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Original Article

Regional Differentiation of Mortality from Cardiovascular and Respiratory Diseases in Correlation with Concentrations of PM_{10} Particles in Montenegro

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Abstract

Background: We aimed to indicate whether the regional disparity in the general mortality rate from cardiovascular (CVDs) and chronic respiratory (CRDs) diseases correlates with the trends of the average annual values of PM_{10} particles in selected cities in Montenegro.

Methods: We used descriptive statistics together with correlation tests. The paper deals with the regional distribution of mortality caused by CVDs and chronic respiratory (CRDs) diseases in Montenegro from 2011 to 2019, while the correlation of mortality in selected cities with PM_{10} particles covers the period from 2011 to 2019.

Results: The selected cities from different regions of Montenegro, such as Pljevlja and Niksic, exhibited significant correlations between increased pollution concentrations and mortality from cardiovascular diseases. In Pljevlja, a strong correlation was found between PM_{10} concentrations and CVD mortality ($r = 0.8$), while in Niksic, the association between PM_{10} particles and CVD mortality in women was relatively strong ($\beta=2.7$). Similar, but weaker correlations were observed in Podgorica ($r=0.5$) and Bar ($r=0.4$). Regarding respiratory diseases, the correlations with PM_{10} particles were negative and weaker in all cities, with the lowest coefficients observed in Podgorica ($r = -0.2$) and Nikšić ($r = -0.3$), suggesting a lesser impact of pollution on mortality from respiratory diseases compared to cardiovascular diseases.

Conclusion: Mortality trends particularly for cardiovascular diseases, show a strong correlation with poor air quality in certain cities, especially Pljevlja and Niksic. Reducing pollutant emissions would significantly contribute to improving public health in Montenegro. Future research must include established measuring stations network for air quality analysis in Montenegro.

Keywords: Cardiovascular diseases; Respiratory diseases; PM_{10} particles; Montenegro

Introduction

In 2019, cardiovascular diseases led to 17.9 million deaths globally, accounting for 32% of all deaths, with ischemic heart diseases being the leading cause. Deaths from ischemic diseases in-

creased significantly from 2 million in 2000 to 8.9 million in 2019. Strokes, the second largest cause of death, accounted for 16% of all fatalities. Lower respiratory tract infections were the fourth leading cause of death, resulting in 2.6 million deaths worldwide (1). In Europe, cardiovascular diseases are responsible for 45% of deaths, and in the European Union, they account for 37% (2). According to Eurostat data for 2018, the highest mortality rates from cardiovascular diseases among the countries of the Western Balkans were in Serbia (837.7/100,000) and Croatia (609.4/100,000). Respiratory diseases are the third leading cause of death in the EU, causing 8% of deaths in 2015, with over 440,000 fatalities that year, primarily among those over 65 (3).

From 1990 to 2019, cardiovascular disease deaths in Asia rose from 23% to 35% of total deaths, reflecting a growing issue in this region (4). Chronic respiratory diseases, particularly COPD, are also a significant concern in Asia-Pacific, with high rates of deaths and hospitalizations (5). In sub-Saharan Africa, cardiovascular diseases caused over a million deaths in 2019, representing 13% of all deaths in the region (6). COPD cases in sub-Saharan Africa rose by 117% from 1990 to 2019 (7).

Environmental risk factors, such as air pollution, heat waves, and chronic stress, contribute significantly to non-communicable diseases. Unlike other modifiable risk factors, air pollution is pervasive and unavoidable for most people (8). High concentrations of PM particles are particularly harmful to health (9), and air pollution is expected to double its mortality impact by 2050 (10). Air pollution ranks fifth among global risk factors and significantly affects the pathophysiology of asthma and COPD (11, 12). Epidemiological studies link particulate matter (PM) with increased cardiovascular diseases (13).

In Europe, around 16% of the population lives in areas where PM_{10} concentrations exceed EU limits (14). In Asia, 58% of cities exceed the annual PM_{10} limit of 70 $\mu g/m^3$, with an average concentration of 89.5 $\mu g/m^3$ (15). Central and West Africa face severe pollution, with levels over four times the WHO guideline, contributing to 700,000 deaths annually (16). Montenegro is a country with a diverse geographical structure and different levels of industrial activity and urbanization in different regions. This topic in Montenegro has not been analysed, which emphasizes the need for detailed research in order to better understand the situation and identify potential mortality problems by region (cities).

Materials and Methods

The paper presents a retrospective descriptive study, for the purposes of which data from the Statistical Office of Montenegro (Monstat) and the Institute for Public Health of Montenegro were used on mortality caused by cardiovascular diseases (I00-I99) and mortality due to respiratory diseases (J00-J99) in the interval from 1991 until 2019, both for the male and female population. The analysis of the causes of death and their correlation with PM_{10} particles considers the period 2011-2019, due to the fact that systematic measurement of the concentration of polluting substances has been carried out in Montenegro (only) since 2011.

The correlation was made on the basis of data for four municipalities in the period 2011-2019: Pljevlja (Northern region); Podgorica and Niksic (Central region); Bar (Southern region). The study used general mortality rates from cardiovascular (CVDs) and respiratory (NCDs) diseases calculated per 100,000 inhabitants. The connection between the variables was determined by correlation analysis, i.e., by calculating the Pearson correlation coefficient and β coefficient of linear regression. Data on the concentration of PM_{10} particles were obtained from the monthly reports on air quality of the Centre for Ecotoxicological Research of Montenegro.

The analysis was done for 2011-2019, looking at data from 4 measuring stations for air quality located in Pljevlja, Podgorica, Niksic and Bar, where systematic daily measurements of basic pollutants are carried out. This paper analyses the mean annual values for PM_{10} particles, as well as the lower thresholds of PM_{10} particle concentra-

tions adopted by CETIM at the recommendation of the EU (17) and the WHO (18).

Statistical analysis

Descriptive statistical methods and correlation testing methods were used for primary data analysis. Descriptive data are shown as ‰, %, m^3. Pearson correlation coefficient and **β coefficient of linear regression** were used to test the correlation between two variables. Statistical hypotheses were tested at the 0.05 level of statistical significance.

The obtained data were statistically processed in order to obtain a correlation between the general mortality rate from cardiovascular (CVDs) and respiratory diseases (NCDs) and the value of the average annual concentration of PM_{10} particles in the selected cities, according to the regional position (north, central and south regions).

Territorial scope of research

Montenegro is located in the southern part of Europe; its mainland stretches between 41^0 50' 26" and 43^0 33' 23" north latitude and 18^0 26' 00" and 20^0 21' 42" east longitude (map 1). According to the geographical latitude, Montenegro belongs to the Mediterranean (19). In 2023, Montenegro had 623,633 inhabitants (20) (Fig. 1).

Fig. 1: Geographical position of the cities where mortality from cardiovascular and respiratory diseases was analyzed in correlation with concentrations of PM_{10} particles in Montenegro
(Source: base map taken from https://www.arcgis.com/home/webmap/viewer.html?layers=10df2279f9684e4a9f6a7f08febac2a9 , edited by the author in ArcGis)

The regionalization of Montenegro has not been officially adopted, but in 2011 the Law on Regional Development was promulgated, which administratively divided the country into regions. The country is usually divided into three regions: northern or mountainous, middle or central and southern or coastal.

Results

In Montenegro, circulatory diseases accounted for 33.1% of deaths in 2019, while respiratory diseases contributed to 6%. The regionalization of mortality caused by cardiovascular diseases in 2019 shows that the highest mortality rate was recorded in the southern part of Montenegro at

310.3/100,000, followed by the northern region with a rate of 285.2/100,000 and the central region with the lowest rate at 212.9/100,000 (Fig. 2).

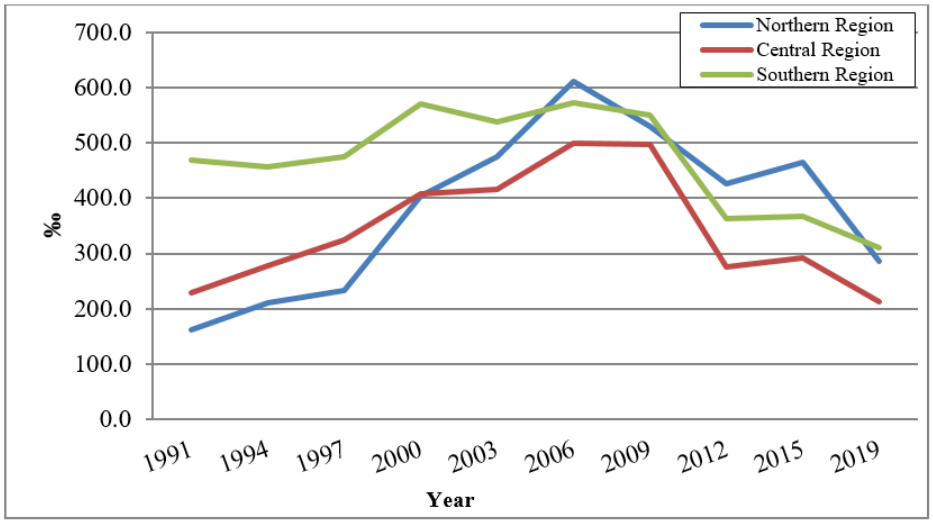

Fig. 2: General mortality rate by region from diseases of the circulatory system
(Source: prepared based on data from Monstat and the Institute for Public Health)

The analysis of deaths from cardiovascular diseases by sex in Montenegro indicates that the share of those who died at a younger age is higher in the male population. In 2019, 24.5% of the male population in the northern region, 21.4% in the middle and 19.4% in the southern region died in the age groups up to 65 yr old, compared to 7.4% of the female population in the north, 9.3 % in the middle and 8.6% in the southern part. Unlike women, half of the deaths caused by diseases of the circulatory system in men occur before the age of 75. The percentage of mortality of the female contingent of the population in the age group of 75 and over reaches a value of 81.2% in the north, 70.8% in the center and 74.1% in the south.

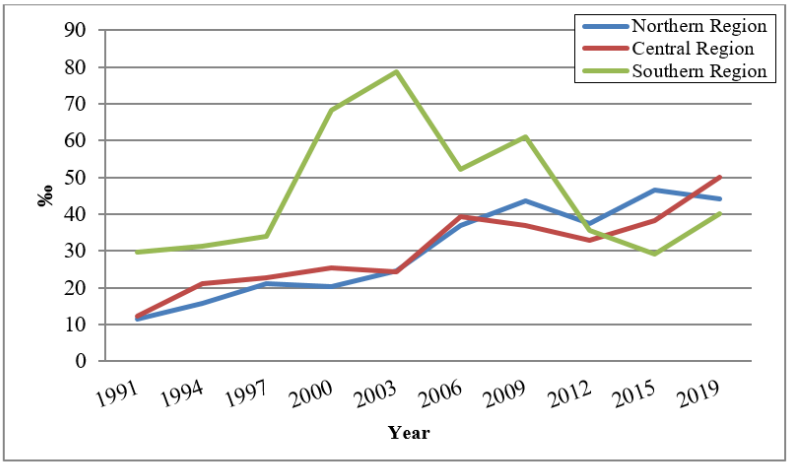

Fig. 3: General mortality rate by region from respiratory system diseases
(Source: prepared based on data from Monstat and the Institute for Public Health)

Looking at the regional component in 2019, the general mortality rate caused by diseases of the respiratory organs is the highest in the central region where it amounted to 50/100,000, in the north it stood at 44.2/100,000, and the lowest value was recorded in the south with 40.1/100,000 inhabitants. The mentioned values in the central region in 2019 also represent the maximum recorded rate (Fig. 3).

Mortality by sex is higher in men in all regions. In terms of the age structure in 2019, in the northern region, the mortality in men up to the age of 65 was 13%, in the central region 30.6%, and in the southern region of Montenegro 23.7%. In the elderly population, the mortality of the male population in the north was 51.9%, in the central part 40.8%, and in the south 36.8%. In the female part of the population up to 65 yr of age in 2019, the proportion of women who died from respiratory diseases was 5.6%, in the central region 24.1%, and in the southern region 37.5%. In the age group over 65 yr, the female population records the highest mortality from respiratory diseases. In the northern region it is 66.7%, in the central region 61.1% and 45.8% in the southern region.

Table 1: General mortality rates from cardiovascular and respiratory diseases in selected cities in Montenegro

	Pljevlja		Podgorica		Niksic		Bar	
Rate	I00-I99	J00-J99	I00-I99	J00-J99	I00-I99	J00-J99	I00-I99	J00-J99
2011	818.6	42.2	204.4	28.0	369.9	16.6	420.9	23.8
2012	684.9	32.9	207.0	28.7	390.6	37.4	433.2	37.7
2013	695.7	70.2	218.2	38.4	370.3	20.9	415.7	32.7
2014	715.6	50.9	260.1	39.0	318.9	36.4	487.5	41.8
2015	716.1	62.0	247.4	35.6	310.5	32.3	468.2	30.0
2016	661.2	56.0	247.3	35.8	352.7	48.2	459.5	32.2
2017	590.2	56.9	281.9	42.0	278.4	40.0	366.2	22.9
2018	588.4	50.9	239.8	39.6	248.4	34.5	367.0	29.6
2019	488.8	51.8	209.8	48.6	226.9	41.9	395.2	47.7

(Source: prepared based on data from Monstat and the Institute for Public Health)

The mortality rate from cardiovascular diseases in Pljevlja has consistently been higher than in other cities from 2011 to 2019 (Table 1). During this period, the average annual concentration of PM_{10} particles in Pljevlja exceeded the allowed limit (<40 μg/m³) every year. Pljevlja recorded between 110 to 205 d annually with PM_{10} concentrations above 50 μg/m³, far exceeding the legal tolerance limit of 35 d per year (11). Consequently, Pljevlja is among the most polluted cities in Europe, with average annual PM_{10} levels consistently above the permitted limit and a maximum concentration of 101.4 μg/m³ in 2015 (Table 2).

Table 2: Mean annual values of PM_{10} particles in selected cities in Montenegro

μg/m³	Pljevlja	Podgorica	Niksic	Bar
2011	98.8	39.3	57.3	33.1
2012	92.0	35.8	54.2	26.7
2013	78.3	34.1	33.8	32.4
2014	77.7	34.1	31.0	27.8
2015	101.4	43.8	39.8	35.0
2016	89.5	38.7	35.5	29.0
2017	66.1	36.8	31.8	30.5
2018	58.8	41.1	31.4	28.0
2019	57.3	34.9	30.7	22.9

(Source: prepared based on data from the Environmental Protection Agency of Montenegro https://epa.org.me/mjesecni-izvjestaji-o-kvalitetu-vazduha/)

The Pearson coefficient in Pljevlja shows that the correlation is positive and strong, which means that an increase in the average annual concentration of PM_{10} particles affects the increase in the mortality rate from cardiovascular diseases (Table 3). The value of the coefficient (r = 0.8) was found in both sexes from CVDs in Pljevlja. The overall β coefficient of 5.8 implies that each increase in the concentration of PM_{10} particles by one-unit results in an average increase in the number of cardiovascular deaths by 5.8 cases in Pljevlja, assuming all other factors remain constant. However, when looking at the data according to sex, in men β=0.8, and in women β=1.0, it suggests that the concentration of PM_{10} particles has a stronger effect on cardiovascular deaths in women compared to men. The general mortality rate in Podgorica from CVDs increased by only 2.6% between 2011 and 2019. Mean concentration of PM_{10} particles in the capital of Montenegro recorded two exceedances in 2015 and 2018 (Table 2). Concentrations of PM_{10} particles in Podgorica were continuously close to the limit of permitted average annual values (>40 μg/m³), with the correlation r = 0.1 being positive and insignificant (Table 3). The coefficient by sex in men indicates a positive and insignificant correlation, while in women a positive and relatively weak correlation. The coefficient **β = 1.2 implies a positive correlation.** In terms of sex according to **β coefficient,** the concentration of PM_{10} particles has a stronger influence on cardiovascular deaths in women compared to men in Podgorica (Table 3).

In Niksic, the situation is particularly severe during winter, with the average daily PM_{10} concentration exceeding 200 μg/m³. In 2011 and 2012, annual exceedances were recorded. There is a positive and moderately strong correlation between CVD mortality rates and average annual PM_{10} concentrations in Niksic, with a notably higher β coefficient of 3.8 for women (Table 3).

Table 3: Pearson correlation coefficient and β coefficient of linear regression of mortality from cardiovascular and respiratory diseases in selected cities in Montenegro

City	Pljevlja	Podgorica	Niksic	Bar
Pearson correlation coefficient (I00-I99)	0.8	0.1	0.7	0.2
β linear regression coefficient (I00-I99)	5.8	1,2	3.8	2.5
Pearson correlation coefficient (J00-J99)	-0.1	-0.3	-0.5	-0.8
β linear regression coefficient (J00-J99)	-0.1	-0.5	-0.4	-1.6
City	Pljevlja	Podgorica	Niksic	Bar
Pearson correlation coefficient men (I00-I99)	0.8	0.1	0.6	-0.3
β linear regression coefficient men (I00-I99)	0.8	1,3	0.9	-0.9
Pearson correlation coefficient of women (I00-I99)	0.8	0.2	0.7	0.6
β coefficient of linear regression of women (I00-I99)	1.0	1.7	2.7	1.7
City	Pljevlja	Podgorica	Niksic	Bar
Pearson correlation coefficient men (J00-J99)	0.1	-0.5	-0.5	-0.1
β linear regression coefficient men (J00-J99)	0.0	-1.5	-0.2	-0.1
Pearson correlation coefficient of women (J00-J99)	-0.1	0.3	-0.2	-0.7
β coefficient of linear regression of women (J00-J99)	0.0	-0.1	0.7	-0.7

In Bar, which had the second-highest CVD rate in 2019, PM_{10} concentrations remained within normal limits, peaking at 35.5 μg/m³ in 2015. The correlation between CVD mortality and PM_{10} concentrations is positive but relatively weak overall, with a positive and moderately strong correlation for women and a negative and weak correlation for men (Table 3). The β coefficient of 2.5 reflects a moderate impact of PM_{10} on CVD mortality, with a positive value for women and a negative one for men (Table 3). From 2011 to 2019, NCD mortality in Pljevlja increased by 18.5%, with the highest rate of 72‰ in 2013. In 2019, mortality from respiratory diseases in Pljevlja was 6.2% higher than in Podgorica, 7.9% higher than in Bar, and 19.1% higher than in Niksic. The correlation between respiratory disease mortality and PM_{10} is negative and insignificant, with both men and women showing similar insignificant correlations (Table 3). The β coefficient in Pljevlja indicates a weak and negative correlation with PM_{10} concentrations, showing no significant linear relationship (Table 3).

Niksic experienced a more than twofold increase in NCD mortality from 2011 to 2019, compared to about twofold increases in Bar and Podgorica. In Podgorica, the correlation between NCD mortality and PM_{10} concentrations is negative and weak overall, with men showing a stronger negative correlation (-1.5) compared to women (-0.1) (Table 3). In Niksic, the correlation between NCD mortality and PM_{10} is weak and negative, with men and women both showing weak negative correlations. The β coefficient in Niksic is positive for women at 0.7, indicating a weak positive correlation (Table 3). In Bar, the correlation between respiratory disease mortality and PM_{10} is negative and strong overall, with a slightly higher value for women (Table 3).

Discussion

Following the global disease burden analysis by the GBD collaboration, country-specific profiles were published. For Montenegro, ambient air pollution is among the top ten risk factors for disease and disability. The analysis suggests that about 4% of mortality in Montenegro is linked to air pollution, equating to around 235 premature deaths annually (11). Studies have established a link between pollution particles and cardiovascular and respiratory diseases globally. Air pollution increases hospitalization and mortality risks from CVDs and CRDs (21). Short-term PM_{10} exposure affects cardiovascular and respiratory mortality in over 600 cities worldwide (22). The results of this study showed that the mean annual concentrations of PM_{10} suspended particles have a strong and positive correlation with mortality rates from cardiovascular diseases in Pljevlja ($r = 0.8$; $\beta = 5.8$) and Niksic ($r = 0.7$; $\beta = 3.8$). An insignificant and relatively weak correlation was recorded in Podgorica ($r = 0.1$) and Bar ($r = 0.2$), while the linear regression showed somewhat higher values in Podgorica ($\beta = 1.2$) and Bar ($\beta = 2.5$).

The obtained results of the mortality from respiratory diseases in correlation with PM_{10} particles in the cities where the measurements are performed showed negative values. In Pljevlja ($r = -0.1$; $\beta = -0.1$), Niksic ($r = -0.5$; $\beta = -0.4$); Podgorica ($r = -0.3$; $\beta = -0.5$) and Bar ($r = -0.8$; $\beta = -1.6$).

Between 2012 and 2016, PM_{10} concentrations in 2,590 European cities ranged from 55 to 140 μg/m³. Turkey had 38 cities with high pollution levels, North Macedonia 5, and Bosnia and Herzegovina, Bulgaria, Belarus, and Poland had 1 city each (23). In 2018, Tuzla (Bosnia and Herzegovina) recorded PM_{10} levels twice the legal annual average for 144 d, with an average concentration of 78.9 μg/m³ (24). In 2019, the most polluted cities were Lalapaşa, Düzce, and Sindirgi in Turkey, according to IQAir AirVisual data.

A study related to the rates of emergency room visits for respiratory and circulatory diseases in four of the five largest Colombian cities during the period between 2011 and 2014, correlates these visits with concentrations of air pollution and PM particles. An increase of 10 μg/m³ PM_{10} particles was associated with an 8% increase in respiratory disease in children under 10 yr of age and a 5% increase in cardiovascular disease in the

elderly (25). The study of the relationship between long-term exposure to ambient air pollution with PM particles in the elderly population of Iranians between 1990 and 2019 shows that the correlation coefficient recorded a positive and strong correlation r = 0.99 with mortality from CVDs diseases (26).

From 2009 to 2012, the impact of the short-term effects of PM_{10} particles on the circulatory system showed that elevated concentrations of floating particles are positively correlated with the number of patients in emergency centers for cardiovascular diseases, also, analysis by sex showed that men and elderly people are more vulnerable to exposure to PM_{10} particles (13). A study in London from 1987 to 1994 showed similar values with the conclusion that prevention measures could reduce the total hospitalization for 6,000 patients with cardiac disorders (27). Prevention measures primarily include minimizing activities and staying in the city, especially in the morning and evening when pollutant concentrations are highest. Respiratory protective masks should be used outdoors. Risk groups, such as those with chronic, pulmonary, cardiac conditions, and allergies, as well as healthy individuals, are advised to spend as much time as possible in fresh air and low-pollution areas, such as picnic spots.

Research conducted in Thailand over 11 years (2004-2014), which refers to the ambient concentration of PM_{10} particles and the prevalence rate of respiratory organs, the correlation coefficient did not indicate a connection (r = 0.191). However, the research revealed a highly significant positive correlation between the annual average ratio of ambient PM_{10} concentration and the relative risk of patients with respiratory diseases (r = 0.852, df = 4). Based on these research findings, an increase in ambient PM_{10} concentration levels above 30 $\mu g/m^3$ has a negative effect on the human respiratory system during long-term exposure (28).

For Bogotá, a time-series study from 1998 to 2006 found a 0.71% increase in all-cause mortality and a 1.43% increase in respiratory outcomes for a 10 $\mu g/m^3$ PM_{10} increase (25). A study conducted in Kuwait related to the concentration of PM_{10} particles in sandstorms in correlation with respiratory diseases showed a strong correlation with subgroups of respiratory diseases. The correlative relationship with lower respiratory tract infections r = 0.7 and acute upper respiratory tract infection r = 0.8 was particularly highlighted (21).

The analysis carried out by year also provided an insight into the trends in mortality from cardiovascular and respiratory diseases in Montenegro. This approach makes it possible to see the evolution of mortality over time and to identify potential changes or trends that could be related to variations in air pollution. Although more detailed analyzes by days or months would have been more desirable in order to see daily and seasonal variations, the lack of available mortality data on a daily and monthly level limited the research possibilities. Nevertheless, the analysis by year provides a basic insight into the long-term effects of air pollution on the health of the population. The ultimate objective of this research is to contribute to a better understanding of the connection between air pollution and health problems in Montenegro. It is possible to identify priority areas for interventions and development of environmental protection and public health policies that will aim to reduce the negative effects of air pollution on the population.

Conclusion

The trends in the mortality from cardiovascular and respiratory diseases, viewed through the regional component, indicate a significant connection between increased general mortality rates from the mentioned diseases and selected cities where air quality is impaired by anthropogenic influence. Reducing the emission of pollutants, especially from the burning of solid fuels for heating in residential buildings, which especially applies to Pljevlja and Niksic, should be a priority to reducing the population's exposure to air pollution and its impact on health. Increasing energy efficiency, switching to cleaner fuels (gas, electricity) for cooking and heating, and the use of solar

energy for heating and electricity generation would have a favourable impact on health and would have additional positive effects on the environment throughout Montenegro.

Journalism Ethics considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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Conflict of interest

The authors declare that there is no conflict of interests.

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