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THE IMPACT OF CLIMATE CHANGE ON KEY MACROECONOMIC INDICATORS IN MONTENEGRO

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1. Introduction

Climate change represents a great challenge which, with its complexity and unpredictable dynamics, shapes the opportunities and possibilities in modern times. Climate factors directly affect important and critical economic resources such as water, agricultural products and human health. Changes in the climate may also affect production in manufacturing, energy, transport and other services. We witness increasingly frequent climate extremes and disasters such as droughts, fires, floods, which modern scientific research links to global warming. Namely, the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) study, published in 2021, confirmed the unequivocal link between global warming and extreme weather conditions.

The impact of such developments on macroeconomic conditions is obvious. It is therefore not surprising that leading international financial institutions are encouraging discussion about economic activities that can be considered environmentally sustainable. According to the World Bank (2023), climate change now has an increasingly pronounced negative impact on economic development, given that changeable weather conditions, i.e. more frequent natural disasters such as floods and droughts, cause instability in food markets. Furthermore, central banks in many countries agree that a deeper understanding of the risks associated with climate change is needed, so in the last few years, there has been an increasing literature examining climate change, its impact on economic activity, and ways to address these challenges.

Climate change is also becoming an increasingly important factor when monitoring and forecasting inflation trends by central banks in conducting monetary policy (NGFS, 2020; Batten et al., 2020; ECB, 2021). Namely, climate change represents a risk for price stability as it has a negative impact on inflation, encouraging its seasonality and intensifying the effects caused by the extremes.

The impact of climate change on economic activity should also be examined in macroeconomic forecast models, quantifying their impact on key macroeconomic indicators: GDP, investments, inflation, unemployment rate, and the like. Leading central banks, such as the ECB, are trying to accelerate the development of new models and tools for including the impact of climate change and related policies in regular macroeconomic analyses. In general, the models that include climate-related topics estimate the effects of transition policies on low-carbon economies and weather-related events. In particular, it can be noticed that carbon prices (taxes) are starting to be included in the technical assumptions in inflation models, and that the effects of extreme weather conditions on production and inflation in the near future are included in the modeling, as well as in long-term estimates of the potential growth.

However, the quantification of the macroeconomic impacts of climate change faces numerous challenges, some of which have already been addressed in the economic literature. As stated by Batten (2018), these challenges are directly related to the characteristics that distinguish climate change externalities from other externalities: (1) they are global in both their causes and consequences; (2) the impacts of climate change are long-term and persistent; (3) pervasive uncertainty about economic impacts and (4) there is a serious risk of major, irreversible changes. As stated in NGFS (2023), proper calibration of these shocks is particularly difficult due to strong nonlinearities in the intensity and frequency of future climate change impacts.

The aim of this paper is to investigate the effects of weather shocks on inflation, industrial output and employment in Montenegro, as well as to offer a contribution to the increasingly current literature on the effects of climate change on the macroeconomics, using the example of a small developing country.

The content of the paper, in addition to the introduction, consists of an overview of the current literature in the second chapter, an explanation of the importance of the topic for Montenegro in the third chapter, a methodological framework for modeling and data analysis we will use in the fourth chapter, the main results of the analysis in the fifth chapter and concluding considerations in the sixth chapter.

2. Literature review

Batten et al. (2016) identify two ways in which climate change can affect monetary and financial stability. Natural disasters caused by extreme weather may cause financial and macroeconomic instability if they damage the household property, the balance sheets of companies, banks and insurance companies. Therefore, the first type of impact is the so-called physical risks. Second, a sudden, unexpected tightening of the carbon dioxide emission policy could lead to a repricing of carbon-intensive assets and a negative supply shock, which represents the so-called transition risks. As explained in NGFS (2023), natural disasters i.e. the materialisation of an acute physical risk, which manifests itself as a weather event that needs to be specified depending on the geographical area in which it is observed, can be captured through different variables, including the impact on the sector's gross added value (as a result of the destroyed property of a company and business interruption), the total supply that is, the productivity of labour (migration of the population affected by natural disasters), capital (destroyed arable land) and finally, on the gross domestic product (that is, direct damage). The appropriate impact variables will depend on the type of weather shock (such as drought or flood).

Batten (2018) explains that the main supply-side shocks caused by the extreme weather aspects of climate change result in shortages of imported inputs, especially commodities such as food and energy, and volatility in import prices as a result of these shortages. Climate change, i.e. extreme temperatures and precipitation, affect cereal crops. This was empirically proven by Accetturo and Alpino (2023), who analyse the impact of weather shocks on the corn crops, durum wheat and wine grapes on the example of a group of Italian provinces. Their estimates reveal significant non-linearity in the impact of temperature on agricultural yields. Combining their estimates with climate projections until 2030, the effects of climate change on cereal crop yields are negative, while maize crops are most at risk of yield reductions.

Supply shocks also arise from damage to capital and infrastructure. On the demand side, losses resulting from climate events, such as floods and storms, could reduce household wealth and therefore private consumption. Finally, Batten (2018) states that business investment could also be reduced by damage to physical and financial assets. If we observe the production side of the gross domestic product, the impact of extreme weather events is most obvious in the agriculture, electricity generating sector, but they may also cause damage to infrastructure, thus affecting production in other sectors, such as construction, industrial output, as well as on the activities of the service sector such as tourism, transport and financial and other services.

Empirical literature on the historical impacts of climate shocks on inflation suggests that continued warming, as well as intensification of weather extremes and variability due to anthropogenic greenhouse gas emissions (Arias et al., 2021), may have consequences for inflation. Batten et al. (2016) indicate that changes in weather conditions and increased reliance on bioenergy could increase the volatility of food and energy prices, and thus the volatility of the overall inflation rate, which would make it difficult for central banks to assess inflationary pressures and maintain price stability.

Recent empirical literature indicates the presence of significant seasonal reactions of inflation to temperature shocks, mainly through the prices of food, energy and services. Namely, Ciccarelli et al. (2023) estimate that the increase in average monthly temperatures has pronounced inflationary effects during summer and autumn, with a stronger reaction in the southern regions of the euro area. Peersman (2022), analysing inflation in the euro area, shows that exogenous shocks, such as adverse weather conditions and food prices, have a strong impact on consumer prices, indicating that the volatility of inflation in developed economies could increase with the increased frequency of global extreme weather events. Similar findings are confirmed by a recent working paper of the European Central Bank (2023), which examines the effects of climate change on inflation in 121 countries and reveals that higher than average temperatures increase the price of food and other goods and services. Namely, the results of new sophisticated models, which include climate change, show that, in the absence of historical adjustment, future warming will cause a global increase in annual food prices and annual inflation of 0.92-3.23 percentage points and 0.32-1.18 percentage points, respectively, under the projected climate scenario for 2035. Also, this paper specifically points out that the summer heat during 2022 in Europe increased food inflation by 0.67 percentage points, and that future warming predicted for 2035 would increase the impact of these extremes by 50%.

Kahn et al. (2019), using a panel of 174 countries from 1960 to 2014, showed that persistent climate change has long-term negative impacts on economic growth. The authors reveal that real GDP per capita is negatively affected by constant changes in temperature above or below its historical norms. However, the authors do not obtain statistically significant effects for changes in the amount of precipitation. If the temperature deviates from its historical norm by 0.01 °C per year, long-term GDP growth will be lower by 0.0543 percentage points per year.

Cevik and Jalles (2023), investigating the impact of weather-related natural disasters on a set of 173 countries over the period 1970–2020, showed that inflation and growth respond significantly to natural disasters. Namely, the authors empirically proved that temperature shocks lead to lower inflation, and droughts and storms lead to higher inflation. In addition, the authors showed that all types of climate shocks have a negative impact on economic growth, but nevertheless, the magnitude and pattern of the response show variations in the long run. Namely, the results show that the temperature shock leads to a permanent decrease in real GDP growth, and that the impact of droughts and storms is more volatile and less permanent. Also, the authors divided a large sample of countries into advanced and developing countries and observed a striking contrast in the impact of natural climate disasters on total inflation and growth according to the level of economic development, state of the economy and fiscal space when a climate shock occurs. The conclusion of the research showed that developing countries have a harder time coping with the consequences of natural disasters.

Also, an area of concern relates to the consequences of the implementation of climate policies on employment, as they may directly or indirectly cause the job openings or closures. In this context, "direct" employment effects refer to jobs directly affected by these policies, while "indirect" employment effects refer to jobs created or closed in the supply chain for products and services affected by the "green" policies (Bowen, 2012). Babiker and Eckhaus (2007), for instance, who examined the impact of climate change on the labour market, found that policies to limit greenhouse gas emissions can lead to increased unemployment in the sectors affected by the policy.

An important dimension to consider is the relevant time horizon. Batten (2018) explains that the timing and persistence of the economic consequences of climate change differ depending on the type of risk. Extreme weather events tend to cause immediate economic damage, which may persist in the medium term, while damage from gradual global warming will manifest itself in the longer term and could potentially be more permanent, according to Batten (2018).

Table 1 – Time horizon of climate events (risks)

Type of risk		Economic impact	Duration of impact
Physical risks	Risks of extreme climate events	Unexpected shocks to the demand and supply components	Short and medium term
	From global warming	Impact on potential production capacity and economic growth	Medium and long term
Transitional		Demand/supply shocks or economic growth effects	Short and medium term

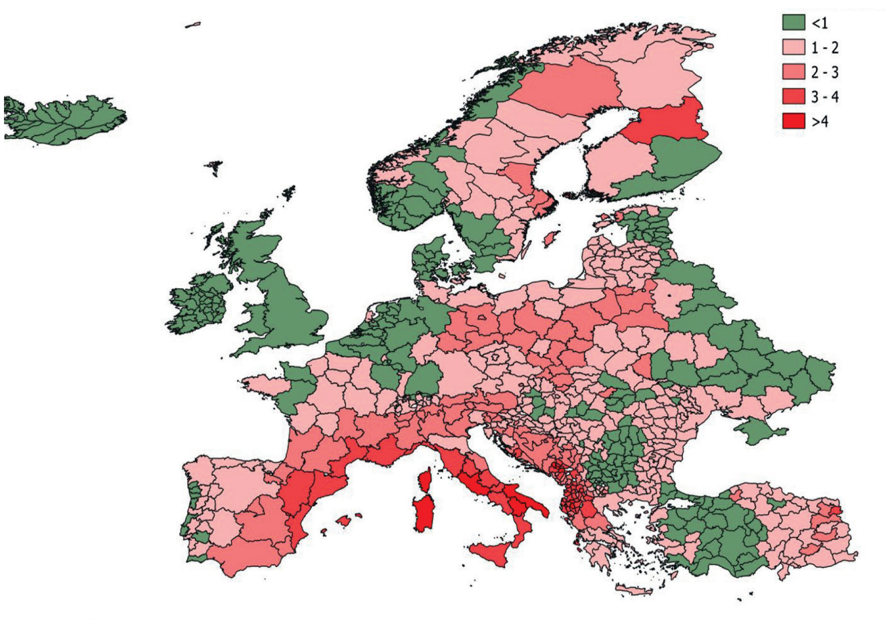
Source: Batten (2018)

Also, in the European Banking Authority (EBA) guidelines on climate and environmental risks (2020), the effects of extreme weather events, such as floods and droughts, take place in the short and medium term, while other climate and environmental risks take place over longer periods of time periods.

3. Research context

As stated in the Third Biennial Update Report of Montenegro to the United Nations Framework Convention on Climate Change, Montenegro is extremely vulnerable to the impact of climate change due to its geographical, geological and socio-economic position. According to the latest data from the Environment Protection Agency, 2021 was a year with temperatures above the climatic norm. According to the percentile distribution, the air temperature was in the category of *extremely warm*, while the precipitation was in the categories of *very dry*, *dry* and *normal*. A similar meteorological situation was recorded in 2022 as well.

Image 1- The extreme heat wave that hit Europe in June 2022



Source: IFAB(2023)

Image 1 shows that Montenegro is among the countries on the European continent that were most affected by the heat wave in June 2022. According to the IFAB website, the summer of 2022 was the warmest in Europe so far, with the highest temperature from June to August. Europe had the second warmest June on record, about 1.6°C above average.

As we mentioned earlier, the appropriate assessment and calibration of weather shocks is complex due to the strong non-linearity in the intensity and frequency of climate change impacts in the future. However, as stated in NGFS (2023), there are several sources for finding some guidance/intuition. For instance, EM-DAT is a database of historical damages from natural disasters, which can be used to estimate the frequency of occurrence of these disasters.

Table 2 – List of extreme weather in Montenegro

Year	Type of natural disaster	Subgroup	Location	Cause	Death toll	Number of people affected/ injured/ homeless
1992	Flood	River flood	Mojkovac		1	6000
2000	Fire	Forest fire	Mojkovac, Pljevlja, Plužine, Šavnik, Žabljak, Danilovgrad, Berane, Bar, Budva, Cetinje, Herceg Novi, Kotor, Tivat, Ulcinj			12
2000	Flood	River flood	Danilovgrad, Kotor, Cetinje, Bar, Podgorica	Heavy rain		2000
2005	Storm	Covenctive storm	Šavnik, Žabljak, Plužine, Kolašin, Bijelo Polje, Cetinje, Nikšić, Mojkovac, Berane, Rožaje, Pljevlja, Andrijevica, Plav, Bar			
2005	Extreme temperature	Heavy winter weather conditions	Andrijevica, Berane, Bijelo Polje		3	
2007	Flood	Torrent	Berane, Andrijevica, Rožaje, Mojkovac, Podgorica, Kolašin	Heavy rain and melting snow		1086
2009	Flood	River flood	Golubovci (Podgorica), Bar, Cetinje, Danilovgrad, Nikšić, Ulcinj			450
2010	Flood	River flood	Nikšić, Danilovgrad, Bijelo Polje, Berane, Andrijevica, Plav	Heavy rain		1350
2010	Flood	River flood	Golubovci (Podgorica); Danilovgrad, Cetinje; Skadarsko jezero (Bar, Podgorica)	Heavy rain		5000
2012	Extreme temperature	Cold wave	Kolašin, Mojkovac, Berane, Andrijevica, Plav, Rožaje, Bijelo Polje, Pljevlja, Žabljak, Šavnik, Plužine, Nikšić, Cetinje, Bar		1	4500
2017	Fire	Forest fire	Luštica (Tivat), Kotor, Tivat, Herceg Novi			200

Source: Emdat data base (2023)

In addition, NGFS[1] together with the leading academic climate-related institutions, developed a common platform (image) of how economies could look under different so-called *climate scenarios*. Namely, the ***NGFS Climate Impact Explorer*** offers the possibility to look at future expected damages from several different types of disasters under different warming scenarios at the level

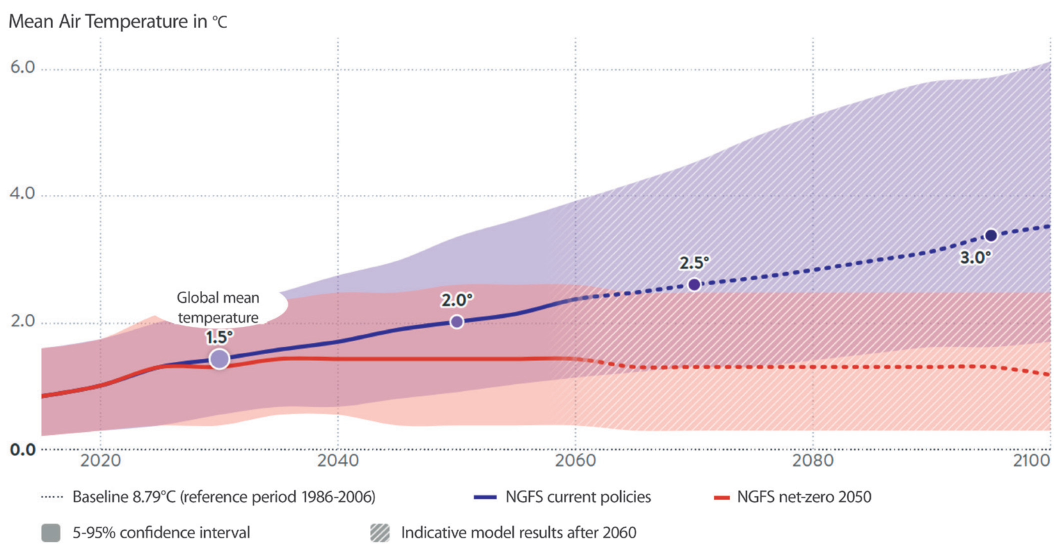
[1] *NGFS is the Network for Greening the Financial System. The Central Bank of Montenegro has been a member of the NGFS as of October 2022.*

of individual countries, regions and cities. Whereas the **NGFS current policy scenario** assumes that the implemented climate change policies (from 2020) will not change, the **Net-Zero 2050 scenario** assumes a transition to a net-zero economy with drastic and coordinated global actions and new policies. In the first scenario, in the absence of ambitious policies to prevent global warming, emissions are on track to reach at least 3.3°C of warming by 2100, while in the second scenario warming peaks at 1.6°C in 2050, and then decreases to 1.5°C by 2100.

In the following graphs, we will show the available estimates of certain climate impacts in the current NGFS policy scenarios and the NGFS net-zero 2050 scenario.

Graph 1 shows how absolute changes in mean air temperature[2] (expressed in Celsius) will unfold over time in Montenegro at different global warming levels compared to the reference period 1986-2006, based on the NGFS current policy scenario and the NGFS net- zero 2050 scenario.

Graph 1 – Absolute change in mean air temperature in Montenegro

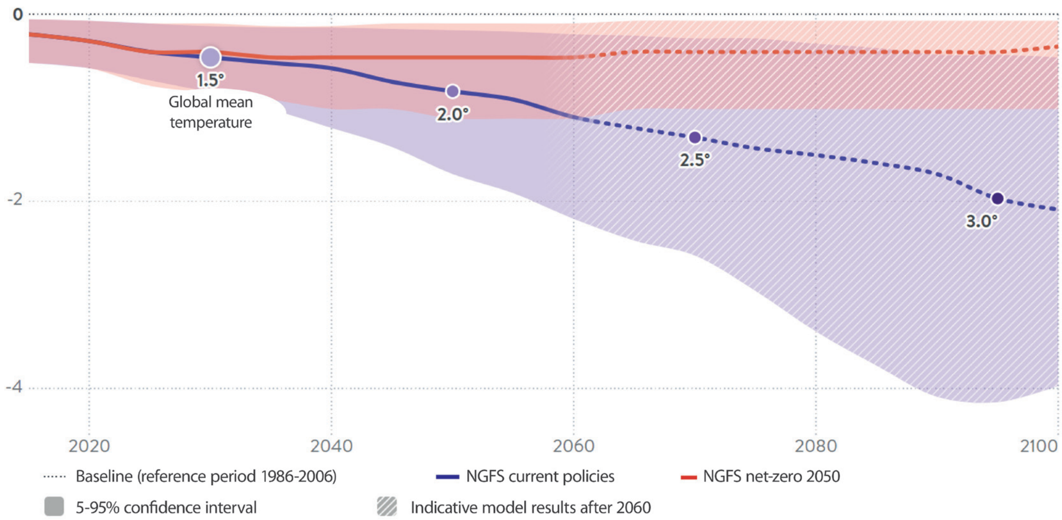


Source: NGFS Climate Impact Explorer (2023)

Graph 2 shows how the relative changes in labour productivity due to heat stress (expressed in percentage points) will unfold over time in Montenegro at different levels of global warming compared to the reference period 1986-2006, based on the current NGFS policy and the NGFS net-zero 2050 scenario.

[2] *Mean air temperature refers to the average temperature of air masses near the surface of the Earth (2 meters above the ground). The data used for this variable underwent a bias adjustment procedure to correct for deviations between modelled and observed values during overlapping time periods. Projections weighted by population or GDP are calculated under the assumption that both the size and distribution of these two parameters will remain constant from 2005.*

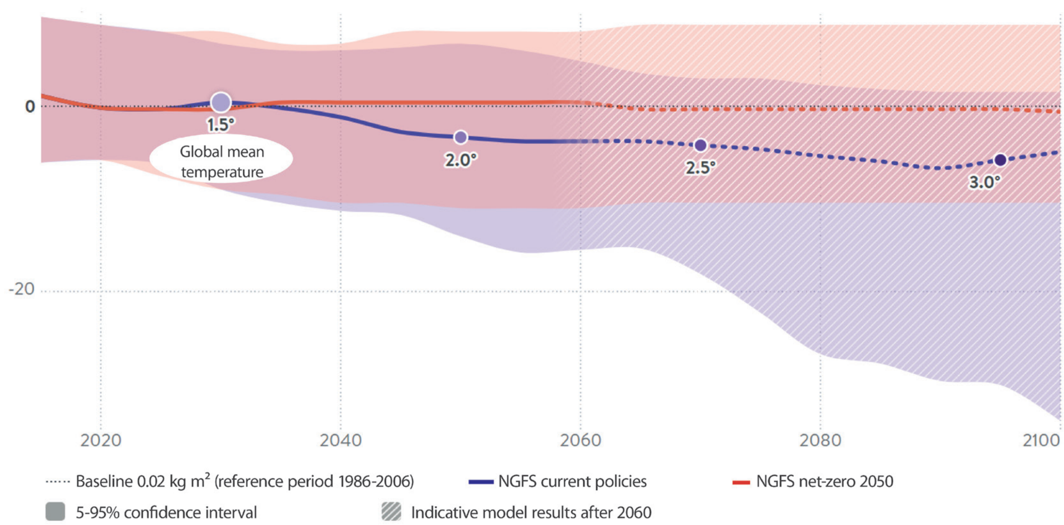
Graph 2 – Relative change in labour productivity due to heat stress in Montenegro



Source: NGFS Climate Impact Explorer (2023)

Graph 3 shows how the relative changes in precipitation (expressed as a percentage) will take place over time in Montenegro, at different levels of global warming, compared to the reference period 1986-2006, based on the current NGFS policy and the NGFS net-zero 2050 scenario.

Graph 3 – Relative change of precipitation in Montenegro



Source: NGFS Climate Impact Explorer (2023)

From the graphs shown, one can observe that warming would reach 2°C by 2050 and, as a result, physical climate risks would also increase. The world would face warming of at least 3.3°C by 2100. Climate change would be more intense and more frequent, including increase in temperature, precipitation, and the like. Also, society's facing chronic climate disasters would certainly affect the reduction of worker productivity. The transition to a net zero economy by 2050 will require a drastic global change, as well as a change in regulatory requirements that may carry certain economic costs, having in mind that many industries would be affected, which would lead to changes in the labour market. These actions, first of all, will involve the use of the so-called green technologies, with the aim of stopping warming at a maximum of 1.6°C in 2050.

Taking into account the global effect of climate change, the planned action should have a global scale, which implies the inclusion of large and small economies.

Back in 1991, Montenegro adopted a Declaration in the Parliament that marked the Republic of Montenegro as an ecological state with defined goals of implementing the highest standards and norms in the field of environmental protection, nature conservation and economic development based on the principles of an ecologically sustainable system. Unfortunately, due to the wars in the former Yugoslavia, the consequences of which, such as sanctions, economic, social and even moral crisis, did not bypass Montenegro either, the idea of an ecological state remained on paper only. Nevertheless, even as such, its permanence remained strong in the consciousness of citizens and always had a positive value. Guided by wishes, but also by concrete accession negotiations for the EU membership, putting the ecological state into operation begins with the ratification of the Paris Agreement on Climate Change (COP21) from 2015, which confirmed our readiness to actively participate in all international processes related to reducing the harmful effects of climate change. Also, with the ratification of the Glasgow Climate Pact (COP26) from 2021 to reduce global warming, as well as the commitments of the 2015 National Strategy for Sustainable Development by 2030, Montenegro's commitment to fight against the negative impact of climate change was confirmed.

The Central Bank of Montenegro, in order to achieve the function of financial stability, and bearing in mind the growing concern regarding the effects of climate change on economic development and financial stability at the global level, leads a policy of an active action to strengthen the resistance of the financial system to the challenges of climate change. In March 2022, the Central Bank of Montenegro Council adopted the Central Bank Policy concerning the challenges of climate change, as well as a short-term action plan for the implementation of the policy, with the aim of reducing the negative impact of climate change on the financial system and devoting itself to the "greening" of the financial system. In accordance with its competences, available instruments and resources, the Central Bank strives to raise society's awareness of the importance of climate change and its impact on the financial and economic system and the environment. This working paper also testifies to that.

4. Methodology and data

Montenegro has short series and data size compared to other countries, which introduces significant limitations when choosing a methodological approach. Additionally, extreme weather events tend to cause immediate economic damage that, as the empirical literature indicates, will last in the short to medium term. To examine the impact of weather variables on macroeconomic indicators, we will use the VAR model, which is widely used in econometric analyses. The VAR model provides a meaningful representation of dynamic reactions between the observed variables, and its application can also open up some economic questions that were not previously theoretically posed.

A detailed approach to the VAR model is given in the work of Lutkepohl (1993, 2006). Equation 1 shows the VAR model. There are a number of different forms of VAR models, the details of which are described (Lutkepohl, 2006).

$$y_t = A_1 y_{t-1} + \cdots + A_P y_{t-p} + C x_t + \epsilon_t$$

$$y_t = (y_{1t}, y_{2t}, \dots, y_{kt},)', is\ k \times 1\ vector\ of\ endogenous\ variables,$$

$$x_t = (x_{1t}, x_{2t}, \dots, x_{dt},)', is\ d \times 1\ vector\ of\ exogenous\ variables\ ,$$

$$A_1, \dots., A_p\ is\ k \times k\ matrix\ of\ lagged\ ratios\ to\ be\ estimated$$

$$C\ is\ k \times d\ matrix\ of\ ratios\ of\ exogenous\ variables\ that\ are\ estimated$$

$$\epsilon_t = (\epsilon_{1t}, \epsilon_{2t}, \dots, \epsilon_{kt}\ )', is\ k \times 1 \text{ white noise innovation process, with } \mathrm{E}(\epsilon_t) = 0,$$
$$\mathrm{E}(\epsilon_t\ \epsilon_t') = \Sigma_\epsilon, i\ \mathrm{E}(\epsilon_t\ \epsilon_t') = 0\ za\ t \neq s.$$

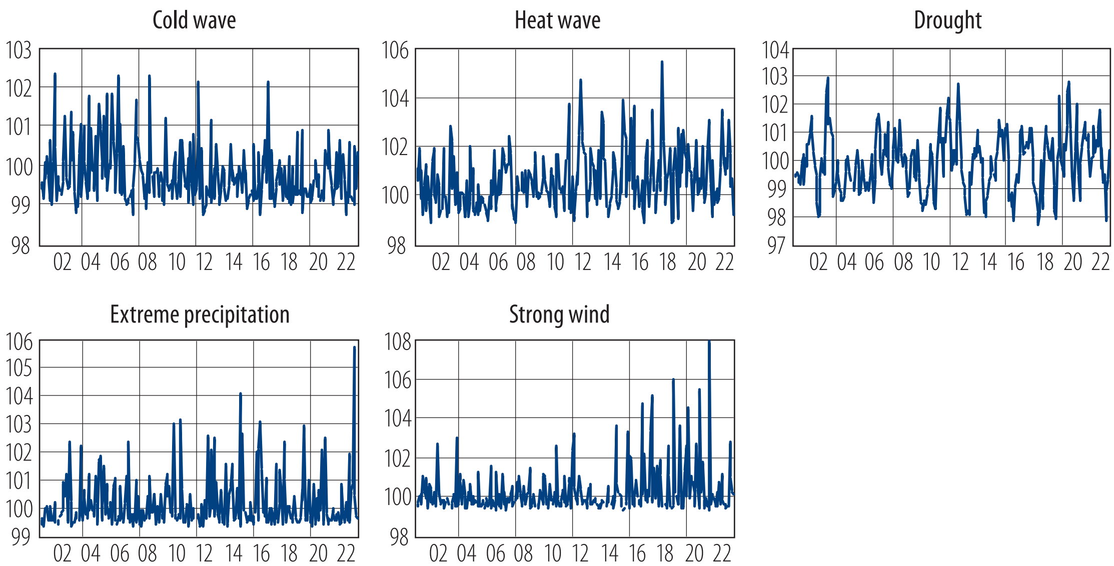
The last equation indicates that innovation vectors are simultaneously correlated with the full rank matrix, but not correlated with their leading and lagging ones, and not correlated with all endogenous and exogenous variables on the right side of the equation.

In the estimation of the VAR model, the monthly data of weather variables and key macroeconomic indicators in Montenegro from January 2001 to the last available data, for April 2023 will be used. Weather variables whose impact we want to examine include cold wave shock, heat wave shock, drought, extreme precipitation and strong wind. These data were collected from the IFAB database (2023), where deviations from the reference values in the range from 1980 to 2010 are calculated for each month. The values of these variables range from -3 to +3. The calculation of these variables is explained in detail on the IFAB website.

Bearing in mind the limited length of GDP time series and its recurrence in Montenegro, we will use the industrial output index as a proxy variable for gross domestic product. Industrial output, as an indicator of economic activity, was also used by other authors (Cicarelli et al. (2023), Škrinjarić (2023)). Among the other macroeconomic indicators, we will use the inflation rate and the unemployment rate, the importance of which is indicated by the findings of the empirical literature presented in the literature review. As Škrinjarić (2023), we will use the growth of industrial output and the inflation rate in the European Union as exogenous variables, bearing in mind that Montenegro is a unilaterally euroised, small and open economy, whose main foreign trade partner is the EU. All macroeconomic variables were transformed into year-on-year growth rates.

Graph 4 shows the development of the variables used to express extreme weather conditions in the previous period.

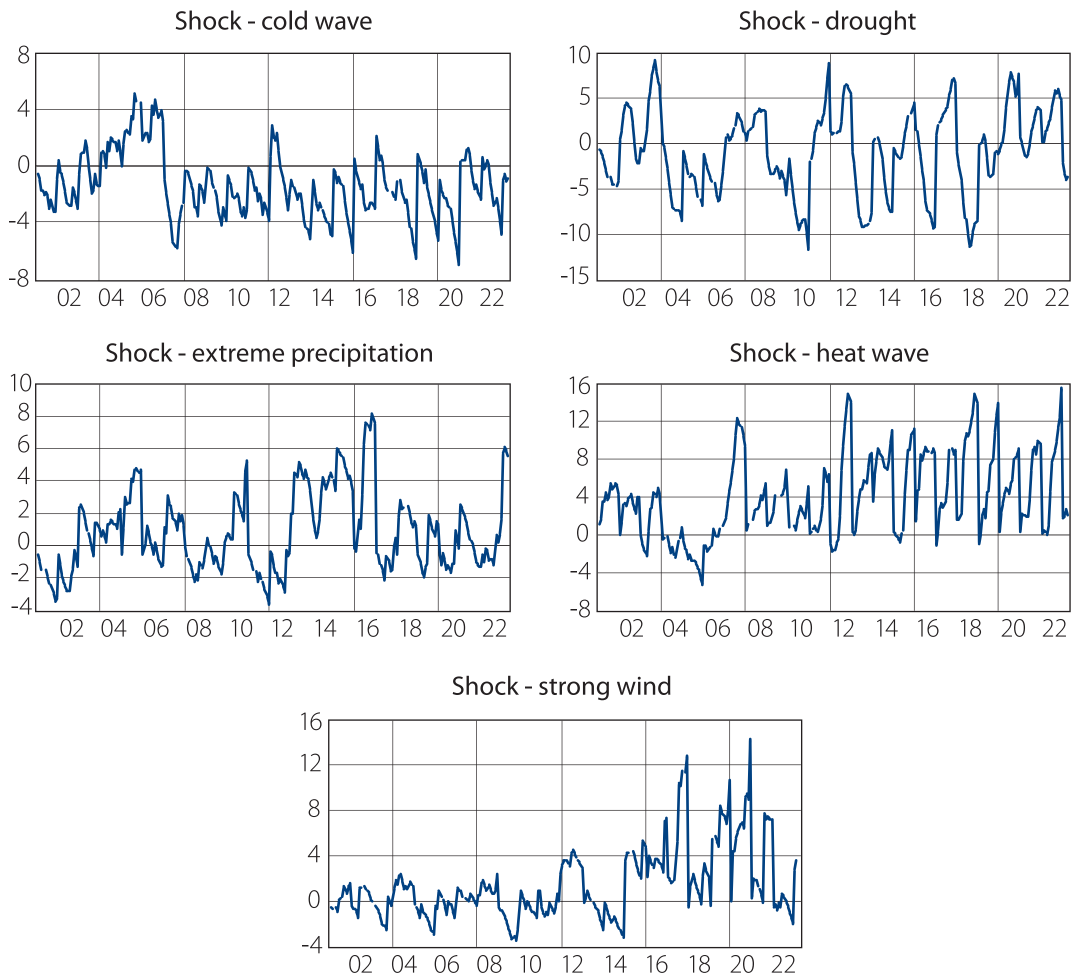
Graph 4 – Weather variables development



Source: Author's calculations

Nevertheless, in order to evaluate the impact of extreme weather events, the cumulative annual sums of the given weather variables will be used in the working paper and shown in Graph 5.

Graph 5 – Cumulative sum of weather variables



Source: Author's calculations

Table 3 shows measures of the central tendency of weather variables (average value), that is, the most likely outcome in the distribution of data, maximum and minimum changes, and measures of variability (standard deviation), which show to what extent the results are grouped around the central tendency. The results of skewness and kurtosis[3] indicate that the distributions of the variables are flattened and with positive asymmetry, which indicates that the extreme values of these variables play an important role in this data set.

[3] *Skewness is an indicator of skewness or symmetry of the distribution. Kurtosis is an indicator of the convexity or flattening of a distribution, which reflects the extent to which scores far from the arithmetic mean contribute to the variability of the variable.*

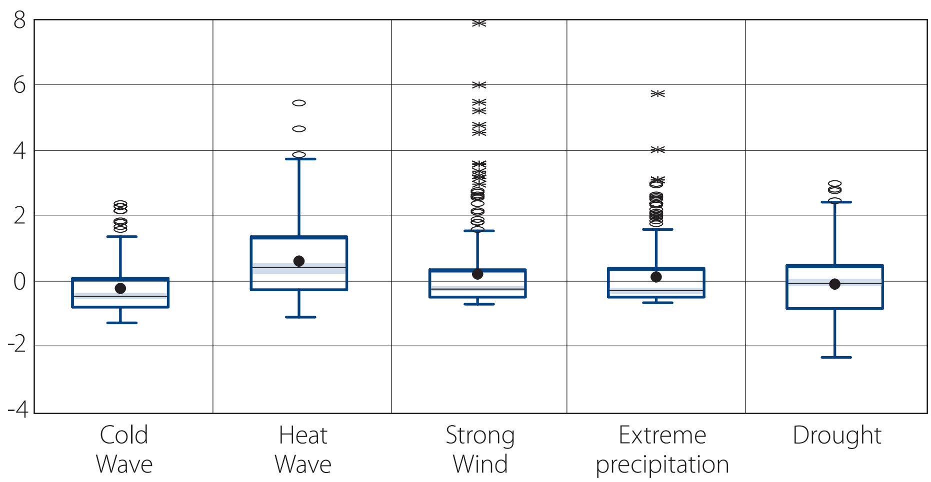
Table 3 – Descriptive statistics of weather variables

	Cold wave	Drought	Extreme rainfall	Strong wind	Heat wave
Average	-0.251	-0.093	0.069	0.181	0.644
Median	-0.453	-0.013	-0.267	-0.217	0.426
Maximum	2.381	2.979	5.748	7.913	5.442
Minimum	-1.267	-2.315	-0.660	-0.718	-1.100
Standard deviation	0.721	1.061	0.886	1.181	1.185
Skewness	1.361	0.224	2.476	3.243	0.982
Kurtosis	4.902	2.835	11.475	16.288	4.009
Jarque-Bera	103.844	2.153	907.343	2058.829	45.950
Probability	0.000	0.341	0.000	0.000	0.000
Sum	-56.680	-20.961	15.675	40.890	145.570
Sum of deviations^2	116.987	253.098	176.464	313.873	316.177
Observation	226.000	226.000	226.000	226.000	226.000

Source: Author's calculations

The appearance of the box diagram clearly indicates the degree of dispersion and asymmetry, as well as significant values that deviate from other data, the so-called outliers.

Graph 6 – Box graph



Source: Author's calculations

Observing the methodology of Škrinjarić (2023), VAR models were created for each time variable separately. Therefore, in the VAR model there will be one time variable and a set of macroeconomic variables (industrial output, inflation and unemployment rate), and a set of control exogenous variables for the EU, which control the high exposure to the EU monetary and economic policy.

We will approach the evaluation of the VAR model after checking the stationarity of all time series, because if this principle is violated, we cannot expect consistent evaluations of the model. The results of the unit root test for all the variables we use in the model show that the mentioned time series are stationary (Table 1 in the Annex). The optimal number of events in the VAR model was chosen based on the criteria of the Akaike and Schwartz tests (Table 2 in the Annex), which suggest the use of two lags in the model. By analysing the residuals, through autocorrelation and heteroskedasticity tests, the obtained results are satisfactory from an econometric point of view.

5. Research results

In this part, we will present the effects of weather variables on macroeconomic indicators in the short term. Instead of the classical interpretation of the ratios obtained in the econometric model, we will present the results of the VAR model in the form of functions of impulse responses of macroeconomic variables to an unexpected change in weather variables. The impulse response function follows one unit, that is, one shock of the standard deviation of the endogenous variable and its effects on all endogenous variables in the VAR model, keeping other variables and shocks constant. The impulse response function is useful for understanding the dynamic behaviour of variables in the observed system. Namely, impulse response functions are often important tools in forecasting macroeconomic developments and analysing economic policies.

Graph 7 shows the short-term impact of the drought shock on macroeconomic variables. Drought shocks immediately increase total inflation. More precisely, the drought shock increases inflation from the first to the twelfth month (up to 0.28 pp), after which the impact of this shock begins to gradually decrease. This finding is justified due to the fact that food makes up 35% of the total consumer price index, and that food prices have a dominant impact on the development of the total inflation, as indicated by the Central Bank working paper (Ivanović, 2023). Drought poses a particular threat to crops and livestock, thus affecting agricultural supply, and consumers face higher prices. Additionally, beside lower supply, higher unit costs for agricultural producers and traders encourage the sustainability of high prices.

Similarly, Cevik and Jalles (2023) show that the drought shock results in an immediate increase in total inflation and that it is present in the long term as well, amounting to about 1.5 percentage points compared to the situation, i.e. scenario in which the shock is not foreseen. What this paper specifically points to, and which corresponds to our findings, is that total inflation increases above its initial level in the first year and over a longer period, with this effect being present in developing countries, while the shock of drought is of lower intensity and it is quickly being pushed out in developed economies. Also, a similar result is indicated by Škrinjarić (2023), whose analysis also establishes that drought is the weather variable that most affects inflation, i.e. economic activity.

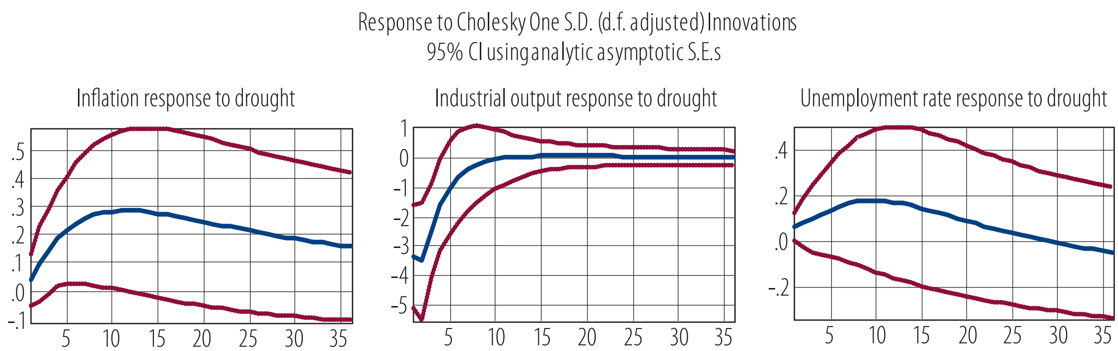
Our results additionally show that drought has a significant immediate and short-term impact on industrial output. This result is not surprising, having in mind that hydropower plants influence about 42 percent of total electricity production, according to CGES (Electric Transmission System of Montenegro) data, and energy production has a significant formative force in total industrial output. This finding is quite understandable, as the reduced inflow of water, due to the current droughts, directly affects the amount of electricity produced in hydroelectric power plants. As an example, we state that the production performance of Montenegrin hydroelectric power plants in 2022, compared to the same period of the previous year, was lower by some 30% due to the great drought that occurred in 2022. In addition to the above, the weak river water flow, as stated by Radonjić (2012), also affects the operation of thermal power plants, considering their dependence on the cooling water.

And other research shows that climate change is increasing the risks for the supply and production of electricity throughout Europe. Namely, as stated in the European Commission autumn report, a series of extreme heat waves in the summer of 2022 made Europe the hottest continent in history. As a result, the production of electricity in hydroelectric power plants has been significantly reduced across Europe in 2022.

The impact of long dry periods on electricity supply can also contribute to the increase in electricity prices. The rise in electricity prices, along with the rise in the prices of agricultural products caused by the drought, certainly raise the level of inflation, which further justifies the result that droughts have a significant impact on inflation. However, it should be emphasized that their full and precise effect is difficult to assess in the context of other significant inflationary pressures such as the consequences of the Covid-19 pandemic and the war in Ukraine.

The impact of droughts is not statistically significant when it comes to unemployment, that is, the unemployment rate.

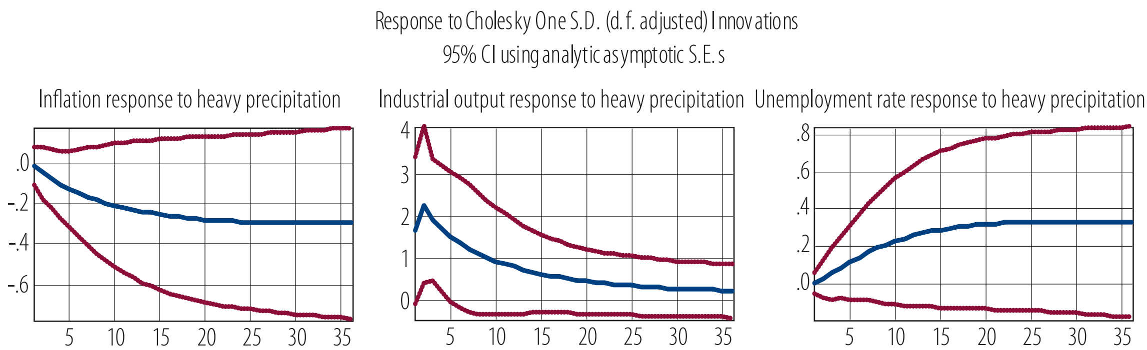
Graph 7 – Impact of drought shock



Source: Author's calculations

When it comes to heavy (extreme) precipitation, Graph 8 shows that the short-term impact of the shock of heavy precipitation was recorded only when it comes to industrial output. Namely, heavy rainfall after the first month has a short-term positive impact on industrial output which is understandable given the significant share of electricity production in total industrial output, but also the large share of hydropower in total electricity production (previously described). Although not statistically significant, the inflation variable has the expected economic sign indicating that heavy rainfall reduces inflation, which is in line with earlier research by Škrinjarić (2023). It should be noted that the quality of the data in Montenegro (short and methodologically inconsistent time series), with large fluctuations in the variable that describes heavy precipitation, as stated by Auffhammer et al. (2020), may be the reasons for the errors and show the statistically significant inconsistency of the impact of the heavy rainfall shock.

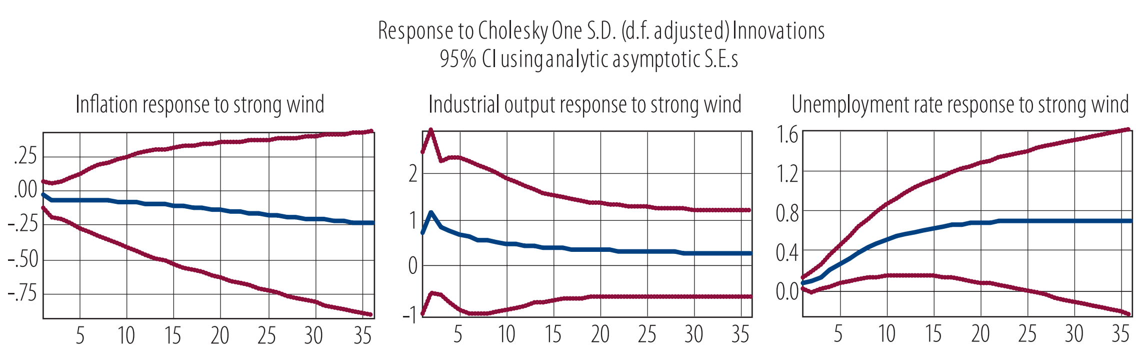
Graph 8 – Impact of heavy rainfall shock



Source: Author's calculations

Graph 9 shows the short-term impact of extreme wind shock on macroeconomic variables. The strong storm wind has no effect on the observed macroeconomic variables in Montenegro, except for the current positive shock on industrial output, although this result is at the threshold of statistical significance. A positive short-term shock to industrial output can be justified by the participation of electricity from wind farms, which is about 10% in the total electricity production.

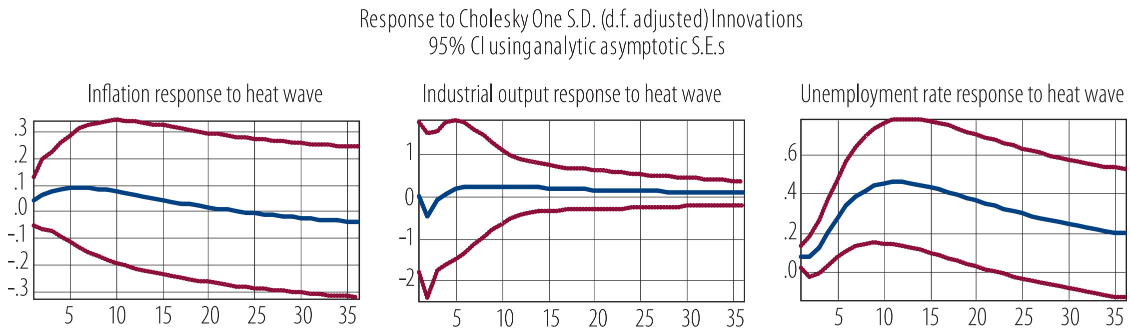
Graph 9 – Impact of strong wind shock



Source: Author's calculations

Graph 10 shows the short-term impact of the shock of extremely high temperatures on macroeconomic variables. The results of the analysis show that the shock of the heat wave has an impact on the unemployment rate only. Namely, this shock increases the unemployment rate from the second to the twelfth month (up to 0.42 pp), after which the impact of the shock begins to gradually decrease. We can interpret this result as a consequence of the characteristics of the production cycle of some significant activities in Montenegro, such as construction and agriculture. Namely, the seasonality and long-term production cycle in these activities are a suitable environment for the manifestation of the above-mentioned effect.

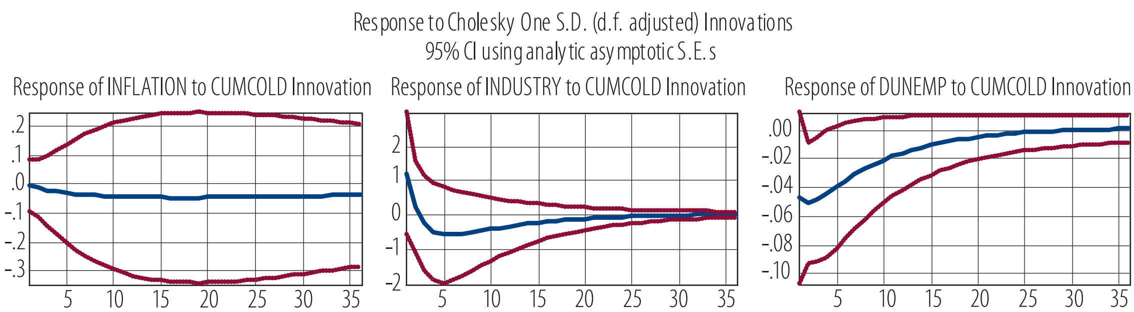
Graph 10 – Impact of heat wave shock



Source: Author's calculations

Graph 11 shows the short-term impact of the shock of extremely low temperatures on macroeconomic variables.

Graph 11 – Impact of cold wave shock



Source: Author's calculations

Based on the results of the model that examines the impact of extremely low temperatures on macroeconomic variables (graph 11), it can be concluded that selected macroeconomic variables do not react to this shock.

6. Conclusion

As extreme weather events caused by climate change are becoming more intense and difficult to predict, it is clear that research on the topic of possible economic consequences is necessary.

Accordingly, the aim of this working study is to examine the impact and present a framework for understanding the different transmission channels of weather shocks on macroeconomic variables. In this paper, we tried to empirically examine the impact of weather shocks on inflation, industrial output and unemployment in Montenegro, despite numerous challenges. Namely, our analysis of the impact of climate change, i.e. extreme weather conditions, is certainly hindered by the lack of quality data and methodologically consistent time series. In the observed period, from 2001 to 2023, we had numerous methodological changes in the calculation of macroeconomic indicators because Montenegro was going through radical political, structural and systemic reforms. Also, for analyses of this type, greater granularity of data is necessary.

In the estimation of the model, we used monthly data of weather variables and key macroeconomic indicators in Montenegro from January 2001 to the latest available data for April 2023. Weather variables whose impact we examined are: cold wave shock, heat wave shock, drought, extreme precipitation and strong wind.

The results of the analysis showed that extreme drought increases inflation and reduces industrial output, especially due to the importance of hydropower production. Also, heat wave has a negative impact on employment, i.e. it increases the unemployment rate. Abundant precipitation and strong winds have a short-term positive effect on industrial output, more precisely on the production of electricity.

As the supply of electricity in recent years has increasingly come into contact with renewable sources, the sensitivity of prices to climate change and adverse weather events is of particular importance and requires further research. A detailed analysis of price aggregates, especially the price of electricity, as well as the price of agricultural products, can be useful for future work, as well as for investigating important inflationary mechanisms such as the spillover of climate effects on inflation.

Based on these findings, we conclude that global warming and its consequences on climate change certainly have an impact on the development of key macroeconomic variables in Montenegro, which obliges the creators of economic policies to encourage the process of the so-called green transformation of key economic activities. In fact, understanding the importance of climate change assumes the cultural transformation of society itself, in order to create an environment for accelerated application of green technologies and living in balance with the nature.

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Annex

Table 1 – Results of unit root tests for weather variables

Critical values	Cold wave	Heat wave	Drought	Extreme rainfall	Strong wind
-3,4537 ; 1%	-15.8562	-11.7900	-6.2715	-16.2974	
-2,8717; 5%					
-2,5723; 10%					-2.7272

Table 2 – Criteria for selecting a VAR model

	AIC	SC	HQ
Drought	2	2	2
Extreme rainfall	2	1	2
Cold wave	2	1	2
Heat wave	3	1	2
Strong wind	2	1	2