			
Temperature average value – max	**December-January-February**	**March-April-May**	**June-July-August**	**September-October-November**	**December-January-February**	**March-April-May**	**June-July-August**	**September-October-November**
Country:	-3.83	3.31	11.82	5.31	-2.9	4.35	13.69	6.27
Highest:	1.93	8.78	17.59	10.97	2.69	9.77	19.46	11.91
Lowest:	-5.87	1.45	9.74	3.34	-4.95	2.47	11.58	4.32

Figure 1 presents data with average monthly air temperatures in Montenegro for the period 1961-1990 and 1991-2020. Based on the data analysis, we observe an increase in temperature by almost 1°C, with a greater increase in the minimum air temperature.

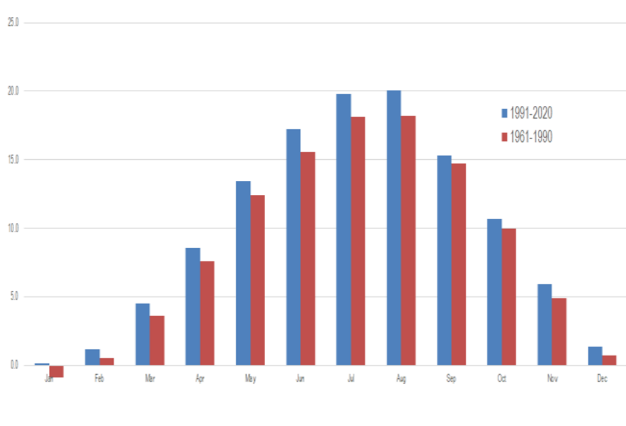

Fig. 1. Average monthly air temperatures in Montenegro for the period 1961-1990 and 1991-2020.

According to the Third National Communication on climate change [121] results of climate projections show an increase in annual temperature of 1.5°C to 2°C by 2040 in the whole country – during the winter months between 2°C and 2.5°C, and in the summer months an average of about 2°C. For the period 2041–2070 deviations of the mean annual temperature range from 2.5°C to 3°C, i.e. for the period 2071–2100 the deviation is about 5.5°C. Additionally, for the period 2011-2040 an increase in precipitation in the north of the country is expected up to +5%, and a decrease in the southern regions up to -5%, while for the period 2041-2070 a decrease of up to 20% in average annual precipitation is expected in the entire territory. For the period 2017–2100, the average annual precipitation is expected to decrease by up to -20% in most of the country.

The amount of annual precipitation indicates a drier climate, while in the period 1961-2020 there were no significant changes in seasonal annual precipitation with the lowest annual amounts of precipitation being in the period 1961-2000. Number of days with more than 1 mm of precipitation decreased, and the number of days with more than 40 mm increased [120].

Surface waters from the territory of Montenegro flow into two water-rich basins, whereby the Adriatic basin occupies an area of 7,545 km² and covers 45.4%, and the Black Sea basin occupies an area of 6,268 km² and covers 54.6% of the total territory. Generally, both of these basins are rich in water, which makes Montenegro one of the most water-rich countries globally. According to the approximate water balance of Montenegro, about 624 m³/s of Montenegrin water flows from its territory. Ground water in Montenegro is present in rocks of different ages and it represents the only practical source of water for the population. 75 sources are used to provide public water supplies to 40 urban settlements; 21 of these urban settlements are municipal centers and there are also a large number of suburbs.

In general, Montenegro has significant surface and underground waters of relatively good quality. The biggest consumers of water are industry and the population. In the period 2005–2020 the amount of water captured for the public water supply increased by 19%, i.e. from 101.9 million m³ in 2005 to 121.3 million m³ in 2020. However, the water delivered to the final consumers in 2020 is 13% lower, compared to 2005, when water distribution losses increased from 47% to 61%, for the same period. In 2020, non-revenue water on the national level is 67.14%. The industry is predominantly supplied from its own water intakes, surface and underground. Of the total water used in industry, 99.27% is water used in the energy supply sector, while 0.73% is water used in the sectors mining and processing industry

Analysis of the long-term SPEI index, and its comparison with the cumulative anomalies of precipitation and temperature, indicates that from 1980 to 2000 there was a drastic decrease in precipitation, while from 2000 onwards, precipitation slowly normalized to the average multi-annual precipitation. At the same time, the average temperature was constantly increasing and the analyzes show a high correlation between precipitation anomalies and surface water resource anomalies.

We note that the water sector is sensitive to climate changes, i.e. to changes in mean temperature and precipitation, changes in sea level, as well as to changes in the intensity and frequency of extreme weather events. Current and future climate changes have an impact on water supply and water demand, which is why the problem of water shortage is current, and concern about the impact of climate change on the water sector is growing. In order to assess the vulnerability of the water sector, the appropriate indicators of vulnerability (exposure, sensitivity, potential impact and adaptive capacity) to defined stressors of climate change (e.g. temperature and precipitation) should be evaluated.

With recorded and projected temperature increases and decreases in precipitation during summer and fall, further increases in the magnitude and occurrence of droughts are expected. Montenegro is a drought-prone country with large areas of fast-drying lands that become dry due to increasing temperatures, even if rainfall does not decrease. Droughts significantly reduce water levels causing negative secondary impacts on biophysical systems such as forest fires and significant reductions in hydroelectric production and crop yields. Successive droughts that occurred in certain periods particularly disturbed the water balance in the southern regions of Montenegro in late autumn and will probably continue to occur.

As for precipitation, based on official data, it can be concluded that there is an increase in daily maximum precipitation in the northern region (Ćehotina and Ibar), in the entire coast and in the basin of Skadar lake. In the Piva, Tara and Lima sub-basin regions, there is a slight decrease or minimal change in extreme precipitation.

Torrential, or flash floods represent a danger that social communities do not take seriously enough. Since Montenegro is primarily a mountainous country, with steep slopes and special geology, the human factor (deforestation and increased agricultural activity) additionally contributes to increased susceptibility to torrential floods. Although Montenegro can be exposed to all kinds of floods, two categories of floods are characteristic: fluvial and meteorological floods. Fluvial floods are result of abundant rain series of a few days with a large amount of rainfall. In extreme cases can reach about 500~1000 lit/m2, covering larger space. They connect with river systems and lakes in such a way that water levels have extremely high values. They rarely occur, and when they occur, certain thresholds are reached and exceeded. Meteorological (pluvial and flash) floods are local and they are more likely to occur and they are related to torrents and urban environments or a certain fragment of space. They are of short time span, but can be very aggressive, destructive and difficult to foresee and locate in time and space, because they are related to the formation of storm-thunder clouds which are very dynamic and capture only a certain locality from which, in a very short time, an abundant amount of rain is excreted, which in only a few hours can reach over 100 lit/m2 and thus very often exceeds the thresholds.

Not a small number of studies indicate the susceptibility of Montenegrin rivers to torrential floods. The National Flood Protection and Rescue Plan proposed by the Government of Montenegro mentions the inventory of 300 flood basins that can damage the primary traffic infrastructure. However, flash floods have a much greater potential for damage than transportation infrastructure. According to the Torrential Flood Susceptibility Model – TFSM, which was developed for the needs of the Vrbas River Basin in Bosnia and Herzegovina [122], the northern and northeastern part of Montenegro is the most susceptible to torrential floods, along with the coastal region, where most of the identified torrential flood areas from the inventory are located. However, areas with medium to low susceptibility to torrential flooding should not be neglected either. At the same time, 67-69% of the area belongs to the "strong" and "very strong" class of sensitivity, and only 3% to the "very low" class of sensitivity. Supplementing the inventory with data on flash floods that cause damage beyond the traffic infrastructure can be used for prognostic purposes in the future.

Largest floods in Montenegro since the half of the past century until now have occurred in: 1963, 1979, 1999, 2000, 2010 and 2011. The EM-DAT Disaster Database has documented 4 flood disasters in Montenegro from 2000 to 2011, which caused half a century of water level records on the rivers. Skadar lake has reached its historical maximum water level of 10.44 m above sea level. Three rainy series of precipitation led to approx. 1000 lit/m² in some places. These floods have affected around 8000 people. The damage and losses caused by the 2010 flood alone amounted to around €44 million (1.4% of gross domestic product) [123]. The FAO estimated that this flood impacted around 30,000 hectares of agricultural land. The most affected was the area around the River Zeta valley and the area around Lake Skadar, where most of the national vegetable production occurs. Total agricultural damages and losses were estimated at over €13 million, of which over €6 million was in damages and over EUR 7 million was in losses [124]. The most recent significant flood was in November 2019 resulting in multiple impacts for people and infrastructure in municipalities of Nikšić and Kolašin. The total estimated damage on households from this flood was around €73,000 and for infrastructure (e.g. roads, bridges) it was around EUR 211,500 [125]. The UN-DRR Disaster Information Management System has documented 34 flood events in Montenegro from 2005 to 2018, with 1264 damaged houses, over 550 evacuated population and 4.500 ha flooded agricultural land.

In Montenegro, protection from floods has not been given much attention so far, although the consequences are frequently significant. The scope of work performed so far on the arrangement of watercourses and flood defense on all watercourses in Montenegro is very modest and they were mostly performed in the 70s of the last century. Due to the partial approach to this issue, most of the constructed structures are of a local character, so the lengths of defensive embankments, coastal fortifications and regulated riverbeds are very short - from a few hundred meters to 1-2 kilometers. A special problem is the weak and irregular maintenance of flood defense facilities, which inevitably led to a reduction in the level of protection of coastal areas. Larger defensive units were realized only along Moraca (embankment Cijevna-Vranjina 16 km long and three more sections 3-5 km long) and along Bojana (three sections of the embankment, 3-6 km long). Certain works have been carried out since 2011 in order to repair the consequences of the floods that occurred in 2010, as a prevention of future floods.

Water is a basic element for production and the energy sector. The huge quantities and quality of surface water bodies result in significant water potential, which can be transformed into hydropower potential. Hydropower potential along the main watercourses of Montenegro amounts to 1,124 MW, i.e. 9,846 GWh of annual energy production. Based on data on installed energy capacities, hydroelectric power plants in Montenegro account for about 67% (702,895 MW). Analyzing the already existing installed capacities for energy production, the current energy mix of Montenegro is represented by hydropower plants with 67.06% (702,895 MW).

3 Data and methodology

In Montenegro, as in the region, there is no officially defined methodology on the procedure and manner of determining the damage caused by climate change, as well as the methodology for assessing future harmful economic impacts caused by climate change. The activities so far in assessing these damages are mainly based on the activities of concrete assessment of material damage, due to certain emergency events, which are a consequence of changed climate. As the goal of our paper is economic vulnerability assessment in water sector of Montenegro, with a focus on electricity production in hydropower plants, negative impacts were analyzed in the context of additional costs for import of electricity, due to reduced electricity production, caused by reduced water potentials as a result of climate change. To carry out this activity it was necessary to:

- Collect appropriate statistical data on the quantity of electricity production in hydropower plants in the previous period;
- Process and analyze collected data, as a basis for further projections;
- Project the future electricity production in hydropower plants, for the basic scenario - the scenario "without climate change";
- Assess quantitative damage - reduced electricity production, caused by climate change, in accordance with established climate scenarios;
- Analyze the prices of electricity imports in the region and Europe and determine future unit prices, as a basis for damage assessment;
- Based on previously collected and processed data, perform calculation and projection of economic damages caused by climate change in this sector.

Defining the time frame for observation/analysis was the next important step. Climate change is a phenomenon that occurs slowly and not so noticeably, so its consequences, namely negative effects, cannot be adequately assessed for shorter periods of time (e.g. up to 20 years), which is common for different types of economic analysis. For this reason, and based on research and recommendations from numerous studies and documents, it was decided to assess economic damage as a consequence of climate change for [126]:

- The period of the near future, until 2050 (Near Future) and
- The period of the distant future, up to 2100 (Far Future).

In the scope of the further analysis, and due to the impossibility to precisely define at this moment the extent of impact on the climate which will occur in these defined periods, and therefore what negative consequences these changes will cause, it was decided to observe two scenarios - more favorable and less favorable, within each period of time. The number of scenarios can certainly be higher, but it is estimated that for the sake of clarity of the analysis, and also its objective (to determine the preliminary approximate level of considered adverse effects), this number of scenarios is sufficient.

Ideally, further analysis would imply that within each considered sector, adverse effects are quantified by defined categories of analysis, for both time frames and for both climate scenarios. Given that this is very difficult at the moment, since adequate researches are scarce, as well as data in Montenegro on it, the experiences in analysis and research in Europe and the world were considered. Data and assumptions in these sources vary, so only those which served to define the criteria for this analysis are presented below.

Callaway et al. [127], undertook the assessment of economic damage for individual sectors was performed on the basis of the following assumptions:

- For the period up to 2050, 2 scenarios: losses of 3% and 8%;
- For the period up to 2100, 2 scenarios: losses of 8% and 15%

Researches abroad have mainly focused on predicting adverse effects on the total national GDPs as a result of climate change. Thus, for example, in a study prepared by the Swiss Re Institute [128] the expected impact on global GDP by 2050 was presented, according to four different scenarios, as compared to the world "without climate change". Those are the following scenarios for Europe:

- Decrease of GDP of 2.8%, if the goals of the Paris Agreement are achieved (increase in temperature well below 2° C);
- Decrease of GDP of 7.7%, if further mitigation measures are taken (temperature increase of 2° C);
- Decrease of GDP of 8.1%, if some mitigation measures are taken (2.6° C increase in temperature);
- Decrease of GDP of 10.5%, if mitigation measures are not taken (temperature increase of 3.2° C).

As it can be seen, harmful effects by 2050 are estimated in the range from about 3% to approximately 10% for the period until 2050.

International Monetary Fund study [129] served as the basis for further analysis in this paper. In this study, there is analysis of negative impact of climate change on GDP, by countries, grouped in relation to their geographical location and economic situation. The analysis showed that these damages, for a group of countries including Montenegro, would be the following:

- For the period up to 2050: losses of 2.18% and 3.11%;
- For the period up to 2100: losses of 6.05% and 8.25%.

It is obvious that the predicted adverse effects within this study are somewhat lower than in the previous ones, which only confirms the view that their prognosis is not simple and depends on numerous input assumptions. Therefore, in order to cover the broader framework of analysis and future estimates, within this paper the analysis was performed for water sector with the following scenarios:

- Near future, damage level by 2050 5% (Near Future 1, NF1);
- Near Future, damage level by 2050 10% (Near Future 2, NF2);
- Far future, damage level by 2100 10% (Far Future 1, FF1);
- Far Future, damage level by 2100 15% (Far Future 1, FF2).

In order to better understand and monitor the analysis of the impact of climate change on the water sector in Montenegro, with a focus on hydropower production, we present a methodological flowchart in Figure 2.

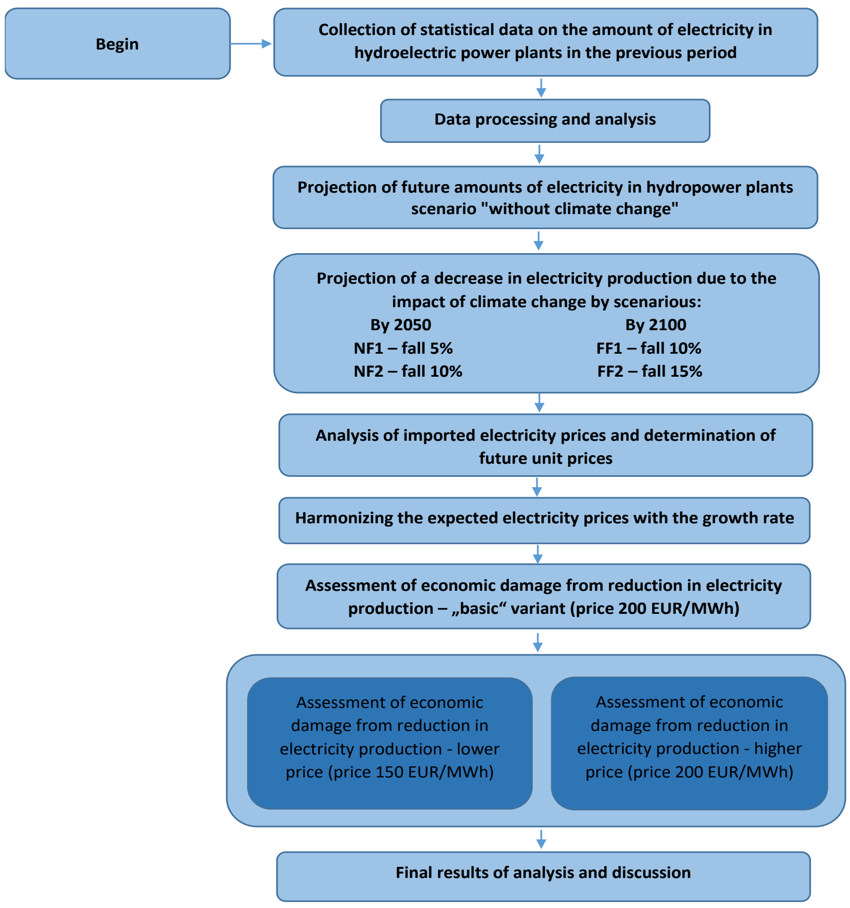

Fig. 2. Methodological flowchart.

4 Analysis and results: economic vulnerability assessment in water sector of Montenegro with a focus on electricity production in hydropower plants

Projections of individual economic categories are made relying on certain growth rates based on historical data, or on the fluctuations of a certain category in the past period, or using official GDP growth rates, or certain sectoral rates or a combination of all mentioned above with appropriate estimates of sectorial experts. In this particular case, some historical rates

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are not fully relevant due to the atypical 2020. This also applies to the GDP growth rate, which dropped significantly in 2020. For that reason, it was decided to follow the precautionary principle with moderate growth rates, in relation to the initial state in the water sector with proposed annual increase of 0,5%. As it can be seen, growth rate in water sector is lower, due to real capacity, which is limited.

In general, negative effects of climate change on the water sector and watercourses have already been described in more detail in other parts of this document, so it should only be repeated here that they can be very diverse from an economic point of view. The impact of climate change on water resources is very different and affects many sectors of the economy. Changes in the quantity, type and distribution of surface water flows, caused by precipitation and changes in temperature, can lead to a reduction in surface runoff, which can then negatively affect both the amount of water supply and water quality.

Water use is wide and diverse: water for human consumption, water for agriculture, water for industry, technical water for wastewater treatment, water for thermal cooling, water for hydropower production, water for transport and recreation, etc. Although water use has a significant role in all mentioned areas, the most important economic use of water in Montenegro is for electricity production, so the assessment of the harmful effects of climate change in the water sector would be focused on impacts in this area. In order to do this, it was necessary to collect the most important statistical indicators in the field of electricity generation, analyze them in the process of preparation for appropriate projections, determine future quantities of missing electricity due to reduced water potential caused by climate change and finally analyze electricity import prices, in order to quantify economic damages.

The electricity sector is one of the most important segments of the energy sector in every country, including Montenegro. Montenegro's energy sector is characterized by high natural potential (coal, hydro potential, biomass potential, wind and solar potential), which is underused, low energy efficiency, as well as dependence on imports of electricity and fossil fuels. The energy sector is of particular importance for the economic and long-term development of Montenegro, which suffers from the consequences of the payment deficit caused by energy imports. The installed capacity of power plants participating in the regulation of the system is 874 MW, of which 649 MW in accumulation hydropower plants and 225 MW in thermal power plants. The range of available active power at the threshold of power plants participating in the regulation of the system, depending on regular annual overhauls or necessary delays due to equipment modernization, ranges from 430 MW (August) to 848 MW (January, February, March and December). The realized energy balances of electricity for the past 7 years (period from 2016 to 2022), are presented in Table 2.

Table 2. Energy balance of Montenegro – balance of electricity 2016-2022 (in GWh).

Structure	2016	2017	2018	2019	2020	2021[2]	2022[3]
Hydropower plants	1,807.2	1,033.8	2,092	1,621.1	1,447.8	2,061.3	1,428
Thermopower plants	1,216.2	1,265	1,444	1,506.4	1,615.4	1,306	1,424
Wind power plants	0	95	141	293.4	320.1	322.5	333
Solar power plants	2.2	2.2	2.3	2.3	2.3	2.6	3.78
Total production	**3,025.6**	**2,396**	**3,679.3**	**3,423.2**	**3,385.6**	**3,692.4**	**3,188.78**
Import	1,209.8	1,536.9	780	1,195.5	5,943	N/A	N/A
Export	905.9	416.7	976	942.9	5,864	N/A	N/A

Gross energy supply	303.9	1,120.2	-196	252.6	79	-191	97.06
Available electricity	3,329.5	3,516.2	3,483.3	3,675.8	3,464.6	3,501.4	3,285.84
Consumption in energy sector	118	119	133.7	128.7	141	N/A	N/A
Transmission and distribution losses	540.7	512.2	503	492.9	486.9	496,9	492.7
Final energy production	**2,670.8**	**2,885**	**2,846.6**	**3,054.2**	**2,836.7**	**3,004.5**	**2,793.1**

* Data for the period 2016-2021 are official data of Statistical Office, Monstat, Energy, Electricity balance, https://www.monstat.org/cg/page.php?id=40&pageid=40

* Data for 2022 were taken from the official Energy Balance of Montenegro for 2023, https://www.gov.me/dokumenta/5fe82480-023b-431a-b8fb-57d67098aada

We conclude that the structure of electricity production was quite uneven during the observed period. However, it is obvious that the most significant production of electricity is by hydropower plants, except in 2017 and 2020, and that it amounted to a maximum of 59.7% of the total electricity produced in 2016. The share of thermal power plant (TPP Pljevlja), was on average at the level of about 35-45% of the total electricity produced. According to the data for 2022, almost equal share in electricity production were realized from hydropower plants and from thermal power plant.

In the observed period, Montenegro was mainly import dependent on electricity, except in 2018 and 2021 when it had a surplus, and these imports varied significantly due to different circumstances. According to the plan for 2022, the import of electricity is planned at the level of less than 2% of the total needs. Finally, it should be noted that the total amount of final energy for consumption is affected, in addition to consumption in the energy sector, by significant transmission losses.

Previously presented data within the Energy Balance of Montenegro served as a basis for the projection of electricity production by hydropower plants in the base case scenario - the scenario "without climate change", as presented in Table 3.

Table 3. Projection of electricity production by hydropower plants in the scenario "without climate change" (in GWh) *

Year	Production of electricity by hydropower plants (GWh)	Year	Production of electricity by hydropower plants (GWh)
2025	1.756	2065	2.144
2030	1.800	2070	2.198
2035	1.846	2075	2.253
2040	1.892	2080	2.310
2045	1.940	2085	2.369
2050	1.989	2090	2.429
2055	2.040	2095	2.490
2060	2,091	2100	2,565

*reducing the size of the tables in paper was done by omitting a certain number of years from the series

After the projection of electricity production in hydropower plants, it is necessary to assess the impact of climate change on this production for different projected time periods, as well as for the appropriate climate scenarios. As defined above, four scenarios were considered:

- Near future, reduction of electricity production - hydropower plants by 2050 by 5% (NF1)
- Near future, reduction of electricity production -hydropower plants by 2050 by 10% (NF2);
- Far future, reduction of electricity production - hydropower plants by 2100 by 10% (FF1);
- Far future, reduction of electricity production - hydropower plants by 2100 by 15% (FF1).

Calculation of the reduction of electricity production in hydropower plants due to the effects of climate change was performed on the basis of the previously determined data, as presented in the Table 4.

Table 4. Projection of reduction of electricity production by hydropower plants, due to the effects of climate change (in GWh).

Year	NF1	NF2	FF1	FF2
2025	9	18	6	9
2030	25	50	18	26
2035	42	84	30	44
2040	60	120	42	62
2045	79	158	55	82
2050	99	199	69	102
2055			84	124
2060			99	147
2065			116	172
2070			133	197
2075			151	224
2080			170	253
2085			190	283
2090			210	315
2095			232	348
2100			257	385
Total	**1,369**	**2,718**	**8,779**	**13,077**

The reduced amount of electricity produced would have to be offset by imports. Electricity import prices have varied extremely in the previous period, not only long-term, but also during, for example, 2021. Montenegrin Electric Company (EPCG) announced that in 11 months in 2021, it spent twice as much on imports than in the same period last year, i.e. 60 million EUR. EPCG imported almost the same amount of electricity in 2021 and 2020, but in 2020 the average price was EUR 38 per MWh, while during 2021 the price was EUR 90 per MWh. During the first half of 2022, EPCG imported 664 GWh of electricity, with a total value of EUR 107.1 million, which represents an amount of about EUR 161 per MWh. This big jump is mostly a consequence of the current energy crisis.

Prices on European and regional electricity exchanges currently range from 150 EUR per MWh in Portugal and Spain to 470 EUR per MWh in Italy. Average electricity prices in 2022 in the European markets were around EUR 230 per MWh. However, the companies in charge of procuring electricity, and thus, EPCG, do not have to procure it, and usually do not do so on the stock exchanges, but usually announce their tenders for deliveries for several months.

In these situations, lower prices are obtained than those on the stock exchanges, but if urgent imports are needed, for a shorter period of time, then prices go up significantly. Prices also depend on the financial situation of the company and its history of payment or non-payment of debts.

For further assessment, electricity prices were increased in accordance with projected growth rates in Europe [130], as presented in Table 5.

Table 5. Projected growth rates in Europe.

2020 – 2030	2030 – 2050
2.3%	1.5%

Considering that in Table 4 growth rates are presented until 2050, covering the near future scenario, the growth rate used for the distant future scenario, until 2100, was calculated in accordance with the trend from the previous period. Due to the reasons stated above, related to fluctuations of electricity import prices, it is not possible to determine with certainty its value as a basis for further calculations (especially in such a long period of observation), so it was decided to conduct further analysis in three variants. The basic variant of the analysis would be the existing price of electricity imports for 2022, in the amount of 200 EUR per MWh. The other two variants would be one higher and one lower (250 and 150 EUR per MWh, respectively), in order to gain an overview of the future price fluctuations in a certain way. An estimate of economic damage of reduced electricity production in hydropower plants, due to the effects of climate change, in the basic variant, is shown in Table 6.

Table 6. Estimate of economic damage of reduced electricity production by hydropower plants, due to the effects of cli-mate change – basic variant (in EUR).

Year	NF1	NF2	FF1	FF2
2025	1,926,445	3,772,658	1,349,857	1,981,112
2030	5,926,917	11,655,527	4,147,564	6,095,857
2035	10,684,160	21,099,084	7,466,835	10,990,063
2040	16,410,827	32,544,796	11,453,998	16,882,794
2045	23,262,130	46,327,211	16,214,560	23,934,123
2050	31,415,655	62,831,309	21,869,027	32,327,230
2055			28,554,912	42,271,542
2060			36,429,002	54,006,289
2065			45,669,924	67,804,526
2070			56,481,025	83,977,678
2075			69,093,637	102,880,672
2080			83,770,746	124,917,740
2085			100,811,132	150,548,967
2090			120,554,038	180,297,686
2095			143,384,419	214,758,821
2100			170,583,343	255,875,015
Total	**381,055,340**	**756,926,116**	**4,234,518,719**	**6,315,638,969**

Based on the presented data in Table 6, we conclude that elaborated future economic damage in the water sector of Montenegro due to the effects of climate change could be significant, especially considering that only the damage due to reduced electricity production was analyzed and that by including estimate of other damages, this amount could be higher.

In the near future scenarios, these damages could be around EUR 30 to 60 million per year in the final year of the observation, which would be cumulatively around EUR 380 to 750 million for the total observed period. In the distant future, these damages in the final years would be from about 170 to about 255 million EUR per year, so the total amount of these damages for the total period up to 2100 would be from about 4.2 to 6.3 billion EUR.

Following tables (Tables 7 and 8) show the projections of economic damage of reduced electricity production in hydropower plants, due to the effects of climate change, in alternative variants – with lower and higher price.

Table 7. Estimate of economic damage of reduced electricity production by hydropower plants, due to the effects of cli-mate change – variant with lower price (in EUR).

Year	NF1	NF2	FF1	FF2
2025	1,444,834	2,829,493	1,012,393	1,485,834
2030	4,445,188	8,741,646	3,110,673	4,571,893
2035	8,013,120	15,824,313	5,600,126	8,242,548
2040	12,308,120	24,408,597	8,590,498	12,662,095
2045	17,446,598	34,745,409	12,160,920	17,950,592
2050	23,561,741	47,123,482	16,401,770	24,245,423
2055			21,416,184	31,703,656
2060			27,321,752	40,504,716
2065			34,252,443	50,853,394
2070			42,360,769	62,983,258
2075			51,820,228	77,160,504
2080			62,828,060	93,688,305
2085			75,608,349	112,911,725
2090			90,415,528	135,223,264
2095			107,538,314	161,069,116
2100			127,937,507	191,906,261
Total	**285,791,505**	**567,694,587**	**3,175,889,039**	**4,736,729,227**

Table 8. Estimate of economic damage of reduced electricity production by hydropower plants, due to the effects of climate change – variant with higher price (in EUR).

Year	NF1	NF2	FF1	FF2
2025	2,408,057	4,715,822	1,687,321	2,476,389
2030	7,408,646	14,569,409	5,184,455	7,619,821
2035	13,355,200	26,373,855	9,333,544	13,737,579
2040	20,513,534	40,680,995	14,317,497	21,103,492
2045	29,077,663	57,909,014	20,268,200	29,917,654
2050	39,269,568	78,539,136	27,336,284	40,409,038
2055			35,693,640	52,839,427
2060			45,536,253	67,507,861
2065			57,087,405	84,755,657

2070			70,601,282	104,972,097
2075			86,367,047	128,600,840
2080			104,713,433	156,147,175
2085			126,013,915	188,186,209
2090			150,692,547	225,372,107
2095			179,230,524	268,448,526
2100			213,229,179	319,843,768
Total	**476,319,175**	**946,157,644**	**5,293,148,399**	**7,894,548,712**

For greater visibility and comparability of climate change impact scenarios, all four scenarios of total economic damage for the selected 3 variants of electricity prices are presented in Figure 3.

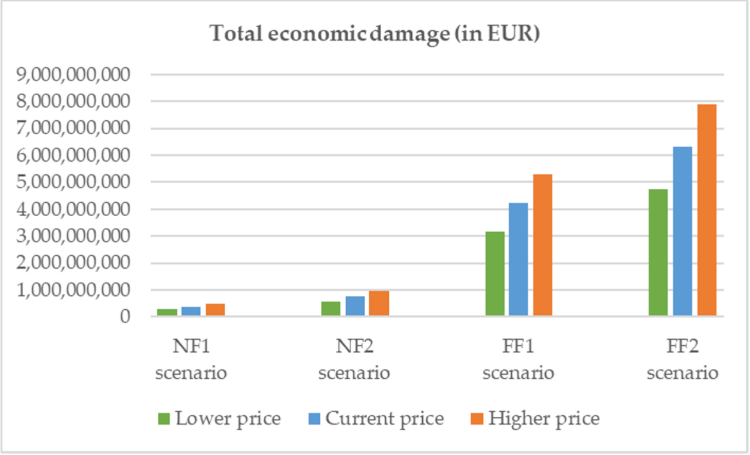

Fig. 3. Total economic damage for 4 scenarios with different electricity prices.

As presented, the total economic damage of reduced electricity production in hydropower plants, due to the effects of climate change by 2100, in the case of higher electricity import prices in the future, could exceed up to almost 8 billion EUR. For a small country, such as Montenegro, the estimated damage on this basis represents a significant economic loss.

Results of our paper coincide with the results of a large number of conducted studies on the impact of climate change on hydropower production in Europe. Thus, the research of Vliet et al. [110] indicated the vulnerability of the European power sector and the impact of reduced summer river flow on hydropower and thermoelectric power in Europe, with significant impacts on electricity prices. Lehnera et al. [111] predict a drop-in hydropower potential of around 6% by 2070, for the whole of Europe.

Sample et al. determined the stronger impact of climate change on the hydropower potential of Mediterranean Europe or catchments in the Alps was pointed out [116], while Wagner et al. [117] recently forecasted that in the period 2031-2050. to reduce the average annual electricity generation of run-of-river plants (up to -8%), for the whole Alpine region, compared to the period 1961-1990. Also, Turner et al. [113] forecast losses in the total production of electricity in the range of 5-20%, for the countries of the Balkans, as the most threatened, while research by Tobin et al. [114] indicate the greater sensitivity of southern European countries, where the production of hydro and thermal energy can be reduced by up to 20%. Similarly, a recent study done for Spain predicts, depending on plants and scenarios, a reduction of hydropower in that country from 10% to 49% by the end of the century [115].

6 Conclusion

Based on the conducted analysis, we conclude that Montenegro is facing serious challenges related to the impact of climate change in the water sector. In general, in order to better adapt Montenegro to climate change in the water sector, certain priority actions can be recommended that address climate-driven vulnerabilities, in accordance with international recommendations, at several levels. Many of the options identified are structural or physical adaptation options. Such options are often referred to as “hard” adaptation options. They involve on-the-ground physical infrastructure and technical equipment, like additional water storage capacity or reconstruction of existing water related facilities. Structural adaptation options also include a variety of ecosystem or nature-based adaptation measures. There are also a variety of nonstructural (or “soft”) adaptation options. Some of them are applying an integrated approach to water resources and systems management, and a strengthening of cross-sector planning and activities, as well as increased public motivation and ensured its involvement in all phases of planning in the water sector. Improving the efficiency and cost-effectiveness of water services (nonrevenue water levels have to be lowered by improving the quality of metering devices and reducing network leakage through sound maintenance and renewal of assets). This may provide significant contribution to the improvement of the water sector. In the coming period, we should count on the implementation of sound cost recovery principles (tariffs may need to be reviewed according to sound cost recovery principles, especially since the investments to upgrade the existing infrastructure will generate an increase in operational costs).

Limitations in this paper are related to the categories used to assess economic damage in the water sector. One of them is related to the projected production of electricity in hydroelectric plants. Namely, there are many unknowns that can affect the annual production of hydropower, with the fact that the production itself varied significantly in the observed years (from 1000 to 2000 GWh), which is not a small variation. However, we believe that averaging historical data provides a solid basis for reliable projections, and we appreciate that this is not a significant limitation. Input data on electricity prices, which have recently changed many times, have a much greater influence on the analysis. Also, their further movement is unknown, which can be a limitation of the work. Also, the concept of such analyzes with a time frame up to 2050, i.e. 2100 can be a limitation. This is due to the fact that it is about long periods of time in which various social, political, economic, and natural events are possible that can have a significant impact on the results of this analysis. Finally, the aim of this paper is to assess economic vulnerability in the water sector of Montenegro, with a focus on electricity production in hydropower plants. Other climate change impacts were not analyzed and evaluated. However, we believe that the mentioned limitations cannot dispute the obtained results, but only represent a motive for future research in this very current and important area.

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