Climate Change and Air Pollution

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"True progress happens when people from different fields come together to solve the world's most complex challenges."
Rector of MIT, L. Rafael Reif

Editors's note

The book in your hands Climate Change and Air Pollution is the output of the summer school "Climate Change and Air Pollution", held from July 1 to 5, 2024, at the Center for Interdisciplinary Studies "Prof. Dr. Zdravko Grebo" of the University of Sarajevo. This project was realized with the support and financing of UNICEF in Bosnia and Herzegovina, whose involvement in the education and empowerment of young people enabled the creation of this platform for knowledge exchange, awareness raising, and capacity building of future leaders and experts dedicated to creating a more sustainable future. Our gratitude to UNICEF is enormous because, without their contribution, this project would not be possible.

The summer school was intended for young people aged 17 to 25, including students and high school graduates from Bosnia and Herzegovina, interested in gaining knowledge about critical environmental topics. The main goal was to raise awareness about climate change and air pollution and deepen the understanding of the causes and consequences of these phenomena. Participants gained practical knowledge about global environmental challenges through lectures, interactive workshops, research projects with mentors, and field visits. Additionally, our goal was to empower young people to actively act and implement environmental protection measures in their communities.

Climate change is a complex global problem that affects all aspects of human life, the environment and our planet. The consequences are manifested through the loss of biological diversity, extreme weather, air, water and soil pollution and increased frequency of natural disasters such as floods, droughts and fires. In addition, climate change significantly affects human health, facilitating the spread of infectious diseases, which makes the fight against them urgent and resource-demanding. Air quality management is becoming a key measure for preserving public health and reducing the negative effects of pollution on the environment.
The mission of our summer school was to gather experts from different disciplines to jointly analyze the challenges posed by climate change and air pollution, with a particular focus on Bosnia and Herzegovina. This book provides comprehensive insight into these critical topics through theoretical papers, practical workshops, and the experiences of summer school participants, offering readers not only knowledge but also inspiration for active action.
The book is divided into two parts: Theoretical Perspectives on Climate Change and Air Pollution, which brings together the works of leading researchers and experts, and Interactive Learning: Workshops on Climate Change and Air Pollution, which focuses on practical aspects

and young people's participation in the discussion of environmental challenges. The first part provides a theoretical framework based on scientific facts and data, while the second part offers concrete tools and strategies that young people can apply in their communities.

We hope this book will serve as a valuable base for further research and inspire readers to become actively involved in solving global environmental challenges through research, education, or concrete actions in communities. Climate change and air pollution require urgent attention, but we can make a significant impact by working together.

We firmly believe that by empowering and educating the young generation, we are fostering the leaders who will create a brighter, more sustainable future for life on our planet.

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Acknowledgments

We owe special thanks to our key partners and donors, without whom implementing the "Climate Change and Air Pollution" summer school would not be possible. Their support has enabled this school to be maintained at the highest level, providing education and practical skills to young leaders facing climate change and air pollution challenges.

We sincerely thank UNICEF, who recognized the value of this initiative and provided financial and logistical support, and the government of Sweden (Sverige) for their long-term commitment to supporting educational and environmental projects.

Our partners share a common vision for a better society and a sustainable future, which is in line with the Summer School's mission. Together, we created a platform for young professionals, empowering them to tackle global challenges. We are grateful for their role in making this opportunity possible and look forward to future collaborations that promote education and sustainability.

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Part I
Theoretical Perspectives on Climate Change and Air Pollution

Earth’s Climate System

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Abstract: Climate refers to a set of weather phenomena, or atmospheric processes, that characterize the average physical state of the atmosphere above a particular place or over a larger or smaller area of the Earth’s surface. More specifically, climate is defined as the average state of the atmosphere over a specific location during a particular period (considering both average and extreme deviations), typically based on 30-year series.
Climate change has been characteristic of planet Earth since its formation until today. In recent years, climate changes have intensified, most notably manifested through rising air temperatures and accompanying processes. Climate change has significant impacts on natural processes, social activities, and business activities, which exhibit pronounced regional differences. In light of this, there is a pressing need to mitigate climate change as well as to adapt and mitigate its effects.

Keywords: climate, climate change, nature, society, business, consequences, adaptation, mitigation

1. ATMOSPHERE

The atmosphere is one of the spheres of the Earth's geographical envelope. In addition to the atmosphere, the geographical envelope includes the lithosphere, hydrosphere, biosphere, and pedosphere. Each sphere consists of various components (air, water, soil particles, plants, and animals), but one component predominates, which gives the sphere its name. The atmosphere is a mixture, a mechanical blend of several gases, with their proportions remaining more or less constant in the lower layers of the atmosphere (Šegota, T., Filipčić, A., 1996). Dry air at sea level consists mainly of 78.08% nitrogen and 20.95% oxygen, with small amounts of argon (0.934%) and carbon dioxide (0.035%). Other gases include noble gases such as xenon, neon, krypton, and helium, along with trace amounts of others (CH_4, CO, N_2O, HNO_3, NH_3, etc.).

Figure 1. Composition of atmosphere

THE NAME OF THE GAS	VOLUME
Nitrogen (N_2)	78.088
Oxygen (O_2)	20.949
Argon (Ar)	0.930
Carbon dioxide (CO_2)	0.0318
Neon (Ne)	1.80x10-3
Helium (He)	5.24x10-4
Methane (CH_4)	1.40x10-4
Krypton (Kr)	11.14 x10-4
Nitrous oxide (N_2O)	5x0-5
Xenon (Xe)	8.6x10-6
Hygrogen (H)	5x10-5
Nitrogen dioxide (NO_2)	2x10-8
Ozone (O_3)	2x10-6
Sulfurdioxide (SO_2)	2x10-8
carbon monoxide (CO)	2x10-5
Ammonia (NH_3)	1x10-6 - trace

Source: Milosavljević, M., 1985; Spahić, M., 2002; Šegota, T., Filipčić, A., 1996

The atmosphere also contains between 0.1 to 5% water (water vapor), with a typical range of 1 to 3% (Baskar et al., 2021). It influences the radiation balance and other atmospheric processes. Its relative amount is highly variable, being higher in summer and lower in winter, depending on temperature and moisture sources. In addition to regular dust (fine clay particles, various minerals that form clay, and other soils transported by winds), the air contains ash (from volcanic origins and fires). The atmosphere also contains significant concentrations of soot (pure carbon formed by the combustion of carbon-rich organic matter), various gases (from industrial plants, internal combustion engines, household heating), fine salt particles, pollen, spores, bacteria, etc. (Šegota & Filipčić, 1996).

The quantity of these impurities in the atmosphere varies significantly, depending on their production, the distance from emission sources, and anthropogenic activities, which play a crucial role in their creation and release into the atmosphere. All the previously mentioned gases, water vapor, and particles play a significant role in atmospheric processes that directly and indirectly impact other geocomponents, geospheres, and geosystems, which are integral parts of the Earth's geographic envelope.

The *vertical differentiation of the atmosphere* into structural layers is primarily based on temperature (Šegota & Filipčić, 1996). The atmosphere is divided into different layers, each with specific properties. These layers differ in terms of temperature, composition, and other characteristics. The Earth's atmosphere can be divided into five main layers:

- Troposphere,
- Stratosphere,
- Mesosphere,
- Thermosphere,
- Exosphere.

Between each layer is a transition zone (1-2 km thick) known as the tropopause, stratopause, mesopause, and thermopause.

The ***troposphere*** is the layer closest to the Earth's surface, extending roughly 8 to 15 kilometers above it (depending on latitude). In the troposphere, temperature decreases with altitude, averaging a temperature drop of 0.56°C per 100 meters (from -45°C over the poles to -80°C over the equator) (Šegota & Filipčić, 1996). This layer is the densest, containing 80% of the total atmospheric mass (Spahić, 2002). Due to thermal differences in the vertical profile and varying heat capacities of the surface, this layer is highly dynamic, with advective and convective air currents. Additionally, this layer is characterized by weather phenomena such as clouds, storms, and precipitation. The troposphere is of utmost importance as it is the layer where we live and where all life activities on Earth occur.

The ***stratosphere*** is the second-lowest layer of the Earth's atmosphere, extending up to 50 km above the surface. The stratopause forms the upper boundary of the stratosphere, while the tropopause is its lower boundary. The stratosphere contains the highest concentration of ozone molecules, forming the ozone layer that protects the Earth's surface from ultraviolet radiation. The stratosphere has a lower concentration of water vapor, making it quite dry, and no precipitation clouds form there.
Above the stratosphere lies the mesosphere, which extends to about 85 kilometers above the Earth's surface. The mesosphere is characterized by extremely low temperatures, dropping to as low as -90°C. In this layer, meteors burn upon entering the atmosphere. Furthermore, the mesosphere plays a key role in protecting Earth from impacts from space debris. It also helps in transmitting radio waves for long-distance communication. Specific clouds sometimes form in the mesosphere near the poles at high altitudes, known as "noctilucent clouds" or "polar mesospheric clouds" (Baskar et al., 2021).

The ***thermosphere*** is located above the mesosphere at an altitude of 85 to 600 kilometers. Due to a high degree of ionization, the atmosphere above 80 km is called the ionosphere, where the air behaves as plasma (Šegota & Filipčić, 1996). In this layer, temperatures rise significantly due to the absorption of high-energy solar radiation. This layer is essential for satellite and spacecraft operations, as it facilitates the transmission of radio signals and houses the International Space Station.

The *exosphere* is the outermost layer of Earth's atmosphere, extending from the upper boundary of the thermosphere to the edge of space (600–10,000 km). The exosphere is characterized by extremely low atmospheric pressure and a gradual transition into the vacuum of space. This layer contains a sparse distribution of gas molecules, primarily hydrogen and helium. Due to the low density, particles easily overcome Earth's gravitational pull and escape into outer space (Spahić, 2002), which has significant implications for studying long-term climate change on Earth.

2. CLIMATE AND WEATHER

Weather represents the actual state of meteorological elements and phenomena at a given moment (Milosavljević, M., 1985; Spahić, M., 2002; Šegota, T., Filipčić, A., 1996). Weather is the current state of the atmosphere at a specific location. It comprises the values of meteorological elements that, at a given time and place, define the atmospheric condition. Weather is thus a concept well-defined and expressed by numerous meteorological values, symbols, or terms, but it is also highly changeable and unstable. Such defined weather is observed within a given time frame, typically no shorter than 15 minutes.

The most important meteorological elements and phenomena that determine and characterize weather are: solar radiation and terrestrial radiation, air pressure, air temperature, humidity, wind direction and speed, clouds, fog, rain, snow, etc. Therefore, observed weather is characterized by a complex of meteorological elements and phenomena that are closely interconnected. This mutual connection and dependence influence not only the quantitative aspects of individual meteorological elements and phenomena but also cause certain qualitative changes.
Climate refers to the aggregate of weather phenomena, or atmospheric processes, that characterize the average physical state of the atmosphere over a specific location or a larger or smaller area of the Earth's surface. More specifically, climate is defined as the average state of the atmosphere over a certain place during a defined period (considering average and extreme deviations), typically using 30-year data sets. (Drešković, N., 2011; Drešković, N., 2004; Šegota, T., Filišpčić, A., 1996., Spahić, M., 2002., Milosavljević, M., 1985).

The climate elements and phenomena that constitute weather are the result of various physical processes occurring on the Earth's surface, in the shallow subsurface, and the atmosphere. The main factors affecting weather are the intensity of solar radiation, air circulation in the atmosphere, and the nature of the surface. Climate elements constantly change under the influence of climatic factors, which are also called modifiers of climate elements. Thus, climate elements are changeable, while climatic factors are constant (although some can also change).

Climate elements include:

- Radiation (shortwave and longwave);
- Temperature (air and Earth's surface);
- Air pressure;
- Wind direction and speed;

- Air humidity and evaporation;
- Cloud and sunshine duration;
- Precipitation;
- Snow cover (height and duration);
- Air electricity.

When observed or measured meteorological elements are collected, and their average values are calculated for defined time intervals (day, month, year, etc.), climate elements are obtained.

Climatic factors include:

- Earth's rotation,
- Earth's revolution,
- Geographic latitude,
- Altitude,
- Distribution of land and sea,
- Ocean currents,
- Distance from the sea,
- Lakes,
- Relief (elevation, terrain structure, exposure),
- Types of surface (water, snow, ice, rock, sand, clay, etc.),
- Types of vegetation cover (forest, meadow, barren areas, etc.),
- Human activities (alteration of vegetation cover, establishment of forest belts, urban expansion, reclamation activities, etc.) (Šegota, T., Filišpčić, A., 1996., Milosavljević, M., 1985)

3. METEOROLOGICAL MEASUREMENTS

Weather refers to the current state of the atmosphere, continuously monitoring the condition of key meteorological elements. To accurately represent certain meteorological values, measurement instruments are used. While humans can "sense" values of meteorological elements (such as differences in warmth or cold), meteorological instruments are necessary to display these values in measurable units. According to World Meteorological Organization (hereinafter: WMO) standards, the area where meteorological measurements and observations are conducted is called a meteorological station. The meteorological station should be located as far from significant objects as possible due to the increasing influence of urban areas on meteorological parameters and should be placed in a representative location to most accurately reflect the weather and climate of an area.

Meteorological stations are categorized based on their purpose and operational program into:

- Main meteorological stations
- Ordinary meteorological stations
- Rain gauge stations

According to technological approaches, meteorological stations are divided into those with conventional, conventional-electronic, and purely electronic instruments.

Meteorological measurements in Bosnia and Herzegovina began long ago, with instrumental measurements over 120 years old and records of meteorological elements available from even earlier. The first meteorological records of climatic elements are found in the chronicle of Osman-ef. Šuglija from 1665. There are also records of meteorological phenomena and processes in the travel writings of Evliya Çelebi. Since 1892, results from the network of meteorological stations have been published annually. The establishment of meteorological stations in Bosnia and Herzegovina began in the 1880s with:

- The meteorological observatory on Bjelašnica in 1894
- The meteorological station in Sarajevo in 1902
- The meteorological station in Mostar in 1898
- The meteorological station in Tuzla in 1898 (www.fhmzbih.gov.ba)

Following the establishment of the first meteorological stations, the country's economic development, rapid urbanization, and industrialization led to the expansion of the meteorological station network. Despite occasional interruptions, continuous monitoring, measurement, and archival of meteorological data have been maintained since the establishment of the stations. Bosnia and Herzegovina became a full member of the WMO on June 30, 1994 (www.fhmzbih.gov.ba).

4. THE CLIMATE ELEMENTS

The climate elements and phenomena that constitute weather are the result of various physical processes occurring on the Earth's surface, in the shallow subsurface, and the atmosphere. In the following, some of the most important climatic elements will be analyzed, such as: radiation, temperature, air pressure, wind direction and speed, air humidity and evaporation, precipitation, cloud and sunshine duration.

4.1. Energy Processes in the Atmosphere

Heat at the Earth's surface comes from internal sources (endogenous heat sources) and solar energy (exogenous processes). Internal energy originates from the Earth's internal layers, generated by the emission of radioactive energy and the decay of heavy elements, which is converted into thermal energy. Research confirms that the temperature increases with depth from the Earth's surface at an average rate of 10°C for every 35 meters of depth (values refer to layers 10-25 km thick). The amount of internal heat transferred from the Earth's surface to the atmosphere is 0.00042 J cm^{-2} $year^{-1}$. This is negligible compared to the energy Earth receives from the Sun (Spahić, M., 2002).

Solar energy is the energy that reaches a surface in a given period through electromagnetic radiation. Earth receives a two-billionth part of solar energy radiation. The amount of thermal energy reaching Earth is less affected by the distance from the Sun and more by the angle of radiation incidence and the duration of sunlight. Due to the varying distance between Earth and the Sun on the ecliptic, a standard measure called the solar constant has been introduced. This represents the amount of radiant energy Earth receives per minute per cm^2 at the upper boundary of the atmosphere, perpendicular to the Sun's rays.
The solar constant, the flux of solar radiation at the upper boundary of the atmosphere per 1 cm^2 surface perpendicular to the radiation, is 8.17 J/cm^2 min^{-1} (Šegota, T., Filipčić, A. 1996). Solar radiation consists of corpuscular radiation (particle radiation) and electromagnetic

radiation. Corpuscular radiation originates from protons and electrons moving from the Sun's surface. Solar electromagnetic radiation is divided into three spectra:

- Ultraviolet (less than 0.40 µm)
- Infrared (greater than 0.76 µm)
- Visible part (from 0.40 µm to 0.76 µm)

In addition to these energy processes, longwave radiation from Earth, or terrestrial heat radiation, also influences the warming of the atmosphere and Earth's surface. It is a part of infrared radiation with wavelengths from 4 to 50 µm, resulting from the absorption of shortwave solar radiation. A portion of this infrared radiation (longwave radiation from Earth) escapes into space (about 30%), while the larger portion (about 70%) returns to Earth as counter-radiation from the atmosphere, thus increasing the Earth's surface temperature.

4.1.1. Transformation of Solar Radiation Passing Through the Atmosphere

As solar radiation passes through the atmosphere, it is transformed. The solar radiation reaching Earth's surface is diminished, depending on atmospheric transparency. Atmospheric transparency depends on the physical properties of the gases making up the air and the number of suspended particles. The transparency coefficient indicates how much of the solar radiation that reaches the upper layers of the atmosphere reaches the Earth's surface. The average transparency coefficient during clear weather, with dry air and the Sun at the zenith, is 0.78. The thicker the atmosphere through which the solar rays must pass and the murkier the air, the lower the transparency coefficient (Šegota, T., Filipčić, A., 1996).

The influence of the atmosphere on solar radiation manifests through:

- Reflection or scattering of light (diffusion on airborne particles)
- Absorption (selective absorption - gases in the atmosphere, e.g., ozone for UV, carbon dioxide, and water vapor for infrared)

At the upper boundary of the atmosphere, only direct solar radiation is present. If electromagnetic waves come into contact with a medium (e.g., air, water, soil, or ice), they can be absorbed, reflected, or transmitted more or less intact. The property of a body to transmit radiation is called diathermancy, which depends on the nature of the medium through which the rays pass (Šegota, T., Filipčić, A., 1996). Thus, in addition to direct radiation, diffuse or scattered radiation also reaches the Earth's surface. The sum of direct and diffuse radiation reaching a horizontal surface on Earth is called global radiation.

4.1.2. Insolation

Insolation (Latin: insolatio: sunlight) represents the duration of sunshine, i.e., the actual time a place on Earth is illuminated. Actual sunshine duration – the time of sunlight depends on the openness of the horizon, the length of the visible part of the day, and cloud cover, while the astronomically possible sunshine duration can be calculated using solar declination and the geographical latitude of the observed place. Relative sunshine duration represents the ratio between actual and potential sunshine. Sunshine is expressed in units of time. Based on measured values, the average number of sunshine hours per day is determined, representing the ratio between the actual number of hours of sunshine in a month and the number of days in that month. Locations with the same amount of insolation on maps are connected by lines called isohels.

4.2. Heat Transfer in Soil, Water and Atmosphere

In the lowest layer of the atmosphere, near Earth's surface, the most significant temperature processes occur. This layer shows pronounced daily and annual temperature changes in both horizontal and vertical profiles.

4.2.1. Heating and Cooling of Land

The ground represents an adiabetic medium for solar radiation. The heating of the land depends on the general geographical and physical characteristics of the soil. The surface of the land receiving solar energy is called the active radiation layer. Heat is transferred to deeper layers of soil through conduction. Land not covered by water, ice, or snow expends all energy on heating the soil, while land covered by water, ice, or snow uses part of the energy to change the state of water.

4.2.2. Heating and Cooling of Water/Oceans

Water has almost the highest specific heat capacity. The heat capacity of water is twice that of land (Spahić, M., 2002). The smooth surface of water reflects a large part of solar rays. Ocean surfaces heat up by absorbing solar radiation, with part of the energy used for evaporation. The surface layer of the sea warms up, while lower layers are heated through heat transfer from particle to particle. Oceans and seas are never at rest; thus, heat is transferred through mixing and water currents. The surface warms up and evaporates, increasing salinity and density and causing water layers to sink until reaching a layer of the same density but at different temperatures. The sea accumulates a large amount of heat, which is released at night and during colder periods (winter).
A very important property of fresh water is that it has the highest density at 4°C. According to this property, vertical circulation occurs in stagnant waters. After insolation ceases, the surface begins to cool. The cooler surface becomes denser and heavier, and the cooled surface layer starts to sink until it reaches a layer of the same density and temperature, replaced by a warmer, less dense layer.

4.2.3. Heating and Cooling of Air

Air is primarily heated and cooled indirectly through the Earth's surface. Most of the thermal energy entering atmospheric processes comes from the Earth's surface, while only a small part results from the absorption of shortwave radiation in the atmosphere (Šegota, T., Filipčić, A., 1996). Heating and cooling of the air mainly depend on the thermal state and changes in Earth's surface beneath the air. Air heats up and cools relatively slowly due to its much lower specific heat compared to water. Causes include high air permeability, continuous air currents, and poor thermal conductivity (Simonović, I. A., 1970).

Accordingly, the atmosphere heats up and cools through:

- Absorption of shortwave radiation and absorption and emission of longwave radiation
- Conduction or heat transfer;

- Convection: (the vertical movement of air masses);
- Turbulent Diffusion or Turbulent Heat Transfer or Thermal Turbulence:
- Molecular Diffusion (Šegota, T., Filipčić, A., 1996).

These processes lead to significant differences in daily and annual (continental and maritime) air temperature flows on horizontal and vertical profiles, depending on the factors influencing their variability.

4.2.3.1. Temperature Inversions

In meteorology, an inversion (or reversal) refers to an unusual change in altitude of some atmospheric property, most often air temperature. A temperature inversion is characterized by an increase in air temperature with altitude. Favorable conditions for inversion formation occur when the ground is covered with snow, in closed basins and valleys, and during clear and calm weather in anticyclones (Pandžić, K., 2002). The layer of the atmosphere where temperature increases with height is called the inversion layer, which is bounded by the lower (base) and upper (top) boundaries of the inversion.

Temperature inversions are classified according to their influencing factors:

- Ground or Radiational Inversions: Formed due to the cooling of the ground layer in direct contact with the surface, which cools through longwave (thermal) radiation. These inversions often occur during clear and calm nights, especially in winter. During summer nights, radiational inversions can start forming in the evening and intensify through the night, reaching a maximum just before sunrise. They are quickly “broken” after sunrise due to heating and turbulence, temporarily becoming elevated inversions. In winter, ground inversions can last several days, but their duration is usually multi-day. Radiational cooling may lead to fog formation if the air is sufficiently moist. In large cities, smog is a common phenomenon associated with temperature inversions (Pandžić, K., 2002). Prolonged cooling can also lead to extremely low temperatures, especially with snow on the ground in winter.
- Subsidence Inversions: Occur when air masses descend, compressing and heating the air, making it warmer compared to the air below.
- Frontal Inversions: Occur when warm and cold air masses meet, with cold front air masses sliding underneath warm front air masses.
- Altitude Inversions: Occur when air masses with different movement directions meet at higher altitudes. When these air masses pass each other, friction causes heating, making the air warmer compared to the air below. Another type of altitude inversion occurs with counter-radiation from cloud systems, contributing to the heating of the air masses above.

4.3. Water in the Atmosphere

Water is a simple and persistent compound of hydrogen and oxygen in a ratio of 11.19% hydrogen and 88.81% oxygen. At temperatures of 0 and 100°C, water is in a liquid state. At temperatures below 0°C, it is in a solid state, and at temperatures above 100°C, it boils and turns into a gaseous state. However, under certain conditions, water can exist in both solid and gaseous states at other temperatures. The transition of water to a solid state is called freezing, while the reverse process is melting, and the transition to a gaseous state is called evaporation. The conversion of water vapor to a liquid state is called condensation, and to a solid state is sublimation (Spahić, M., 2002). The amount of water vapor in the atmosphere affects the likelihood of precipitation. Water vapor efficiently absorbs longwave radiation from the Earth, indirectly affecting air temperature. During evaporation, a certain amount of thermal energy is consumed, so water vapor contains significant latent heat, which is released during condensation.

4.3.1. Evaporation

Evaporation is the amount of water evaporated from a surface. The measure of evaporation is the height of the evaporated water layer in millimeters over a specific period. The rate of evaporation depends on several factors:

- The size of the evaporating surface (larger surface – higher evaporation);
- Temperature (higher temperature – faster evaporation);
- The amount/saturation of water vapor above the evaporating surface (drier air – faster evaporation);
- Wind speed above the evaporating surface (stronger wind – higher evaporation);
- Air pressure (lower air pressure – faster evaporation);
- The amount of precipitation falling on the evaporating surface (more precipitation – lower evaporation).

The process where plants evaporate water obtained from the soil through their roots is called transpiration. Evapotranspiration represents the total evaporation and transpiration.

4.3.2. Air Humidity

Evaporated water from the Earth's surface enters the atmosphere as water vapor, making it humid. The amount of water vapor in the atmosphere is variable. The amount of water vapor in the air depends on temperature and pressure or vapor pressure. If the air contains the maximum amount of water vapor, it is saturated, and any excess vapor condenses into liquid water droplets or sublimates into ice crystals. The temperature at which the air is maximally saturated with water vapor is called the dew point. Humidity in the air is expressed in absolute, specific, and relative values.

Absolute humidity represents the number of grams of water vapor in 1 cubic meter of air. At a given temperature, there is a maximum amount of water vapor that a specific volume of air can contain. Air is saturated with water vapor if it contains the maximum amount of vapor that the air can hold at a given temperature. If the amount of water vapor exceeds this maximum (e.g., due to a temperature drop), condensation or sublimation occurs. Relative humidity is a percentage showing the ratio between the amount of water vapor present in the air and the maximum amount of water vapor the air can hold at that temperature. At higher temperatures, the air can hold more water vapor, while at lower temperatures, it can hold less. Relative humidity (U) indicates the degree of saturation of air with water vapor: $U = e/E \times 100\%$ (e = actual vapor pressure; E = maximum vapor pressure). Specific humidity represents the water vapor content expressed in grams per 1 kilogram of air.

4.3.3. Condensation and Sublimation

Condensation involves the transition of water vapor to a liquid state, while sublimation refers to the transition from a gaseous state to a solid state (at temperatures below 0°C).

These processes release heat, which is involved in atmospheric processes. Conditions for condensation and sublimation include:

- Cooling the air to the dew point or below;
- The presence of hygroscopic particles where condensation nuclei form (e.g., table salt crystals, sea salt droplets, aerosols, etc.).

Condensation and sublimation start with cooling the Earth's surface and the air layer in contact with it through longwave radiation, leading to the formation of dew, frost, fog, contact between warm air and cooler surfaces, mixing air masses of different temperatures with water vapor close to saturation in both, and cooling of air through expansion during lifting.

4.4. Fog

Fog consists of tiny water droplets with diameters ranging from 2 to 130 μm or ice crystals. Fog reduces visibility to 1 km or less; if visibility is up to 3 km, it is called mist.
- Air Mass Fog: Radiational and advection fogs;
- Frontal Fog: Forms at the boundary between two air masses with different thermal properties.
- Radiational Fog: Forms when the near-surface air layers cool significantly due to longwave radiation at night, cooling below the dew point. Conditions for this fog include poor daytime heating of the ground (short days or cloudy weather) and strong longwave radiation at night. During the day, fog rises with warming. This type of fog is associated with temperature inversions during anticyclones.

Advection Fog: Forms when air moves horizontally from one area to another over surfaces with different temperatures, causing the air to cool and condense.

Frontal Fog: Occurs at the boundary between warm and cold air masses. At the boundary, warm air cools and condenses, forming fog.

Besides these types, "urban" fogs or smog occur above urban and industrial areas, resulting from mixing fog with pollutants released into the atmosphere. In large cities, the frequency of fog can be up to 30% higher in summer and even 100% in winter compared to non-urbanized areas.

4.5. Clouds

Clouds are visible products of condensation and sublimation of water vapor, consisting of visible clusters of water droplets or ice crystals, or both, in lower atmospheric layers. To sustain water droplets in the air, a certain vapor pressure is required; if it is less than the maximum, the droplets will evaporate.

Cloud Formation: The basic conditions for cloud formation include adequate amounts of water vapor and a sufficient number and quality of condensation and sublimation nuclei.

Clouds are classified by shape, height, origin, and special features.
Morphological Classification: Clouds are divided into genera, species, and varieties. Genera

of clouds are named based on Latin terms corresponding to three groups: cirrus (feathery), cumulus (heap-like), and stratus (layered), which are also the main cloud forms. Additional designations include alto (high) and nimbus (rainy). Combining these types of clouds results in genera such as Cirrus, Cirrostratus, Cirrocumulus, Altostratus, Altocumulus, Nimbostratus, Stratus, Stratocumulus, Cumulus, and Cumulonimbus (Šegota, T., Filipčić, A., 1996; Spahić, M., 2002).

Clouds are classified based on altitude into high, middle, and low clouds. Additionally, clouds can be classified based on their formation into Orographic clouds, which form when air masses are lifted over orographic obstacles (usually mountain ranges); Frontal clouds, which form at the boundary between two air masses differing in temperature and moisture content, Radiative clouds, which form due to the cooling of the ground layer of air from longwave radiation emission, and Thermal turbulence or convection clouds, which develop in ascending air currents that form during the day over a heterogeneous surface.

Special types of clouds include those that appear in the stratosphere (e.g., nacreous clouds at an altitude of 22-30 km) or even the mesosphere, as well as condensation trails from aircraft, etc.

4.6. Precipitation

Precipitation encompasses all forms of condensed and sublimated water vapor in the air that appears on the Earth's surface in liquid or solid form. Precipitation results from previously defined processes of condensation, sublimation, and cloud system formation. Precipitation is classified based on its genesis into:

- Frontal (lifting of warm air over cold air at fronts). This type of precipitation is typical for autumn and winter.
- Orographic (lifting of air masses due to overcoming orographic obstacles – mountain ranges).
- Convective (vertical lifting of air masses heated by contact with a warm surface).
- Based on the location and type of precipitation, it is divided into:
- High or Cloud-Based Precipitation occurs within cloud systems. The most well-known types of cloud-based precipitation include rain, snow, and hail.
- Low or Surface Precipitation, which forms directly on the Earth's surface. This includes dew, frost, rime, and ice.

4.7. Air Pressure

Air/atmospheric pressure is the force exerted on a unit of horizontal surface area equal to the weight of the column of air extending from the ground to the upper boundary of the atmosphere. Air molecules press down on the Earth's surface due to their weight. It is most commonly measured with a mercury barometer, where the height of the mercury column is balanced by the weight of the air column and is expressed in millimeters (mm) or millibars (mb). The horizontal surface for measuring air pressure is 1 cm^2. Standard (normal) pressure is conditionally balanced with the weight of a mercury column 760 mm high, with a cross-section of 1 cm^2 at 0°C and 45°N latitude, which corresponds to 1013.27 mb. As altitude increases, air pressure decreases, and this decrease is faster in lower layers compared to higher layers. The vertical distance over which the air pressure changes by 1 mb is called the barometric step. Besides changes in air pressure due to altitude variations, air pressure is also influenced by air density, which is directly related to air temperatures. Any change in air temperature leads to changes in atmospheric pressure. In meteorology (especially synoptic meteorology), air pressure is one of the most important physical quantities in the atmosphere, as weather conditions are directly related to this meteorological element. The atmospheric pressure at the Earth's surface over a horizontal area and its changes over time are referred to as the barometric field (Spahić, M., 2002). The distribution of air pressure in the lower layers of the troposphere, shown by isobars (lines connecting points of equal barometric pressure), is called barometric relief. Based on the position and inclination of isobars, areas of high and low air pressure are observed (Šegota, T., Filipčić, A., 1996). Areas of low pressure – barometric minimums (depressions) and areas of high air pressure – barometric maximums are regions where anticyclones and cyclones form. In the process of balancing air pressure, circulation processes in the atmosphere are formed.

4.8. Dynamic Processes in the Atmosphere

Differences in thermal and barometric properties of air masses influence dynamic processes in the atmosphere. Air moves from areas of higher to lower air pressure. Air flows along isobaric surfaces and can move down inclined planes as well as vertically. The main types of air movement are:

- Horizontal (advection/horizontal movement of air masses from areas of higher to lower air pressure),
- Vertical (convective air currents occurring in unstable atmospheres with a vertical thermal gradient greater than the adiabatic gradient),
- Oblique Air Currents (ascending and descending air currents resulting from forced lifting or sinking of air masses over physical obstacles).
- The movement or flow of air primarily in a horizontal direction is called wind. The basic properties of wind are direction, speed, and strength. Basic wind classification includes:
- Permanent or Planetary Air Circulation (jet streams, trade winds, westerlies, polar winds);
- Periodic Air Circulation (daily air circulation, valley winds, mountain winds, Föhn, Sirocco, Bora).

5. WEATHER EXTREMES

Weather extremes are sudden deteriorations in weather over a limited area and duration. They vary in their time of occurrence, duration, and spatial extent. Weather extremes can be categorized into:

- Thermal Extremes (thermal convection due to uneven heating of a heterogeneous surface, affecting horizontal and vertical thermal gradients – very rapid turbulence of air masses, condensation and sublimation, and significant precipitation),
- Frontal Extremes (the meeting of warm and cold air fronts, sudden expansion of moist air, condensation, and sublimation – associated phenomena include wind, heavy showers, hail, and dense snow in winter),
- Orographic Extremes (forced lifting of air over mountain ranges).
- Accompanying phenomena of the aforementioned processes include thunderstorms and wind events (tornadoes, whirlwinds).

6. CLIMATE – CLIMATE TYPES

The heterogeneity of Earth's surface and the extremely complex general atmospheric circulation are the main reasons for the significant differences in climates across various parts of the world. This situation is so pronounced that, theoretically, it can be said that "almost every square kilometer of Earth's surface has its own climate" (Šegota, T., Filipčić, A., 1996). Because of this, efforts have been made since ancient times to group a larger number of smaller (local) climates into a higher-ranked climate with precisely defined basic climatic parameters. These attempts have faced many difficulties, which is why a single unified criterion for classifying global climates has not yet been established. The simplest but also the least successful attempts are those based on the analysis of only one climatic parameter. On the other hand, the ideal classification would include all climatic elements, considering both average monthly and annual values, which is practically unfeasible. Essentially, most of today's classifications are based on the analysis of only a few main climatic elements. It is estimated that over 75 different classifications have been made to date, with varying degrees of success, based on various criteria (Drešković, N., 2011).

6.1. W. Köppen's Climate Classification

To date, it can be said that the best and most successful climate classification was established by German climatologist Wladimir Köppen in 1918. This classification is based on statistical analysis of thermal and precipitation indicators of average monthly and annual air temperatures and precipitation heights. W. Köppen determined that, in lower latitudes, the average monthly temperature of the coldest month is important, while in higher latitudes, the average monthly temperature of the warmest month is crucial. Additionally, vegetation as a natural climate indicator played a significant role in determining the boundaries of various climate types (Drešković, N., 2011).

Based on the analysis of these parameters, W. Köppen divided the world's climate into five climate classes marked by uppercase Latin letters:

A. Tropical Rainy Climates
B. Dry Climates
C. Temperate Rainy Climates
D. Snowy Forest (or Boreal) Climates
E. Snowy (or Polar) Climates

Further differentiation of these climate classes into main climate types is carried out based on the average annual and monthly temperatures of the warmest and coldest months, as well as annual and seasonal precipitation heights, by adding a second letter to the climate class index. In climate A, letters indicating specific characteristics of the annual precipitation regime are added:

f - No dry period; the driest month has precipitation greater than 60 mm.
s - Dry period is in summer.
w - Dry period is in winter; the driest month has precipitation greater than or equal to 60 mm.

Climate B is further subdivided by adding one uppercase letter indicating the average annual or average temperature of extreme months, distinguishing:

W - Desert climate,
S - Steppe climate.

Climates C and D are further divided based on precipitation regime characteristics by adding the following letters:

f - Precipitation is generally evenly distributed throughout the year; no dry period.
w- Dry period is in winter, and the driest month has 1/10 of the precipitation of the wettest month.
s - Dry period is in summer, and the driest month has less than 40 mm of precipitation and less than 1/3 of the precipitation of the wettest month.

In BW and BS climates, additional differentiation into climate subtypes is based on the annual temperature regime by adding the following letters:

h - Warm, with an average annual temperature greater than 18.0 °C.
k - Cold, with an average annual temperature less than or equal to 18.0 °C, but the average monthly temperature of the warmest month is greater than 18.0 °C.
k' - Cold, with an average annual temperature less than or equal to 18.0 °C, and the average monthly temperature of the warmest month is less than 18.0 °C.

Climate classes C and D are further differentiated at the third level based on the temperature regime of extreme months by adding the following letters:

a - Hot summer, with an average monthly temperature of the warmest month greater than 22.0 °C.
b - Warm summer, with an average monthly temperature of the warmest month between 18.0 °C and 22.0 °C.
c - Cool summer, with one to four months having an average monthly temperature of the warmest month greater than 10.0 °C.
In climate class E, additional differentiation at the third level includes:
d - Very cold winter, where the average monthly temperature of the coldest month ranges between -38.0 °C and -3.0 °C.

In E climates, there are two degrees of coldness:

ET - Tundra climate; average temperature of the warmest month between 0 °C and 10 °C.
EF - Ice cap climate; average temperatures below 0 °C.

Using this climate differentiation scheme, Wladimir Köppen identified 11 main climate types on Earth:

1. Af - Tropical Rainforest Climate
2. Aw - Savanna Climate
3. BW - Desert Climates
4. BS - Steppe Climates

5. Cf - Temperate Warm and Humid Climates
6. Cs - Mediterranean Climates
7. Cw - Subtropical Climates
8. Df - Humid Boreal Climates
9. Dw - Dry Boreal Climates
10. ET - Tundra Climate
11. EF - Ice Cap Climate

Further differentiation, which highlights specifics in the annual cycle of basic and other climatic elements, allows for the differentiation of climates into variants of climate subtypes (Drešković, N., 2011).

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Climate Change, Causes, Consequences, Future Projections Of Climate Change

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Abstract: To understand climate change and its effects, it is essential to grasp the Earth's climate system as well as the climatic phenomena and processes occurring in the atmosphere. In order to better understand these processes, definitions of the atmosphere, its chemical composition, and the vertical structure of the atmosphere have been established. Additionally, the difference between the basic concepts of weather and climate has been clarified, and quantitative and qualitative indicators of the spatial-temporal dynamics of key meteorological elements and phenomena in the atmosphere have been defined. The main modifiers of meteorological elements and phenomena related to the distribution of land and sea, relief characteristics, geographic latitude, etc., are also presented. Furthermore, a brief overview of meteorological instrumental monitoring is provided, focusing on the historical work of meteorological stations in Bosnia and Herzegovina. Based on measured climatological elements, climatic types are defined, with a detailed review of W. Köppen's climate classification.

Keywords: atmosphere, climate, weather, climatic elements, climatic factors, meteorological measurements, climate types

1. CLIMATE CHANGES

The Earth's climate has changed since the planet's formation about 4.5 billion years ago. During this time, the climate has oscillated between warm periods and ice ages. Such cycles have always lasted tens of thousands or even millions of years, but in the last 150 years (since industrialization), temperatures have been rising faster than ever before.

The Intergovernmental Panel on Climate Change (hereinafter: IPCC) defines climate change as "any change in climate over time, whether due to natural changes or as a result of human activities" (United Nations Framework Convention on Climate Change, hereinafter: UNFCCC). The United Nations defines climate change as long-term changes in temperatures and weather patterns. They also emphasize that such shifts can occur naturally due to factors like changes in solar activity or large volcanic eruptions, but human activities since the 1800s have been the primary drivers of climate change, primarily due to the burning of fossil fuels.

1.1. Factors Influencing Climate Change

According to the definition of climate change, the influencing factors can be divided into two groups:

- **Natural Factors** (e.g., periodic and secular perturbations – Earth's orbit around the Sun, Earth's movements relative to the Sun, large amounts of aerosols released by volcanic eruptions, wildfires, etc.).
- **Anthropogenic Factors** (e.g., the burning of fossil fuels, changes in land types – urbanization, deforestation, and agricultural development).

The Sun is the primary source of heat on Earth. Solar radiation changes slightly over longer periods due to natural astronomical causes. The Earth orbits the Sun once in a period of a year along an elliptical path, meaning the Earth is not always at the same distance from the Sun. Over a single day, the Earth also rotates on its axis. The Earth's axis has a certain tilt relative to the plane of the ecliptic, and this angle periodically changes, while the axis itself also undergoes slow rotational movement (precession) (Popović, D., Vuković, A., 2019).

Astronomical factors are linked to Milankovitch cycles (natural climate changes caused by the Earth's orbital cycles), which result in significant climate variations. These natural changes take place over tens of thousands of years.

As a result of these processes, in geological history, there have been ice ages and warming periods (glacials and interglacials). The evidence for past climate changes comes from:

- Fossil research,
- Geological studies,
- Geomorphological studies – landforms,
- Dendroclimatological research,
- Research and analysis of pollen to determine past vegetation, which is directly related to climate and climate changes,
- Monitoring, archiving, and analyzing meteorological data during instrumental meteorological monitoring and establishing a network of meteorological stations.

The oldest traces of glaciation are from the Lower Algonquian period (750 million years ago), the Lower Cambrian (550 million years ago), the Upper Cambrian (500 million years ago), and the Permian (260 million years ago). The last glaciation occurred during the Pleistocene (600,000–700,000 years ago), with the maximum of the last glacial period occurring 50,000 years ago. During the last ice age in the Pleistocene, cold glacial periods alternated with warmer interglacial periods. In the Alpine region, four glaciations were identified: Günz, Mindel, Riss, and Würm (Petrović, D., 1982).

The natural concentration of gases in the atmosphere, as well as the distribution of land and sea, are also natural factors that influence atmospheric circulation and climate change. Volcanic eruptions can affect the climate, especially strong eruptions that release large amounts of solid particles (aerosols), gases, and water vapor into the upper atmosphere. Aerosols reflect short-wave solar radiation back into space, thereby causing local cooling in certain areas (Popović, D., Vuković, A., 2019). However, the effects of volcanic eruptions are not long-lasting because atmospheric currents disperse aerosols, diminishing their impact over time.

Geological processes that reshape ocean basins and continental areas also influence climate changes, affecting ocean currents and cold-water flows. In addition to global processes of climate change, statistical climate analyses suggest the existence of internal (regional) climate cycles on Earth, such as El Niño, Pacific Decadal Oscillation, and North Atlantic Oscillation.

Human impact on the climate manifests through various activities. This includes deforestation, the increase in cultivated and urbanized areas, and the consumption of fossil fuels (in energy production, transportation, agriculture, etc.). These activities contribute to increased concentrations of carbon dioxide (CO_2) and other gases in the atmosphere, thus intensifying the greenhouse effect and, as a result, global warming.

The temperature rise since the 1970s has been particularly pronounced in the Northern Hemisphere, corresponding with increased carbon dioxide concentrations, the most important greenhouse gas. IPCC attributes this rise in CO_2 with high confidence to human activity.

In light of these observations, it can be concluded that the Earth's climate has always changed and will continue to do so. In the past, it was subject to natural influences alone, but in the last 100 years, the climate has been changing much faster, primarily due to anthropogenic factors. The climate changes we discuss today refer mainly to the negative consequences of humanity's impact on the factors of the climate system.

1.2. Causes of Increased Greenhouse Gas Emissions in the Atmosphere – The Greenhouse Effect

The primary cause of climate change (aside from natural factors) is the burning of fossil fuels such as oil, coal, and natural gas, which releases greenhouse gases into the atmosphere. Other human activities, such as agriculture and deforestation, also contribute to the increase in greenhouse gas concentrations. The problem is that these gases trap heat in the atmosphere, a phenomenon known as the greenhouse effect. Certain gases in the atmosphere increase the greenhouse effect, i.e., they represent a diathermic environment for short-wave solar radiation but an adiathermic environment (absorb) for long-wave radiation of the Earth, thus contributing to an increase in the temperature of the ground air layers. Among the most important gases that naturally occur in the atmosphere and absorb Earth's longwave radiation, referred to as greenhouse gases, are water vapor and carbon dioxide (CO_2), followed by methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Without the greenhouse effect, the planet's average temperature would be -18°C. Due to the aforementioned everyday human activities, this effect has been maximized, leading to a further increase in our planet's temperature.

Despite international obligations, the amount of carbon dioxide (CO_2) in the atmosphere continues to rise and, according to the World Meteorological Organization, reached another record in 2019 (nearly 150% higher than in 1750). The causes contributing to the greenhouse effect and, consequently, to climate change are:

- Burning coal, oil, and gas produces carbon dioxide and nitrogen oxides.
- Deforestation, for the economic exploitation of forest resources as an energy source and for creating new agricultural and urban areas. Forests help regulate the climate by absorbing CO_2 from the atmosphere. When trees are cut down, this beneficial effect is lost, and the carbon stored in the trees is released into the atmosphere, contributing to the greenhouse effect.
- The increase in livestock farming is a significant factor affecting climate change. Cows and sheep produce large amounts of methane as they digest food.
- The use of nitrogen-based synthetic fertilizers produces nitrous oxide emissions.
- Fluorinated gases emitted from equipment and products that use these gases. These emissions have a very strong warming effect, up to 23,000 times greater than CO_2.

2.3. Key Effects of Climate Change

The main consequence of climate change is the increase in the global temperature of the planet Earth. According to meteorological measurements, the temperature has increased by 1.1°C compared to the pre-industrial period.

If the current warming trend continues, temperatures could rise by 3-5°C by the end of this century, which could have catastrophic consequences for natural and societal processes on Earth. For comparison, it is significant to note that in the last 10,000 years, the temperature has risen by a total of 5°C, and this increase, according to recent temperature changes, could occur in a much shorter time (with varying periods depending on different climate scenarios).

The global average temperature between 2013 and 2023 was 1.19 to 1.22°C warmer than pre-industrial levels, making it the warmest decade in history. There are regional variations in temperature increases. For instance, temperatures in Europe have risen even faster during this period, by 2.12 to 2.19°C. UNFCCC member countries have committed to limiting the global temperature increase to well below 2°C above pre-industrial levels, aiming to limit the increase to 1.5°C. Climate change scenarios suggest that without drastic reductions in global greenhouse gas emissions, the 2°C threshold will be surpassed before 2050. The conclusions of the IPCC warn that global warming of 1.5°C will have serious, even irreversible, consequences for our environment and entire societies.

2. CLIMATE MODELLING

Scientific research plays a crucial role in climate change modeling. By observing and analyzing climate data, we can derive relevant current climate indicators and reconstruct the values of past climate indicators. Observations and measurements also allow us to determine how much greenhouse gases (that contribute to the greenhouse effect) we are currently adding to the atmosphere and what their historical levels were, as well as their correlation with Earth's climate and climate change. If we want to project the future state of climate elements based on past and present data, climate modeling is necessary (Popović, D., Vuković, A., 2019).

Climate modeling is used to estimate future climate changes based on various emission scenarios and socio-economic pathways that underpin these scenarios (Shared Socio-economic Pathways, hereinafter: SSP). Five socio-economic trends and greenhouse gas concentration pathways are used in climate change assessments:

- SSP1 – a sustainability-focused, equity-oriented pathway;
- SSP2 – a middle-of-the-road scenario, following mostly historical trends;
- SSP3 – a fragmented world with growing nationalism;
- SSP4 – increasing inequality;
- SSP5 – a scenario of rapid and unrestricted economic growth and energy use.

Each of these trends is assigned projected greenhouse gas concentrations in the atmosphere, spanning a range of radiation by the year 2100 (1.9, 2.6, 4.5, 6, 7, and 8.5 W/m²).

Table 1. Climate change scenario

	Near term, 2021–2040		**Mid-term, 2041–2060**		**Long term, 2081–2100**	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

Source: IPCC, 2021

Without significant efforts to reduce greenhouse gas emissions, the rise in global temperatures will continue rapidly, even accelerating compared to the previous period.

It is projected that global temperatures will rise by 2.1 to 3.5°C above pre-industrial levels under the SSP2-4.5 scenario, while the SSP5-8.5 scenario predicts a temperature increase of 3.3 to 5.7°C by the end of the 21st century. The only scenarios with a chance of remaining within the limits set by the Paris Agreement are SSP1-1.9, with projected warming of 1.0

to 1.8°C and SSP1-2.6, with temperature ranges between 1.3 and 2.4°C by the end of the 21st century, compared to pre-industrial levels. These scenarios assume drastic emission reductions in the coming decades and CO2 emissions reaching net zero and subsequently negative net emissions around 2050 (SSP1-1.9) or around 2080 (SSP1-2.6).

As in the previous period, the European continent is warming faster than the global average. The average annual temperature over European land areas in the last decade was 2.12 to 2.19°C warmer than in the pre-industrial period. The year 2023 was the second warmest in Europe since instrumental monitoring began. The hottest recorded year in Europe was 2020, with temperature ranges between 2.53°C and 2.71°C compared to pre-industrial levels. Particularly high warming has been observed in Eastern Europe and Scandinavia.

Projections indicate that temperatures across European land areas will continue to rise throughout this century at a rate higher than the global average. It is predicted that temperatures in Europe will increase by 1.2 to 3.4°C under the SSP1-2.6 scenario and by 4.1 to 8.5°C under the SSP5-8.5 scenario (for the period 2071-2100, compared to 1981-2010) (EEA, 2024).

The highest levels of warming are expected in northeastern Europe, northern Scandinavia, and the interior Mediterranean countries. The least warming is expected in Western Europe, particularly in the United Kingdom, Ireland, western France, the Benelux countries, and Denmark.

Research shows a linear relationship between cumulative CO2 emissions and global surface temperature increases, resulting from human activities affecting all major components of the climate system.

3. CONSEQUENCES OF CLIMATE CHANGE

The consequences of climate change are felt across all parts of the world, causing numerous changes in both nature and society. The effects of climate change are already being felt globally and are expected to become even more frequent and intense in the coming decades. Climate change will significantly transform our planet and impact food and water supplies, as well as human health. Climate change affects all regions worldwide. Polar ice sheets are melting, and sea levels are rising. In some regions, extreme weather events and precipitation are becoming more frequent, while in others, extreme heatwaves and droughts are occurring more often.

Climate change is a very serious threat, and its consequences have many different effects on changes in nature and society. The most significant impacts of climate change include increased mortality rates due to changes in ozone concentration, biodiversity loss, the emergence of infectious diseases, reduced food availability, deteriorating societal well-being, and the threat or complete disappearance of certain coastal areas (Popović, D., Vuković, A., 2019). According to the European Commission, the impacts and consequences of climate change are categorized as impacts on nature, societal threats, business threats, and regional threats.

The consequences of climate change on nature include temperature changes, impacts on forests and the increased occurrence of wildfires, freshwater availability, more intense flooding, rising sea levels, the destruction or complete loss of certain coastal areas, changes in biodiversity, intensifying negative effects on soil (such as erosion and landslides), and the availability and endangerment of terrestrial and marine water resources.

The consequences of climate change as societal threats primarily relate to impacts on human health, particularly the most vulnerable population groups (the elderly, low-income populations, and those with little property are more exposed to climate impacts and migration). Additionally, climate change will have significant effects on employment—rising temperatures, changes in precipitation patterns, and rising sea levels will directly or indirectly affect the productivity and sustainability of all economic sectors, as well as education, where education and information are important components of climate change adaptation.

The consequences of climate change on business threats refer to impacts on infrastructure and buildings, energy, agriculture, forestry, tourism, and certain cross-sectoral issues.

As already emphasized, climate change has various impacts when observed across different regions, such as:

- The Arctic is notable for temperature increases, the reduction of summer sea ice extent, and the thawing of permafrost.
- Northern Europe is characterized by reduced snow cover, decreasing ice on lakes and rivers, and increased winter and spring river flows.
- Northwestern Europe experiences increased flooding in volume and frequency.
- Central and Eastern Europe face high temperatures and droughts.
- The Mediterranean region deals with decreasing rainfall, temperature rises, and wildfires.
- Cities and urban areas are marked by high temperatures, pollution, and flooding.
- Mountain areas are distinguished by rising temperatures and fewer days with snow.

4. ENVIRONMENTAL PROTECTION POLICY IN THE CONTEXT OF CLIMATE CHANGE MITIGATION

In light of the aforementioned facts about climate change and future scenarios, environmental protection policies have been shaped to mitigate climate change. At the international level, several agreements impose obligations to reduce greenhouse gases and implement climate adaptation measures:

- The UNFCCC aims to stabilize greenhouse gas concentrations in the atmosphere and reduce human impacts on climate change.
- The Kyoto Protocol to the UNFCCC is an international agreement to reduce carbon dioxide and other greenhouse gas emissions.
- The Paris Agreement, an addition to the UNFCCC, aims to limit global temperature rise to less than 2°C. It also seeks to ensure food supply, strengthen countries' capacities to deal with the effects of climate change, develop new "green" technologies, and help economically weaker nations achieve their national emission reduction plans. The Paris Agreement is the most important international accord providing guidelines for adaptation. The Presidency of Bosnia and Herzegovina adopted the decision to accept the Paris Agreement under the UNFCCC, with the signing ceremony held in New York on April 22, 2016.
- The 2030 UN Agenda – Sustainable Development Goal 13 focuses on urgent action to

combat climate change.

At the international level, in 1988, the IPCC was established with the aim of creating its own reports based on scientific research on climate change. The reports serve to help decision-makers draft policy proposals based on scientific research on climate change, its implications for natural and social systems, and potential future risks in order to adapt and mitigate climate change.

In line with the UNFCCC, Bosnia and Herzegovina has submitted four national reports (the most recent in October 2022). Additionally, a Strategy for Climate Change Adaptation and Low-Emission Development for 2020-2030 has been developed.

Alongside global and national levels, certain regional policies and plans to combat and adapt to climate change are also being established. For instance, the European Commission presented the European Green Deal in 2019 (COM/2019/640 final), underlining its commitment to addressing climate challenges and preserving nature. The Green Deal is part of the EU's strategy to implement the Sustainable Development Goals set by the UN through the Framework Convention on Climate Change and Agenda 30.

Key Goals of the European Green Deal:

- Reduce greenhouse gas emissions: 4The aim is to achieve zero emissions by 2050 and protect the EU's natural capital, along with citizens' health and well-being. The goal is to reduce greenhouse gas emissions by 55% by 2030 compared to 1990 levels and to make Europe climate-neutral by 2050.
- Renewable energy: Increase the share of renewable energy consumption to 32% by 2030 and ensure full climate neutrality in the energy sector by 2050.
- Green infrastructure: Increase green spaces and protect natural habitats to preserve biodiversity and improve environmental quality.
- Green mobility: Reduce emissions from transport, especially road transport, and promote cleaner and more sustainable modes of transportation such as cycling, walking, public transport, and electric vehicles.
- Circular economy: Promote sustainable resource use, reduce waste, and establish a circular economy that recycles and reuses products and materials as much as possible.
- Green Industry: Encourage the development of sustainable industries that use clean technologies and have a smaller impact on nature and the environment.
- Sustainable agriculture, fisheries, and forest management: Achieve sustainable agriculture and fisheries that are less harmful to the environment, have a smaller impact on climate, and promote biodiversity.
- Pollution reduction: Reduce air, water, and soil pollution to improve environmental quality and protect human and animal health.

Scientific research plays a significant role in fighting and adapting to climate change. In Bosnia and Herzegovina, the HORIZON project STECCI (Stone Monument Ensembles and the Climate Change Impact), funded by the European Union and coordinated by the University of Sarajevo's Faculty of Natural Sciences, is notable. STECCI is a multidisciplinary project that combines expertise from conservation, cultural heritage science, climatology, and other natural, social, and humanistic sciences, as well as creative industries, to address the challenges of climate change's impact on cultural heritage.

The main goal of the STECCI project is to create innovative and sustainable strategies for protecting sacred cultural and historical heritage (specifically stone structures) from the impacts of climate change and consequent natural disasters, environmental pollution, and anthropogenic threats.

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The Impact of Polluted Air and Climate Changes on Cardiovascular Health

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Abstract: Climate change is one of the most significant existential challenges facing planet Earth and human civilization. The main cause of climate changes is the burning of fossil fuels to produce energy. The effects of climate change are already being felt around the world, and are predicted to become even more frequent and intense in the coming decades. Air pollution is the largest single risk factor for environmental health in the world and the main contributor to the global burden of disease, it is not new, but it is a neglected cardiovascular risk factor. There is sample evidence of chronic and acute cardiovascular damage caused by air pollution. Pollution can exacerbate already existing health problems. Most pollutants lead to health consequences on the respiratory system, occurrence and intensification of obstructive diseases, as well as on cardiovascular system in terms of increased blood pressure, arrhythmias, anginal pains, which can result in ischemic heart diseases: myocardial infarctions and cerebrovascular insults. Among metabolic diseases, as a consequence of air pollution, diabetes mellitus is the most common. Polluted air can significantly affect children's health; such as pneumonia, bronchitis and asthma. Chronic exposure to high concentrations of suspended particles PM2.5 is related to: a higher rate of miscarriage, premature births, lower birth weight of the child, as well as some congenital heart anomalies. Preventing air pollution-related cardiovascular disease through a large-scale transition from fossil fuels to clean, renewable energy will not only reduce cardiovascular disease and related deaths, but will also slow the pace of climate change and thus benefit all of humanity.

Keywords: polluted air, climate changes,cardiovascular health

HEALTH

Health is a state of good physical, mental and social well-being. Health is most often defined as the absence of disease. Some of the conditions of health are: a balanced diet, physical activity and hygiene. Health is the level of functional and metabolic efficiency of a living organism. The World Health Organization defines health in humans as ”a state of complete physical, mental and social well-being that does not consist only of the absence of disease” and in recent years the definition has been expanded to include the ability to lead a “socially and economically productive life”. Center for Disease Control defines five determinants of health:1. Biological factors and genetics; 2. Behavior of the individuals; 3. Social environment; 4. Physical environment; 5. Health system

Air pollution occurs when concentrations of certain harmful substances (pollutants) reach a level that causes its toxicity. Air pollution is particularly present in industrial zones and urban settlements as a result of the emission of harmful substances from industrial plants. Only by continuously monitoring of the state of atmospheric pollution the knowledge to what extent the concentration of certain pollutants in the environment, in which people live and work, affects health. Most pollutants lead to health consequences on the respiratory system, occurrence and intensification of obstructive diseases, as well as on cardiovascular system in terms of increased blood pressure, arrhythmias, anginal pains, which can result in ischemic heart diseases. On days of high air pollution, myocardial infarctions and cerebrovascular insults are more frequent. Among metabolic diseases, as a consequence of air pollution, diabetes mellitus is the most common. Polluted air can significantly affect **children’s health**. Studies have shown that air pollution is strongly associated with respiratory diseases such as pneumonia, bronchitis and asthma. Pollution can exacerbate already existing health problems. Increased concentration of suspended particles increases the risk of acute respiratory infections, malignant diseases, especially in children. Studies have shown that chronic exposure to high concentrations of suspended particles PM2.5 is related to: a higher rate of miscarriage, premature births, lower birth weight of the child, as well as some congenital heart anomalies /CHD/. Recognizing air pollution as a major cardiovascular risk factor that is often neglected in clinical practice opens multiple possibilities for prevention and control. Preventing air pollution-related cardiovascular disease through a large-scale transition from fossil fuels to clean, renewable energy will not only reduce cardiovascular disease and related deaths, but will also slow the pace of climate change and thus benefit all of humanity.

CLIMATE CHANGE

Climate change is one of the most significant existential challenges facing planet Earth and human civilization. They are dictated by changes in the Earth’s weather and air conditions due to anthropogenic activities. Climate change is caused by global warming and refers to long-term weather conditions on Earth: temperature, sea levels and precipitation. The climate on Earth has changed drastically since planet Earth was created 4.5 billion years ago. It oscillated between warm periods and ice ages. Such cycles have always lasted tens of thousands or even millions of years. In the last 150 years (industrial age), temperatures are rising faster than ever. Climate change has not only resulted in extreme temperatures, but also increased frequency of droughts, forest fires, sandstorms, coastal flooding, storm surges and hurricanes. Deterioration in air quality due to increased pollutants can exacerbate extreme fluctuations in temperature levels, and these changes can lead to further deterioration in air quality. Climate change disrupts meteorological and atmospheric conditions, including temperature, precipitation, humidity, wind speed, pressure levels, and water vapor. These weather conditions can increase the levels of particulate matter (PM) and ground-level ozone (O_3), a phenomenon known as the "*weather or climate penalty*". Higher air temperatures contribute to increased levels of ozone precursors and accelerate the chemical formation of ozone. Changing wind patterns, reduced precipitation, and reduced humidity levels can lead to periods of air stagnation, which can promote O_3 accumulation. Rising temperatures increase the oxidizing potential of atmospheric components to produce more sulfate particles, but may also reduce nitrate particle levels by increasing particulate matter volatility. Forest fires, now more frequent due to climate change, are also increasing creation of O_3 and PM2.5.During the last decades, "*weather penalties*" due to increased levels of O_3 and PM, have been responsible for thousands of deaths;elevated levels of O_3 and PM2.5 responsible for 20,000 deaths between 1994 and 2012 in the US, and high levels of PM10 led to more than 3,200 deaths between 1993 and 2017 in Spain.

CAUSES OF CLIMATE CHANGES

The main cause of climate changes is the burning of **fossil fuels** to produce energy. Fossil fuels are fuels that contain hydrocarbons and were created from the fossilized remains of plants and animals.They are currently the main source of energy on Earth. Energy from fossil fuels is usually released through combustion, and during this combustion, toxic and harmful gases are released that affect the environment, such as: carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen dioxide, etc. These gases have a harmful effect on the environment, accumulating in the atmosphere and thus creating a "*greenhouse effect*", while in contact with water in the atmosphere they turn into acid that falls on the ground - the so-called: "*acid rain*" that destroys plants and corrodes buildings, rocks. *Major fossil fuels include*; peat; coal (lignite, brown coal, hard coal) and natural gas, as a result of which greenhouse gases are released into the Earth's atmosphere, which remain in the Earth's atmosphere together with gases that are naturally present in it. Carbon dioxide (CO2) is a greenhouse gas that is mostly caused by human activity. Additional gases intensify the "*greenhouse effect*" on our planet's atmosphere and thus *cause a rapid increase in the Earth's temperature, which leads to major climate changes*. Fossil fuels or mineral fuels are fuels that are produced from natural sources such as the anaerobic decomposition of buried dead organisms that contain organic molecules produced by photosynthesis. Converting these materials into high-carbon fossil fuels typically requires millions of years of geological processes. Organisms and the fossil fuels produced from them are approximately millions of years old , and sometimes more than 650 million years. Fossil fuels can be burned to obtain heat for direct use (cooking or heating), to drive engines (internal combustion engines in motor vehicles) or to produce electricity. Before burning, some fossil fuels are refined into derivatives such as kerosene, gasoline and propane. During the last century, anthropogenic activities, especially the burning of fossil fuels, resulted in the release of excessive amounts of carbon dioxide and other greenhouse gases, which trap heat in the lower layers of the atmosphere and *cause global warming. The primary constituents of greenhouse gases* include CO_2, methane (CH_4), nitric oxide, fluorinated gases, and ground-level ozone (O_3). Greenhouse gases absorb and emit radiant energy, and the excessive release of greenhouse gases has contributed to droughts, the melting and retreat of glaciers and sea ice, which have further increased the Earth's temperature due to the loss of snow that reflects sunlight. Each of the past four decades has been consecutively warmer than any previous decade since 1850. Environmental stress is the sine qua non of climate change. *Direct exposure to extreme weather, ambient temperatures, heat waves, cold spells*, and a wide range of pollutants has the potential to worsen disease in individuals with underlying cardiovascular conditions and contribute to the development of disease in individuals without known CVD. *Indirect effects of climate change* on the cardiovascular system include multiple complex pathways of exposure through access to *healthy food and clean water, transportation, housing, electricity, communication systems, medical care, and other social determinants of health*. Other human activities, such as agriculture and deforestation, also contribute to the increase in greenhouse gases. **Without the greenhouse effect**, the average temperature of the planet would be -18 °C, but due to daily human activities, this effect has increased to the maximum, which has led to an even greater increase in the temperature of the planet. Despite international obligations, the level of carbon dioxide in the atmosphere continues to rise and, according to data from the World Meteorological Organization, reached another record in 2019 (150% higher than in 1750). The planet has already warmed by more than 1 °C compared to pre-industrial temperatures. Scientists of the Intergovernmental Panel on Climate Change (IPCC) have warned that global warming of 1.5 °C will have serious and even irreversible consequences on our environment and societies.

Consequences of climate changes The main consequence of climate changes is *an increase in the global temperature of the planet.* If the current warming trend continues, temperatures could rise by 3-5 °C by the end of this century, which could have catastrophic consequences. In the last 10,000 years, the temperature has increased by a total of 5 °C. *The increase in temperature affects the melting of the ice mass at the poles*, which causes the sea level to rise, leads to floods and endangers coastal areas. There are large *regional differences* in climatic conditions, and some parts of the world are more severely affected. Health is at risk, as is the security of food supply, especially in Africa and Asia, the continents with the largest number of young people. As stated in the United Nations Environment Program (UNEP), global warming of 2 °C would put more than half of Africa's population at risk of malnutrition. The World Health Organization has warned that rising incidences of *malaria*, water-borne diseases and malnutrition could threaten the health of millions of people. This will also affect the migration of people, along with the expected increase in the number of climate refugees.

Stopping climate changes Although climate changes cannot be reversed, its effects can be mitigated and we can adapt to them. *Mitigation measures* aim to reduce greenhouse gas emissions into the atmosphere, for example: the development of clean energy and the increase of forest areas. Drastic changes are needed in key areas such as: traffic, energy, industry, housing, waste management and agriculture. *Adapting to climate changes* means preparing for its consequences and increasing the resilience of society, for example, using scarce water resources more efficiently, adapting agricultural and forestry practices, ensuring that buildings and infrastructure can withstand future climates and extreme weather conditions. Climate change often severely affects vulnerable areas and vulnerable population groups. The fight against climate change is also aimed at helping the most vulnerable and making progress on other global challenges such as *the fight against poverty, inequality and environmental destruction.*

International organizations, civil society and an increasing number of young people are advocating for global action in the fight against climate change. With the European Green Plan from December 2019, climate change was given an important place in the political program of *the European Union /EU/*. *A plan to further reduce emissions* by at least 55% by 2030 was also presented. *The main goal of the European Green Plan is for Europe to become the first climate-neutral continent by 2050, while at the same time ensuring a fair, healthy* *and prosperous society for future generations.* The EU helps to increase preparedness and capacity to respond to the effects of climate change at the national, regional and local levels, cooperates with other countries and regions to advance measures in the field of climate at the global level and provides support to the work of partner countries, especially the most sensitive ones. The EU also strives to ensure that the recovery from the coronavirus pandemic is linked to the transition to a greener, more digital and more resilient Europe.

Effects of climate change The effects of climate change are already being felt around the world, and are predicted to become even more frequent and intense in the coming decades. If climate change is not stopped, there could be: 400,000 premature deaths due to air pollution, 90,000 deaths per year due to heat waves, a reduction in the amount of available water by 40% in the southern regions of the EU, exposure of 2.2 million people to coastal flooding every year, annual economic losses of EUR 190 billion. Climate change can transform our planet as well as affect food and water supplies, and health. They affect us all, *but they hit the poor and vulnerable members of society harder*. The bigger the problems, the more difficult and expensive they are to solve, so early response and tackling climate change is the best option.

Benefits of climate policies *The transition to a climate-neutral society* is a burning issue and an opportunity to build a better future for all. Taking measures for the climate and the environment can help preserve and protect the planet today and for future generations. Some of *the benefits for society*: new, green jobs, greater competitiveness, economic growth, cleaner air and more efficient public transport in cities, new technologies such as electric or plug-in hybrid cars, energy-efficient homes or buildings with smart heating and cooling systems, secure supply energy and other resources, thanks to which Europe will be less dependent on imports. Studies show that the transition to a green and digital society is feasible and affordable. The costs caused by climate change in the economy and society will be much higher than the costs of fighting climate change today.

Cardiovascular diseases Cardiovascular diseases (CVD) are a large and complex group of diseases of the heart and/or blood vessels (veins and arteries), including disorders of the heart. These are the most common **non-communicable diseases** (NCD, Non - Communicable Disease - also known as chronic diseases) in the world, responsible for almost 20.5 million deaths, more than 3/4 of which occur in *low- and middle-income countries*. Great progress has been made in reducing the incidence of cardiovascular disease and related mortality in *high-income countries*. *The UN's sustainable development goals* are to reduce *premature mortality* from non-communicable diseases by a third by 2030. Despite improvements in primary and secondary prevention, cardiovascular disease remains the leading cause of death worldwide. The human heart is only the size of a fist, but it is the hardest working muscle in the body. With each heartbeat, the heart pumps blood, carrying oxygen and nutrients to every part of the body through blood vessels, while carrying away metabolic waste such as carbon dioxide. The heart beats about 100,000 times and pumps up to 7,500 liters of blood every day.

CVD can be caused by a combination of: *socioeconomic, behavioral, environmental risk factors,* including high blood pressure, unhealthy diet, high cholesterol, diabetes, air pollution, obesity, smoking, kidney disease, some infectious agents, noise and chemicals in the environment and in the workplace, physical inactivity, harmful use of alcohol, stress and limited access to settings that facilitate physical activity such as green spaces. *Family history, ethnicity, gender and age* can also affect the risk of cardiovascular disease. CVD affects the lives of *many Europeans*. It is the most common cause of death in the member states of the European Economic Area. *Every year, more than 6 million new cases of cardiovascular diseases are diagnosed* in the EU, and more than *1.7 million people die from diseases of the vascular system*, which represents about 37% of all deaths (Timmis et al., 2022; WHO, 2022). *The burden of disease* caused by cardiovascular diseases is generally higher in Central and Eastern Europe than in Northern, Southern and Western Europe.

Identification of risk factors Identification of risk factors has increased awareness of cardiovascular disease, improved early detection and targeted treatment and prevention. These advances have contributed to a more than 50% drop in mortality from cardiovascular disease in the United States since 1950. The causes of CVD are also complex. Some of the known *individual determinants* of cardiovascular disease, such as age, sex, race/ethnicity, and family history, are inherent to the *individual* and cannot be changed, while others are extrinsic and can be at least partially modified. *Clinical risk factors* that can *be modified* to reduce the risk of CVD include: high blood pressure, high blood cholesterol, overweight ie obesity and diabetes. Some of them can be *partially hereditary*. *Behavioral risk factors* are unhealthy diet, lack of physical activity, smoking and alcohol consumption. Clinical CVD risk factors are influenced by various *biological mechanisms*, as well as behavioral and *environmental factors*. Both are strongly influenced by *socioeconomic factors* such as low income and education, unemployment or insecure employment, and related psychosocial problems. *Clinical and behavioral risk factors* are the main modifiable factors contributing to CVD, and are therefore typically targeted for prevention.

Environmental contribution to cardiovascular diseases in Europe It is estimated that in Europe (members of the EEA – European Economic Area and cooperating countries), over 18% of all deaths from cardiovascular diseases are caused by key environmental factors. There are significant variations among EEA members and associate countries, with a higher percentage of deaths from cardiovascular diseases due to the environment in the countries of Eastern and Southeastern Europe and in Turkey. This estimate (18% of preventable cardiovascular disease deaths attributable to the environment) is likely to be an underestimate, as it only includes a selection of environmental factors for which sufficient data are available for most EEA member states and cooperating countries (i.e. external and internal air pollution, heat and cold, second-hand smoke and lead), and does not include known risk factors for CVD due to workplace exposure, nor does it include the effect of environmental noise (a major environmental risk in Europe) or toxic chemicals.

The most common Cardiovascular diseases Coronary heart disease, sometimes called coronary artery disease or ischemic heart disease, is the most common type of heart disease. It refers to heart problems caused by narrowed coronary arteries that supply blood to the heart muscle. For some patients, the first sign of coronary heart disease is a heart attack. A heart attack, or myocardial infarction, occurs when a blood clot usually cuts off the blood supply to the heart. Without oxygen and nutrients, the heart muscle begins to die. A heart attack may not sometimes be fatal, but it can cause permanent damage to the heart. A stroke occurs when blood flow to the brain is interrupted, causing the brain to lose its vital supply of oxygen and nutrients. A stroke can be caused by a blood clot in a brain artery or when a blood vessel in the brain bursts and bleeds, damaging brain tissue. Many of the health problems associated with heart disease are related to atherosclerosis, or the buildup of plaque in the artery walls, which can result in blood clots and lead to ischemic heart disease or cerebrovascular disease (stroke).

Other cardiovascular diseases Arrhythmia is an irregular or abnormal heartbeat; Aortic disease (including aortic aneurysm) is a disease that causes the aorta to dilate or rupture; Cardiomyopathies – heart muscle diseases; Congenital heart diseases, i.e. congenital heart anomalies are abnormalities of the position, structure and function of the heart and/or large blood vessels that exist at birth; Deep vein thrombosis and pulmonary embolism – blood clots in the veins of the legs, which can break free and travel to the heart and lungs; Heart failure – heart failure is a condition when the heart does not pump as it should; Heart valve disease – disease of the heart valves that keep blood flowing through the heart; Pericardial disease (pericarditis) – inflammation of the thin tissue sac that surrounds the heart; Rheumatic heart disease is damage to the heart muscle and heart valves, caused by streptococcal bacteria. Vascular disease (disease of blood vessels) – any condition that affects the blood vessel system; Peripheral vascular disease (including peripheral arterial disease) – disease of the blood vessels supplying the arms and legs; Cerebrovascular disease – disease of the blood vessels that supply the brain.

Symptoms of cardiovascular disease vary depending on the condition of the sufferer and may include-chest pain, tightness in the chest, chest pressure and chest discomfort; pain, weakness or numbness in the legs and/or arms; pain or discomfort in the arms, neck, shoulders, jaw and back; shortness of breath; easily tiring during exercise or activity; changes in heart rhythm; very fast or slow heartbeats, palpitations or fluttering in the chest; dizziness, lightheadedness, or fainting; weakness or tiredness; swelling of the hands, legs, ankles or feet; temperature; skin rashes or unusual spots, dry or persistent cough.

The diagnosis of cardiovascular disease depends on the symptoms and condition the patient may have, medical and family history, risk factors and physical examination. They are diagnosed with a series of laboratory tests and imaging studies. Some of the common tests used include; blood test; stress test; x-ray of the heart and lungs, electrocardiogram; echocardiogram, computed tomography scan, magnetic resonance scan, electron beam computed tomography, heart catheterization and coronary angiography.

Treatment varies depending on the condition and may include; *lifestyle changes* such as diet, exercise, alcohol and tobacco use; *medicines*, including those that treat risk factors such as blood pressure or dissolve blood clots; devices such as electrical stimulators/pacemakers or implantable cardioverter-defibrillators (ICDs); *medical procedures* including: stents, heart valve surgery or coronary bypass surgery /aorto coronary bypass/.

Air pollution is the largest single risk factor for environmental health in the world and the main contributor to the global burden of disease, it is not new, but it is a neglected cardiovascular risk factor. There is ample evidence of chronic and acute cardiovascular damage caused by air pollution. **Air pollution** is defined as a mixture of harmful substances, particles and gases, released into the atmosphere by human activity, mainly by burning fossil fuels. Three common air pollutants are: *particulate matter (PM), ozone, and nitrogen dioxide (NO_2)*, and are the focus of most monitoring programs, communication efforts, health impact assessments, and regulatory efforts. Seven million people **die** each year due to **air pollution**, which is responsible for 25% of all deaths from cardiovascular disease. Policies and investments that support cleaner transportation, energy-efficient homes, electricity generation, industrial regulation, access to clean fuels and technologies, and better municipal waste management can effectively reduce key sources of air pollution. Air pollution and its impact on human health have become a significant problem on the global health agenda;

9/10 people worldwide breathe polluted air, which disproportionately affects those living in resource-limited environments. According to the WHO, more than 20% of all deaths from cardiovascular disease are caused by air pollution — the equivalent of more than 3.5 million deaths each year. In 2019, an estimated 6.7 million deaths, or 12% of all deaths worldwide, were attributed to either outdoor or household air pollution. Even ½ of that was due to cardiovascular diseases. Air pollution affects the health of the cardiovascular system, especially through long-term exposure to fine particles and nitrogen dioxide. Ischemic heart disease and stroke are the most common preventable causes of death attributable to exposure to air pollution, followed by lung disease and lung cancer (EEA, 2021). Ambient air pollutants known to contribute to cardiovascular disease include particulate matter, nitric oxide, black carbon, and carbon monoxide. Anthropogenic activities, especially the burning of fossil fuels, have resulted in the release of excessive amounts of carbon dioxide (CO_2) and other greenhouse gases, which trap heat in the lower atmosphere and cause global warming. Evidence for impacts related to exposure to ambient ozone is less clear (Wolf et al., 2021). *Primary air pollutants* are released directly into the atmosphere from either natural sources or human activity. *Secondary pollutants* are formed through chemical reactions or physical interactions involving the primary pollutants themselves or other components within the atmosphere. Although **ozone** exists naturally as a molecule in the Earth's stratosphere, where it serves as a key shield by absorbing ultraviolet radiation from the Sun, *ground-level ozone* is known to be different from stratospheric ozone. At ground level, ozone becomes a significant *secondary pollutant*, created by photochemical reactions involving nitrogen oxides and volatile organic compounds, and acting as a greenhouse gas, contributes to the increase of the Earth's temperature. The reactions leading to the formation of O_3 are also strongly influenced by the meteorological fluctuations seen with climate change. Normally, O_3 is rapidly generated and consumed without significant accumulation over time, and the concentration of O_3 is lowest during the night. However, an increase in ambient temperature leads to an increase in ground-level O_3 concentration that may be difficult to mitigate given the relationship between ambient temperature and O_3 levels. O_3 levels are measured as the 8-hour peak concentration in parts per million or billion by volume. Ozone is mainly associated with *exacerbation of respiratory diseases*, *COPD onset and mortality, and metabolic effects. Pollutants PM2.5 and nitric oxide* are among the most frequently cited pollutants associated with CV risk due to their specific characteristics and mechanisms through which they affect CV health. These are: inhalation, penetration properties, inflammatory reactions, vasoconstriction, endothelial dysfunction with pathological changes in vasomotor tone, prothrombotic pathways, autonomic imbalance, activation of the hypothalamus-pituitary-adrenal axis, all of which contribute to the development of CV risk factors and subclinical atherosclerosis. Inhaling polluted particles is dangerous to health, and the risks depend on the size of the particles. The deposition of particles in the lungs, mainly PM2.5, stimulates an inflammatory cascade, which leads to an increase in blood levels of inflammatory mediators, oxidative stress and a systemic low-grade inflammatory state.

Particulate matter (eng. particulate matter **PM**), also called pollution particles, means a mixture of solid particles and liquid droplets that are in the air. Some particles, such as dust, dirt, soot or smoke, are large or dark enough to be seen with the naked eye. Others are so small that they can only be detected using an electron microscope. The average human hair is about 70 micrometers in diameter – making it 30 times larger than the largest fine particle. These particles come in many sizes and shapes and can be composed of hundreds of different chemicals. Some are emitted directly from sources, such as construction sites, unpaved roads, fields, chimneys or fires. Most particles are created in the atmosphere as a result of complex reactions of chemicals such as sulfur dioxide and nitrogen oxides, which are pollutants released from power plants, industry and cars. PM is usually measured in micrograms per cubic meter (mass per volume) by regulatory and monitoring networks, but is sometimes estimated at finer spatial resolutions using remote sensing data. They are a mixture of solid and liquid substances that originate from natural sources (including crustal material such as sand and salt), agricultural sources (ammonia-based fertilizers) and anthropogenic sources (burning of fossil fuels). PM can be categorized by size, with PM10 referring to inhalable particles with an aerodynamic diameter of <10 μm, PM2.5 fine particles <2.5 μm and PM0.1 ultrafine particles <0.1 μm. The size of PM determines the fate and mode of transport of particles, as well as their position within the respiratory tract where they will be deposited. *Evidence for effects on cardiovascular disease* is most consistent for **particulate matter**, which is responsible for the vast majority of the disease burden through its effects on: *ischemic heart disease and stroke, lung cancer, chronic obstructive pulmonary disease.* COPD is an asthma-like lung disorder in which normal airflow to the lungs is reduced, making breathing difficult/, *lower respiratory tract infections, type 2 diabetes, pregnancy outcomes, and associated infant mortality.* **NO_2** is often used as an indicator of air pollution caused by traffic. Chronic exposure to NO_2 is associated with the onset of **asthma** /chronic obstructive inflammatory disease of the airways/ in childhood, while *short-term* variability is associated with exacerbation of asthma and increased daily mortality. **PM2.5** are tiny particles of different composition of harmful substances that pass through the alveolar barrier and destroy endothelial cells directly or act through endocrine disruption causing *acute coronary syndrome, coronary artery disease* and their risk factors such as *hypertension* /elevated blood pressure in the arteries/, *obesity and diabetes* /high blood sugar levels/. Long-term exposure to PM2.5 is associated *with increased thickness of the carotid intima media, calcification of coronary arteries, calcification of the abdominal aorta, susceptibility to atherosclerotic plaque formation, left ventricular hypertrophy and progression of chronic kidney disease.* Research by the Environmental Protection Agency and others has found that exposure to increased concentrations of PM2.5 over several hours to weeks can cause heart attacks and death related to cardiovascular disease. Longer-term exposure may lead to an increased risk of cardiovascular mortality and reduced life expectancy. In addition, evidence from clinical, epidemiological, and experimental studies links PM2.5 exposure to *insulin resistance and type 2 diabetes*. These associations extend down to pollution levels below 5 μg per cubic millimeter. Globally, PM2.5 air pollution is estimated to contribute to around 3.2 million cases of diabetes each year and up to 196,792 deaths from diabetes. **The mechanisms** by which pollutants cause *cardiovascular toxicity* are **complex and diverse**. These can be classified under three broad headings: *initiating mechanisms*, *effector pathways, and risk factor development.* Initiating mechanisms occur at the site of initial exposure. They include inflammation, activation of neural reflex arcs, and binding of pattern recognition receptors. For exposure to toxic metals and many chemical exposures, the reduction of endogenous antioxidants and oxidative stress play a central role. Effector mechanisms include the activation of fast nerve pathways and the release of biologically active intermediates (inflammatory cytokines, oxidized lipids, immune cells, microparticles and microRNA). Endocrine disorders occur due to many manufactured chemicals and air pollution. The development of cardiovascular disease risk factors, such as *hypertension and type 2 diabetes*, are late-stage events as a result of pollution-induced chronic oxidative stress and inflammation. In **India**, for example, most urban locations have *a poor air quality index with PM 2.5 levels* well above recommended limits. The highest levels of ambient air pollution are in the *Eastern Mediterranean region and Southeast Asia*, with annual mean levels often exceeding five times the WHO-recommended limits, followed by low- and middle-income cities in Africa and the Western Pacific. Reportedly, 60% of Indian cities have PM2.5 levels above national air quality standards.

CARDIOVASCULAR DISEASES AND STUDIES

The connection between maternal exposure to polluted air during pregnancy and the frequency of congenital heart anomalies in the USA (eng. Congenital Heart Disease CHD) is the subject of many studies. USA has a multifactorial causation with a strong genetic component and many environmental triggers. The aim of the 2020 study - China, Suzhou City was to investigate whether maternal exposure to air pollutants (PM10, PM2.5, NO2, CO, SO2) is associated with an increased risk of US. A total of 5213 infants with CHD were included in the study during the period from 2015 to 2019. The first five congenital anomalies were: syndactyly, CHD, ear malformation, cleft lip and palate and hypospadias, the share of CHD was significant. The level of maternal exposure to pollution was highest in the first trimester of pregnancy. Compared to other congenital anomalies, a significantly increased association between PM2.5 exposure during the second and third trimesters with the risk of CHD was observed. Maternal NO2 exposure was significantly associated with CHD in the first trimester (aOR = 1.318; 95% CI: 1.210–1.435). Exposure to PM2.5 and NO2 particles increases the risk of US, but future further research is needed.

Twenty-six systematic studies and meta-analyses from the epidemiological literature in 2020 investigated the relationship between maternal exposure to air pollution and the risk of CHD offspring. Research results of empirical studies suggest that air pollution is an important risk factor contributing to the development of the CHD. Study results indicate a statistically significant association between an increased risk of specific CHD subtypes and exposure to PM2.5, PM10, NO2, CO and O3 compared to low exposure to carbon monoxide (CO) which were associated with an increased risk of **Tetralogy of Fallot** [odds ratio (OR) = 1.21, 95% confidence interval (CI): 1.04-1.41], and exposure to particulate matter ≤ 5 µm (PM2.5) was marginally associated with it. An increased risk of **atrial septal defects** was found for each 10 µg/m3 and 10 ppb increase in particulate matter ≤ 10 µm (PM10) and ozone (O3) exposure (OR = 1.04, 95% CI: 1.00-1.09). OR = 1.09, 95% CI: 1.02-1.17). Exposure to nitrogen dioxide (NO2) was associated with an increased risk of **coarctation of the aorta** (OR for high vs. low = 1.14, 95% CI: 1.02-1.26). Further studies, particularly in developing countries, with improvements in exposure assessment, outcome matching and mechanistic understanding are needed to elaborate these associations.

By 2030, maximum daily O3 concentrations are projected to increase by 1-5 ppb across the US, which, along with projected increases in average daily temperatures, would lead to tens of thousands of additional O3-related illnesses and premature deaths annually. The connection between ***insulin resistance*** (insufficient glucose response to endogenous and/or exogenous insulin) and air pollution has been extensively investigated. **A 2020 meta-analysis** showed a significant association between a 10 µg/m3 increase in PM2.5 levels and the incidence and prevalence of **type 2 diabetes mellitus**. Researchers also found a significant association between a 10 µg/m3 increase in NO2 levels and the prevalence of type 2 diabetes 2. Numerous reviews have also highlighted the connection between blood pressure and air pollution levels. The prevalence of **hypertension** /raised blood pressure in the arteries/ was associated with short-term and long-term exposures to PM2.5 increments of 10 µg/m3. Short-term exposure to increases of 10 µg/m3 in PM2.5 is also associated with increases in systolic and diastolic blood pressure of 3 mmHg. Personal strategies to limit exposure to air pollution *(use of face masks and indoor air purifiers)* significantly reduced blood pressure levels, thus supporting strategies to reduce air pollution as a way to prevent and treat hypertension.

The share of _cardiovascular deaths attributed to the environment_ is higher overall in Southeastern and Eastern Europe, with the highest share of CVD deaths attributed to Macedonia at almost 19%. Northern European countries generally have lower values, with the lowest proportion of cardiovascular disease cases caused by air pollution recorded in Sweden (1.11%). Despite the low levels of exposure to PM2.5 in **Canada and the USA** (9-11 µg/m3), studies from those countries have also shown a *positive association between long-term exposure to PM2.5 and mortality* from cardiovascular disease. In a **large US study** (n = 517,043), long-term exposure (between 2000 and 2009) to PM2.5 was associated with a 10% increase in cardiovascular disease mortality for every 10 µg/m3 increase in PM2.5 levels. Furthermore, data from the 2001 **Canadian** Census Health and Environment Cohort showed that 10-year hazard ratio estimates for cardiovascular disease mortality increased by 25% for every 10 µg/m3 increase in PM2.5 concentration. **Several cohort studies** have also examined the association between long-term exposure to high levels of PM2.5 and cardiovascular morbidity and mortality. In a prospective cohort study from **China**, in an environment of high PM2.5 levels (average 43.7 µg/m3), each 10 µg/m3 increase in PM2.5 levels was associated with a 12% increase in cardiovascular disease mortality.

A 2020 meta-analysis of 28 studies found a modest but significant association between short-term exposure to PM2.5 (measured as 24-hour average concentration) and cardiovascular mortality. Regarding the association between other pollutants and cardiovascular mortality, a **2021** meta-analysis that assessed data from 398 cities in 22 countries, with a total of 19.7 million cardiovascular deaths between 1973 and 2018, found that an increase in **NO_2** of 10 µg/m3 was associated with a 0.37% increase in cardiovascular disease mortality the day after exposure.

Myocardial infarction /MI/ Numerous studies have investigated the relationship between short-term and long-term exposure to air pollutants and the incidence of fatal and non-fatal myocardial infarction. The researchers found a 1.1% and 2.5% increase in the risk of MI associated with each 10 µg/m3 increase in NO2 and PM 2.5 concentrations, respectively. The European Cohort Study of Air Pollution Effects **(ESCAPE project)** showed that a 5 µg/m3 increase in PM2.5 levels was associated with a 13% increased risk of acute coronary events. *Short-term exposure* to the main air pollutants, apart from ozone, increases the frequency of acute myocardial infarction /AMI/. **A multicenter European study** showed an association between *long-term exposure* to air, mainly PM 2.5 and NO2, and the incidence of coronary heart disease and stroke. *The pathophysiological basis* of this correlation lies in the systemic inflammatory response caused by the inhalation of pollutants, which is responsible for the progression and complications of **atherosclerotic plaques** /atherosclerosis is the process of thickening and damage to the walls of blood vessels by the formation of various atherosclerotic changes, for example plaque, atheroma, which is characterized by inflammation and proliferation of blood vessel wall cells vessels/, thereby increasing the risk of AMI, especially *in patients with a known history of coronary artery disease* (CAD). PM2.5 exposure potentiates **plaque** burden and vascular dysfunction in models of **atherosclerosis**, and is also associated with plaque vulnerability, changes in vasomotor tone, increased reactive oxygen species, and proinflammatory mediators. Oxidative stress is pro-inflammatory and vice versa, inflammation is pro-oxidant, leading to a vicious cycle that results in high levels of oxidative stress. Systemic inflammatory effects of cytokines or oxidizing molecules emanating from the lungs can also affect _atherosclerotic plaques_, *leading to their progression, destabilization or* *rupture, causing* *<u>acute coronary syndrome</u>.* There are short-term associations between air pollution and *cardiovascular mortality* that can be explained by thrombogenicity; this is one of the reasons why *acute coronary syndromes are associated with traffic exposure. Obese people and diabetics* may be at greater risk of cardiovascular effects of PM2.5 and conversely, long-term exposure to PM2.5 may promote the development of diabetes, potentially through systemic inflammatory reactions. In an analysis of data from **six population-based cohort studies from Denmark, Germany, the Netherlands, and Sweden** (n = 137,148), increases of 10 $\mu g/m^3$ in long-term exposure to NO_2 were associated with a significant *increase in the incidence of coronary artery disease*, i.e., CAD. coronary artery disease). However, long-term exposure to ground-level O_3 or PM2.5 was not associated with an increased incidence of CAD. Finally, **a 2021 meta-analysis of 42 studies** found that an incremental increase of 10 µg/m3 in long-term exposure to PM2.5 was significantly associated with death from CAD, but not the incidence of MI. *Patients with pre-existing coronary heart disease* may therefore be at further increased risk of the adverse effects of air pollution.

<u>Heart failure /HF/</u> is a medical condition that occurs when the heart is no longer able to adequately pump blood to meet the metabolic needs of organisms. Many studies have shown a link between exposure to air pollution and *hospitalizations for heart failure* (HF). A meta-analysis of **35 studies** found that short-term exposure to major air pollutants (CO, NO2, SO2, PM10 and PM2.5, but not O3) was associated with increased hospitalizations and mortality from heart attacks. A study conducted on residents of **Ontario, Canada**, also showed a link between long-term exposure to major air pollutants and increased admissions of patients from HF; specifically, 5% and 3% increases in HF admissions were associated with each increase in the interquartile range of exposure to PM2.5 and O3, respectively. Using **UK Biobank** data, a prospective cohort study found that long-term exposure to pollutants was associated with a 31% increased risk of incident HF in the highest quartile compared with the lowest quartile of air pollution scores. The relationship between air pollution and HF may be modified by genetic susceptibility. Further studies are needed to confirm the relationship between long-term exposure to air pollution and the risk of HF.

<u>Stroke</u> The link between *short-term and long-term exposure to air pollution and an increased risk of stroke* is well established. A 2021 meta-analysis of **68** studies including >23 million participants showed an association between short-term exposure to PM2.5 (as measured by a 10 µg/m3 increase in PM2.5 concentration) and stroke hospitalization, incidence and mortality from a stroke. In addition, the analysis revealed a positive association between a 10 µg/m3 increase in short-term NO2 exposure and stroke hospitalizations, incidence, and stroke mortality. Similarly, in a **2021 meta-analysis of 42 studies**, a 10 µg/m3 increase in long-term exposure to PM2.5 was associated with a 13% increased risk of stroke and a 24% increased risk of cerebrovascular death. However, an analysis of 11 European cohorts from the ESCAPE project /*The European Study of Cohorts for Air Pollution Effects*/ (n = 99,446) did not show a significant association between long-term exposure to PM2.5 and the incidence of stroke, but a 5 µg/m3 increase in annual PM2 levels ,5 is associated with a higher incidence of stroke among persons aged ≥60 years and those who have never smoked. A pooled analysis of six European cohorts from the ELAPSE /Effects of Low-Level Air Pollution/ project similarly showed a link between an incremental increase of 5 µg/m3 in long-term exposure to PM2.5 and the incidence of stroke. An increase in long-term NO2 exposure of 10 µg/m3 is associated with an 8% increase in the incidence of stroke.

<u>Cardiac arrhythmias</u> Most of the studies in the literature that evaluated *the potential link between air pollution and the frequency of arrhythmias* did not investigate *specific subtypes of arrhythmias*, which could be misleading because this group of diseases includes a wide range of pathologies with different pathophysiological mechanisms. It has been proven that short-term exposure to polluted air increases the risk of *atrial fibrillation*. In a meta-analysis of four observational studies (n = 461,441), a 10 μg/m3 increase in PM2.5 levels was associated with a 0.89% increase in the risk of atrial fibrillation. **The main pathogenetic mechanism** underlying air pollution-induced arrhythmias is associated with low-grade systemic inflammation, CV remodeling, and imbalanced cardiac autonomic homeostasis. Inhaled particles that are deposited in the lungs trigger an inflammatory response and promote oxidative stress and the release of pro-inflammatory cytokines. A sustained pro-inflammatory response due to chronic exposure to air pollutants enhances pulmonary and systemic vascular as well as cardiac remodeling. *Myocardial fibrosis* can lead to enlargement of the atria or ventricles, providing an organic substrate for various types of arrhythmias (ie, atrial fibrillation, supraventricular arrhythmias, premature atrial and ventricular complexes, ventricular tachycardia, and ventricular fibrillation). **A study of 176 patients with an implantable cardioverter-defibrillator** found a 39% increased risk of **ventricular arrhythmia** events with each increase in the interquartile range of PM2.5 levels. Similar findings have also been observed in high-risk populations. Finally, among *healthy individuals and those with a history of cardiovascular disease, both short-term and long-term exposure* to PM2.5 are associated with an *increased burden of premature ventricular contractions*. The presence of a pro-inflammatory environment affects the flow of ions through cell membranes, which leads to a prolonged duration of the action potential of cardiomyocytes. However, cardiac autonomic dysfunction induced by exposure to air pollution can also promote the development of **bradycardia - and tachy-arrhythmias.** The most common type of arrhythmia caused by PM2.5 is atrial fibrillation. A cohort study conducted in **Korea** focused on the proarrhythmic effects of long-term exposure to air pollutants and showed that increases in PM2.5 of 10 μg/m3 were associated with an increased incidence of AF. The **ARIA** study, a multicenter study including patients with implanted devices (i.e. pacemakers or implantable cardioverter defibrillators), aimed to evaluate the adverse impact of air pollution on myocardial electrical stability in high-risk patients and found a significant relationship between elevated atmospheric PM levels and increased frequency of *ventricular arrhythmias*.

<u>Temperature and Cardiovascular Events</u> *Low and high temperatures contribute to cardiovascular morbidity and mortality*. In 2019, the Global Burden of Disease Study identified suboptimal temperatures as a risk factor for death worldwide, with the greatest burden of mortality associated with **low** rather than high temperatures. The Lancet Countdown on Health and Climate Change summarized the effects of extreme temperatures, among many other consequences of climate change, on health and disease, including CVD. **A 2021 global analysis** estimates that >5 million deaths per year are linked to suboptimal temperatures. These trends are expected to worsen in the coming years given continued global warming and greater vulnerability of patients with multiple risk factors for CVD. Temperatures are recorded at meteorological stations near or within residential areas. Although the variability of temperature extremes that can exist in any population or geographic region should be recognized, the actual temperature to which *individuals are exposed is a function of thermally controlled indoor settings* (heaters or air conditioners). The health effects of exposure to *extreme cold* usually last longer (up to 2 weeks or more) than the effects of exposure to extreme heat, which usually last 2-3 days. Extreme temperatures may affect *the risk of developing diabetes* and may also be associated with poor *glycemic control* in patients with diabetes.

Cold exposure promotes energy utilization through activation of brown adipose tissue, which contributes to thermogenesis through compartmentalization mechanisms. Increased brown adipose tissue activity is associated with improved glycemic control and insulin sensitivity in both healthy individuals and patients with type 2 diabetes. At the population level, *high mean annual temperature was associated with elevated fasting plasma glucose levels, insulin resistance, and increased incidence and prevalence of diabetes*. Short-term temperature fluctuations are also associated with blood pressure levels. Studies in different climates and populations have shown an inverse relationship between temperature and blood pressure levels on the same and/or previous days. **A 2017 meta-analysis of 14 studies** found that a 1°C *decrease in mean outdoor temperature was associated with a 0.26 mmHg increase in systolic blood pressure and a 0.13 mmHg increase in diastolic blood pressure*. The effect of temperature fluctuations on the blood pressure level was greater in *people with established CVD.* Interestingly, blood pressure was found to be higher at **night** *during the summer months* than in the winter months, suggesting that climate warming may have the opposite effect and oppose traditional cardioprotection mechanisms. Warmer nights can lead to elevated blood pressure levels several hours later during the following afternoon. *Reduced sleep duration or quality* has also been proposed as a potential mechanism for the seemingly paradoxical increase in nighttime blood pressure levels during warmer weather. In addition, *increases in mean ambient temperature* are associated with **lower levels of HDL**/antiatherogenic lipoprotein, the highest density, so-called. “good cholesterol”/in plasma and **higher levels of LDL**/ proatherogenic low-density lipoprotein aka, "bad cholesterol" / in plasma. **In the Lancet Countdown to 2021** on health and climate change, *hot climates and CVD* were found to be linked through reduced physical activity. Higher temperatures are associated with less time spent **exercising**, potentially increasing CVD risk in the long term. *The relationship between climate change and cardiovascular (CVD) health, mediated by air pollution and increased environmental temperatures, is complex and highly heterogeneous.* ***The main mechanisms underlying the pathogenesis of CV disease at extreme temperatures*** involve several regulatory pathways, including temperature sympathetic reactivity, the cold-activated renin-angiotensin system, dehydration, extreme temperature-induced electrolyte imbalance, and heatstroke-induced systemic inflammatory responses. The interaction of these mechanisms can vary depending on individual factors, environmental conditions and the overall state of health. The final outcome is a *significant increase in CV mortality and a higher incidence of hypertension, type II diabetes mellitus, acute myocardial infarction, heart failure and cardiac arrhythmias*. Patients with pre-existing CV disorders may be more sensitive to the effects of global warming and extreme temperatures. *The increased frequency of extreme heat due* to global warming and air pollution is significantly correlated with the death rate from cardiovascular diseases. *Individuals with greater vulnerability to heat, an acute cardiovascular* event such as myocardial infarction, stroke, acute heart failure, and arrhythmias include **the elderly**, those of **lower socioeconomic status**, and those with underlying clinical conditions such as type 2 diabetes mellitus and hypertension. **In 2020, NO2 concentrations** temporarily fell as a direct result of reduced road traffic during the COVID 19 lockdown. Lower exposure levels do mean a reduction in the health effects of air pollution, including cardiovascular disease. However, despite progress, *we are far from achieving a safe level of air quality across Europe, and air pollution remains a major health concern for European residents.* In 2020, *exposure to concentrations of fine particles (PM2.5) above the World Health Organization guideline level (5 µg/m3)* resulted in 238,000 preventable deaths in the EU. This level of guidance, as stated by WHO and the research community, is still uncertain (EEA, 2022). Moreover, *some cardiovascular diseases* ***have a long latency*** *period*, so current cases may reflect previous exposures, which reinforces the urgency of reducing air pollution to contribute to the prevention of cardiovascular diseases.

STRATEGIES AND RECOMMENDATIONS

Recognition of the climate crisis, pollution and other negative impacts caused by fossil fuels, led to a broad ***political transition and an activist movement*** aimed at ending their use in favor of sustainable energy. However, because the fossil fuel industry is so integrated into the global economy and heavily subsidized, this transition is expected to have significant economic consequences. Many stakeholders argue that this change should be a just transition and the adoption of policies that address the social burden created by the stranded assets of the fossil fuel industry. *International policy, in the form of the United Nations Sustainable Development Goals for affordable and clean energy and climate action, as well as the Paris Climate Agreement*, is designed to facilitate this transition globally. *In 2021, the International Energy Agency* concluded that new fossil fuel extraction projects cannot be opened if the global economy and societies are to avoid the worst impacts of climate change and meet international climate change mitigation goals. World Heart Federation /eng. **The World Heart Federation -WHF**/ is committed to reducing the impact of air pollution on human health and has made it a priority area in our global advocacy efforts. WHF takes action in three key areas to tackle air pollution and cardiovascular disease: *research, advocacy and education*. Air pollution requires a multi-system and multi-sectoral response. The health sector as a whole, which bears the impact of air pollution, can provide much-needed support to the ministries of environment, energy and transport. The World Heart Federation advocates for senior decision-makers in national, regional and global government institutions. Pollution-related heart disease is a priority, and it is necessary *to identify interventions to reduce air pollution and its impact on non-communicable diseases*. As we unravel the intricate links between environmental stressors and cardiovascular disease, policymakers, public health officials, and medical professionals must reconceptualize and integrate health into the context of long-term environmental sustainability goals. The impact of climate change on cardiovascular and overall health is a multifaceted issue that needs to be addressed at different levels. Major scientific societies have published recommendations for reducing negative consequences. In addition to global programs, local initiatives involving the general population are necessary. **The EU** bases its clean air policy on three main pillars: *the Directive on National Obligations to Reduce Emissions, the Directive on Ambient Air Quality* (EU, 2004, 2008), which set air quality standards. In October 2022, the European Commission published a proposal for *the revision of the Ambient Air Quality Directive*, which includes stricter thresholds for pollution, improvement of the right to clean air, more effective penalties and compensation options for violations of air quality rules, stricter rules for air quality monitoring, requirements for improving air quality modeling, better informing the public. This, together with *the revision of the Industrial Emissions Directive* and the recent proposals for *Euro 7 emission standards for road vehicles*, will support progress towards better air quality. In the international context, EU member states cooperate closely with other member countries of the UN Economic Commission for Europe (UNECE) in the control of international air pollution according to the Convention on long-range transboundary pollution. Despite the fact that the connection between air pollution and cardiovascular risk has been known for years, *it has not caught on among experts* who care for patients with cardiovascular pathologies, who are always more *focused on classic risk factors*. It seems crucial to raise awareness among the general population, the scientific community and the public administration about the need to limit the levels of substances that have been identified as harmful to the health of the cardiovascular system and to promote initiatives for the aforementioned; example: the Spanish Society of Cardiology (SEC) together with the Spanish Heart Foundation (FEC) created in 2022 the working group "SEC-FEC-Verde" (Green SEC-FEC). The overall goal of the project is to reduce morbidity and mortality from pollution-related cardiovascular diseases. **The Global Burden of Disease (GBD)** study estimated that pollution was responsible for 9 million deaths worldwide in 2019, of which 61.9% were caused by cardiovascular disease, including ischemic heart disease (31.7%) and stroke (27 .7%). These numbers, as large as they are, almost certainly underestimate the full contribution of pollution to the global burden of cardiovascular disease because they are based on only a subset of environmental risk factors. Until now, pollution reduction has received little attention in *cardiovascular disease control programs* and has largely been absent from *cardiovascular disease prevention guidelines*, which have focused almost exclusively on individual behavioral and metabolic risk factors. This is an important omission, since incorporating pollution reduction into cardiovascular disease prevention could save millions of lives.

CONCLUSIONS

Cardiovascular burden associated with climate change represents one of the latest challenges in preventive cardiology. Understanding the role of air pollution can guide the team: physicians, medical societies, public health institutions, environmental protection agencies, responsible health organizations, health insurers, and governments, in the development of societal strategies for the prevention of cardiovascular disease, based on evidence that links air pollution prevention with the control of behavioral and metabolic risk factors. Prevention of pollution-related cardiovascular disease through a large-scale transition from fossil fuels to clean, renewable energy will not only reduce cardiovascular disease and related deaths, but will also slow the pace of climate change and thus benefit all of humanity.

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Air Pollution and Impact on Human Health

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Abstract: A large number of studies clearly indicate the connection between exposure to pollutants from the air and the development of acute and chronic diseases in humans. Besides the levels of outdoor air pollutants, the indoor air quality (IAQ) is also greatly influenced by pollutants originating from inside the building, so the indoor air can be ten times more polluted than the outdoor air. Symptoms and diseases caused by certain indoor air pollutants are recognized and defined in World Health Organization (WHO) directives and recommendations, as well as in EU directives. Among all populations, children are the most sensitive to the health effects of air pollution. The sensitivity of children, especially children under the age of 5, is most often a consequence of the immaturity of their respiratory, immune, reproductive, central nervous and digestive systems. The harmful effects of poor IAQ are primarily manifested in problems with the respiratory system, including worsening of asthma, the cardiovascular system, the onset of cancer and other diseases, as well as effects on the attention and academic success of school-age children. Data from the WHO from 2019 indicate that 96–99% of the world population was living in places where the WHO global air quality guideline levels recommended in 2021 (fine particulate matter, PM2,5 levels up to 5 µg/m3) were not met, with 4 million people who died from exposure to fine particulate outdoor air pollution. In Bosnia and Herzegovina, annual mean exposure to PM2,5 was 29 µg/m3, being 5,8 times WHO's guideline, with 110 deaths per 100,000 people (3,622 deaths in total) attributed to fine particle pollution in 2019. Therefore, the European Union set the clean air policy within the EU's zero pollution vision for 2050.

Keywords: Air quality, pollution, human health.

1. INTRODUCTION

The World Health Organization (WHO) defines air pollution as air contamination with chemical, physical or biological contents that threaten the normal characteristics of the atmosphere (1). In addition to the levels of outdoor air pollutants, primarily particulate matters (PMs), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) carbon monoxide (CO), the indoor air quality (IAQ) is also greatly influenced by pollutants originating from inside the building, namely volatile organic compounds (VOCs, i..e. formaldehyde, benzene, trichloroethane, toluene, ethylbenzene, xylene), CO, CO_2 and other chemical and biological compounds. These pollutants that originate from inside the building can have concentrations several times higher indoor than outdoor resulting in ten times more polluted indoor than the outdoor air. Having this in mind and as people spend most of their lives indoors, i.e. 80–90%, it is very important to ensure high IAQ.

Today we know that air pollution is a globally recognized threat to human health, other ecosystems, the environment and the climate (2, 3). Long-term exposure to air pollution can lead to adverse health effects even at low concentrations of pollutants. WHO data from 2019 indicate that 99% of the world population was living in places where the WHO air quality guideline levels from 2021 (PM2,5 mean annual level up to 2,5 µg/m3) were not met, with 4 million people who died from the exposure to fine particulate outdoor air pollution. In Bosnia and Herzegovina, annual mean exposure to PM2,5 was 29 µg/m3, being 5,8 times WHO's guideline, with 110 deaths per 100,000 people (3,622 deaths in total) attributed to fine particle pollution in 2019 (1).

2. PARAMETERS OF INDOOR AIR QUALITY

The indoor air quality is determined by thermal conditions (temperature, relative humidity, air flow), light and noise, and concentrations of pollutants (PMs, toxic gases, VOCs, microorganisms in the air, etc.) that affect health, academic abilities and people's well-being (4).

2.1 Thermal conditions (temperature, relative humidity, air flow)

Thermal conditions (temperature, relative humidity, air flow) are key aspects of IAQ for two basic reasons:

- some problems associated with poor IAQ can be solved by simply adjusting the temperature or relative humidity,
- high temperature can lead to increased release of pollutants from building materials.

The recommended acceptable indoor temperature range is 20,0–24,0°C in winter and 24,0–27,0°C in summer. Extreme temperatures have been shown to harm the well-being of school children (5, 6).
The recommended acceptable range of indoor relative humidity is 30–65%, and in classrooms 45–55% (7). Relative humidity is usually measured with a hygrometer and expressed as % of water vapor in the room air in relation to the total amount of water vapor that the same room air can contain at a certain temperature.
Relative humidity affects the human respiratory tract. High relative humidity in humans can cause a feeling of discomfort due to an unpleasant smell and a feeling of suffocation. Low

relative humidity dries out the mucous membranes of the nose, mouth and upper respiratory tract and causes discomfort and coughing. It can cause epithelial damage and decrease mucociliary clearance, an important defense mechanism, so the airways can become more susceptible to viral infections. Despite the lack of a clear scientific explanation, it is thought that the perception of dry air is probably related to "sensory irritants" such as VOCs (8).

Air flow

Using an indoor ventilation system has several benefits (9), namely:

- provides oxygen and fresh air for human breathing,
- dilutes indoor air pollutants,
- uses outdoor air with low aerosol concentration to control aerosols in the facility,
- controls indoor air humidity,
- creates proper air distribution and promotes a healthy and comfortable environment.

A WHO report also suggests that insufficient ventilation increases the transmission of infections between people. Also, it has also been shown that the ventilation rate in the classroom is directly related to the academic achievement of students (10). However, while some authors suggest sore throats and fatigue in school children to be related to the entry of external pollutants through the window into the indoor air through natural ventilation (11), others suggest these two conditions to be related to the presence of air conditioning in the classroom (6).

2.2 Indoor air pollutants

Indoor air pollutants of external origin

Concentrations of pollutants of external origin in indoor air are directly influenced by their concentration in outdoor air. As the concentration of pollutants in the outdoor air increases, they are transported from the outside to the inside via ventilation.

Pollutants originating from inside the building

Toxic compounds (ie formaldehyde, benzene, trichloroethane, toluene, ethylbenzene, xylene etc), CO, CO2 and other chemical and biological compounds originate from inside the building. Most often they are released:

- from materials used in the construction or renovation process, e.g. polyvinyl chloride (PVC) floor coverings, parquets, linoleums, rubber carpets, glues, varnishes, paints, silicones, chipboards, etc.,
- when using electronic devices such as computers, photocopiers, printers and other devices and furniture that emit ozone (O3) and volatile compounds,
- during internal activities, e.g. release from cleaning products during cleaning activities, release during cooking, release from care products, etc.,
- burning in home fireplaces, fireplaces and smoking tobacco,
- humans also create favorable conditions for the development of millions of molds, fungi, pollen, mites, bacteria, viruses and insects.

According to some authors, the IAQ in the classroom is more affected by internal compared to external pollutants (11).

Characteristics, sources, exposure, thresholds, adverse effects/diseases and prevention in humans

Pollutants can remain in the indoor air for a long period of time and thus affect people through different ways of exposure (inhalation, ingestion, through the skin). The most relevant indoor air pollutants, their sources and their impact on health are shown in Table 1.

Table 1. Pollutants, their sources and adverse effects on human health

Pollutant	Source	Adverse effects on health
Particulate matters, PMs	external environment, cooking, combustion activities (burning candles, use of fireplaces, heaters, stoves, chimneys, smoking cigarettes), cleaning	premature death in people with heart or lung diseases, non-fatal heart attacks, irregular heartbeat, aggravated asthma, reduced lung function, increased respiratory symptoms
Volatile organic compounds, VOCs	paints, varnishes, solvents, pesticides, adhesives, wood preservatives, waxes, polishes, cleaners, lubricants, silicones, air fresheners, fuels, plastics, photocopiers, printers, tobacco products, perfumes, chemically cleaned clothes, building materials and furniture	• irritation of the eyes, nose and throat • headache, loss of coordination and nausea • damage to the liver, kidneys and central nervous system • some of these substances can cause cancer
Ozone	external sources, devices for photocopying, air purification and disinfection	DNA damage, lung damage, asthma, reduced respiratory functions
NO_2	gas appliances for cooking and heating	increased asthmatic reactions, damage to the airways leading to respiratory symptoms
SO_2	cooking stoves, fireplaces, outside air	impairment of respiratory function: asthma, chronic obstructive pulmonary disease, cardiovascular diseases
CO_x	stoves for cooking, smoking, fireplaces, generators and other gasoline-powered equipment, outside air	fatigue, headache, chest pains, impaired vision, reduced brain function and death
Heavy metals: Pb, Cd, Zn, Cu, Cr, As, Ni, Hg, Mn, Fe	external sources, combustion products, smoking and building materials	cancer, brain damage, mutagenic and carcinogenic effects, respiratory diseases, cardiovascular disease and death

Radon (Rn)	building materials, natural gas, running water, outside air	causes cell mutations, lung cancer
Aerosols	tobacco smoke, building materials, consumer products, combustion products, cleaning and cooking	cardiovascular diseases, respiratory diseases, allergies, lung cancer, irritation and discomfort
Pesticides, insecticides, rodenticides, fungicides, disinfectants, herbicides	building materials, carpets, textiles and upholstered furniture external environment	irritation of the eyes, nose and throat; damage to the central nervous system and kidneys; increased risk of cancer
Biological allergens	house dust, allergens from pets, cockroaches, insects, and plants, mold/moisture, dust mites, pollen	asthma and allergies, respiratory infections, sensitization, respiratory allergy, diseases and wheezing
Microorganisms: bacteria, viruses, fungi	humans, animals, soil and plants	fever, digestive problems, infectious diseases, chronic respiratory diseases

Compared to 2005, the updated WHO air quality guidelines from 2021 recommended more strict exposition for the most important air pollutants (Table 2).

Table 2. The WHO global air quality guidelines 2005 compared to 2021 (12)

Pollutant	Averaging time	Air quality guidelines from 2005	Air quality guidelines from 2021
Particulate matters, PM2,5	Annual	10 μg/m^3	5 μg/m^3
	24-hour	25 μg/m^3	15 μg/m^3
Particulate matters, PM10	Annual	20 μg/m^3	15 μg/m^3
	24-hour	50 μg/m^3	45 μg/m^3
Ozone, O_3	Peak season	-	60 μg/m^3
	8-hour	100 μg/m^3	100 μg/m^3
NO_2	Annual	40 μg/m^3	10 μg/m^3
	24-hour	-	25 μg/m^3
SO_2	24-hour	20 μg/m^3	40 μg/m^3
CO	24-hour	-	4 mg/m^3

Particulate Matters, PMs

Characterization and sources. Particulate matter (PM) is a widespread, complex mixture of solid and liquid particles suspended in the air. PMs vary in size, shape, origin and composition (13). Their chemical composition includes inorganic ions (e.g. sulfates, nitrates, ammonia), soluble metals, insoluble metals (iron, nickel, copper, zinc and vanadium), elemental carbon, organic compounds including polycyclic aromatic hydrocarbons and polychlorinated biphenyls, biological components (allergens, endotoxin), microorganisms and water (13, 14). The composition of indoor PM is not always comparable to that of outdoor air.
PMs are usually classified according to their aerodynamic diameter:

- ≤10 µm (combined fine and coarse fraction, PM10)
- ≤2,5 µm (fine fraction including ultrafine particles, PM2,5)
- ≤1 µm (ultrafine fraction, PM1) or ≤0,1 µm

The main sources of PM in indoor school spaces are (4):

- children themselves (skin scales, fabric fibers) and children's activities, e.g. playing,
- particles originating from chalk and the decay of the building,
- furniture in classrooms (desks, tables, chairs, etc.),
- use of air conditioning and heating systems, printers and photocopiers,
- other human activities such as cooking in canteens and cleaning.

Also, although PM particles in classrooms mainly originate from internal sources, they can also be of external origin (releases from traffic, domestic combustion, or industrial activities) when they penetrate indoor, mainly if natural ventilation is used during the day (including during teaching hours). hours). This penetration strongly depends on the ventilation of the classrooms, the characteristics of the building, the building material and the season. A greater penetration of PM particles is expected if the windows and doors are directly facing the busy roads.

The main sources of outdoor air pollution with PM2,5 dust particles in Bosnia and Herzegovina are home fireplaces (almost 60%), followed by thermal power plants and heating plants (about 19%) and industry (about 14%). The remaining 7% is traffic, agriculture and waste (15).

Exposure and adverse health effects. Short-term or long-term exposure to PM2,5 and PM10 is associated with a serious threat to human health. According to the EEA, in 2020, exposure to concentrations of $PM_{2,5}$ above the 2021 WHO level resulted in 238,000 premature deaths in EU-27 (16). The mechanisms by which people absorb/adsorb PM particles depend on the age and metabolism of the person, the method of exposure (inhalation, ingestion and through the skin) and environmental conditions (temperature, humidity, solar radiation, wind speed, precipitation rate).

The effect of PM particles on health is directly related to the ability to easily penetrate the human respiratory system, and the size of the particles determines the place of their deposition in the respiratory system (14). Coarse PM10 particles can be deposited in the upper parts of the respiratory system, i.e. in the nose, mouth, throat, larynx and tracheobronchial tree. Fine $PM_{2,5}$ and the finest PM_1 particles can reach the lowest parts of the respiratory system, where they can settle in the conducting airways and, like gas molecules, even reach the areas of gas exchange in the alveoli. Moreover, the smallest particles can even pass through the wall of alveoli and capillaries and reach the blood and the whole body (14).

The smaller the size of the particles, the greater their toxicity for the cardio-respiratory system through the mechanisms of oxidative stress and inflammation. Also, exposure to $PM_{2,5}$ increases the incidence of specific acute cardiovascular diseases, such as high arterial blood pressure, heart failure, ischemic stroke, myocardial infarction, cardiac arrhythmia and atrial fibrillation. In addition to the induction of oxidative stress and systemic inflammation, PM particles can cause cardiovascular diseases by activating platelets, increasing plasma viscosity, fibrinogen and blood coagulability, then autonomic and vascular imbalance and the release of endothelin, which are powerful vasoconstrictor molecules (17).

Many studies have shown that PM particles can affect lung development starting from the period of the intrauterine development. Children exposed to increased concentrations of PM, mainly $PM_{2,5}$, have a higher risk of developing and/or worsening respiratory diseases, including chronic obstructive pulmonary disease (COPD), lung cancer, exacerbation of asthma and cystic fibrosis, regular cough, respiratory infections and allergic diseases, leading to more medication use, doctor visits and hospital admissions (14, 18, 19).
Exposure to PM particles is also associated with an increased risk of skin diseases, especially atopic dermatitis, eczema and skin aging (18).
The development of childhood pre-hypertension is also associated with exposure to PM particles in the environment because systemic oxidative stress and inflammation cause autonomic nervous system imbalance and blood vessel dysfunction and/or vasoconstriction. In addition, pre- and post-neonatal exposure to PM is also associated with an increased susceptibility to the development of cardiorespiratory diseases (19, 20).

Threshold limit values for $PM_{2,5}$: 10 µg/m3 annual mean, 25 µg/m3 24-hour mean (21).
Adverse effects on academic ability. Children aged 7–10 who attend schools in highly polluted areas, where higher concentrations of PM_{10}, $PM_{2,5}$ and CO_2 have been measured in the classrooms due to the proximity of roads, show a lag in the development of working memory and attention with negative consequences for cognitive development, i.e. learning. school achievements and behavior compared to children from less polluted areas. Concentrations of the finest PM1 particles also affected school performance, i.e. students' attention and memory ability.

Strong evidence was also found on the increased risk of developing attention deficit/ hyperactivity disorder in children exposed to PM_{10}, among other air pollutants, and a strong association was also observed between exposure to $PM_{2,5}$ particles during pregnancy and an increased risk of the child developing one of the disorders from of the autistic spectrum (22).

Prevention. Sufficient and constant ventilation and the installation of filters for $PM_{2,5}$ are invaluable for reducing the concentration of PM particles indoor. High-performance air filtration systems behind the integrated air conditioner reduce the concentration of all three types of PM particles (PM_1, $PM_{2,5}$ and PM_{10}) in the indoor air, as well as carbon particles (dangerous soot) by 90–96% (23). Furthermore, detection and removal of known sources of PM particles from indoor air is recommended.

Polycyclic Aromatic Hydrocarbons, PAHs

Characterization and sources. Polycyclic aromatic hydrocarbons (PAHs) are a large group of organic compounds consisting of fused benzene rings, eg benzo(a)pyrene. They appear as complex mixtures whose compositions can differ significantly. PAHs are found in the air either in the gaseous phase or bound to PM particles. Although there are several hundred PAHs, special attention is focused on 16 that are classified as priority pollutants (24), namely:

- lighter compounds with 2–3 aromatic rings (naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene and anthracene), mainly found in the air gas phase and bound to coarse PM_{10} particles,
- compounds with 4 rings (fluoranthene, pyrene, benz(a)anthracene and chrysene) are distributed between both phases,
- compounds of high molecular weight, with 5 or more rings [benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenzo(ah)anthracene, dibenzo(al)pyrene, benzo(ghi)perylene, indeno(123-cd)pyrene], more toxic, mutagenic and carcinogenic, mostly attached to $PM_{2,5}$ and PM_1 particles (25).

Sources. The main sources of PAHs in indoor air are the release of gaseous PAHs from indoor surfaces, resuspension of indoor dust, regular use of heating systems and some electronic equipment (such as printers), release from human activities, including children's handicrafts, cleaning, cooking (e.g. in canteens and diners), smoking tobacco. While open fires of wood and/or other burning materials (coal, agricultural residues or dung) for cooking or heating are usually the more dominant sources of PAHs in developing countries, in larger cities with large populations it is the combustion of fossil fuels. According to the EEA (2017), concentrations of benzo(a)pyrene in the outdoor air in 28 EU countries are primarily caused by releases from boiler houses and home fireplaces (75%), and then by burning agricultural waste (15%), which is mostly recorded in the countries of the South Europe. Road traffic releases only 1% of the total amount of released benzo(a)pyrene (2).

Exposure and concentrations in children. The physicochemical properties of PAHs make them widely distributed in the environment. They are easily absorbed, primarily in the lungs after inhalation (the main route of exposure), and after ingestion or through the skin (14), and easily accumulate in the body. The dose of PAHs absorbed by children can differ significantly from the dose absorbed by adults, mainly due to different physiology, metabolism and behavior. Young children often play on the floor, and hand-to-mouth activities can be an important source of PAH. Skin exposure is also an important route of exposure for children, especially the youngest.

Since PAH concentrations are highest in urban areas with high population density, near industrial zones, children attending schools located in urban areas are, compared to children from rural communities, exposed to a greater risk of PAHs (26). It has also been shown that children living in communities located in the immediate vicinity of thermal power plants are at increased risk of PAH.

Threshold limit value: Can range depending on the chemical, e.g. for naphthalene 10 ppm (21).

Adverse health effects. Exposure to PAHs poses a serious threat to human health. This threat is especially pronounced for the most sensitive population groups such as small children, because these substances are well known for their toxicity, mutagenicity and carcinogenicity (27). Thus, some PAHs are listed on the list of priority pollutants of the EU and the US Environmental Protection Agency (USEPA) (24, 28).

As an important source of oxidative stressors, PAHs are thought to interact with lipids during lipid peroxidation and cause reproductive, developmental, cardiorespiratory and immunotoxic effects in humans. Due to the synergistic and cumulative effects of PM particles and PAHs, their potential health risks cannot be considered separately. The presence of PAH in $PM_{2,5}$ and PM_1 particles is extremely important for health because these PM particles manage to reach the deepest parts of the lungs and enter the human blood system. Exposure to PM particles and PAHs is associated with an increased risk of asthma, lung infections, allergies and skin diseases. Prenatal exposure to PM particles and PAHs is associated with various changes in the child's behavior and neurodevelopment with a decrease in IQ, brain neurotrophic factor, left hemisphere white matter and an increase in attention deficit/hyperactivity disorder(29).

Carcinogenic potential. Due to its carcinogenic potential and abundant presence in the environment, benzo(a)pyrene is defined as an indicator of human exposure to carcinogenic PAHs. Benzo(a)pyrene concentrations above 1,0 ng/m^3 predict a higher frequency of genomic translocations, micronuclei and DNA fragmentation (1). In EU schools, the highest concentrations were recorded in the countries of Central and Eastern Europe (2).

Carcinogenic potential in children. Children attending schools in urban and polluted areas and exposed to high concentrations of PM particles and PAHs showed early markers of genotoxic damage and a lower DNA repair capacity, leading to a higher prevalence of chromosomal aberrations and deletions compared to school children attending rural schools, that is, in less urbanized areas (4). Also, prenatal exposure to carcinogenic PAHs is associated with intrauterine growth restriction in humans (1).

Volatile organic compounds, VOCs

Characterization and sources. Volatile organic compounds (e.g. formaldehyde, toluene, benzene) are gases containing various chemicals that are released from liquids or solids (30). Formaldehyde, the most widespread VOC, is a colorless gas with a pungent odor that is released from many building materials, such as chipboard, plywood. It is classified as a human carcinogen (31).

Since VOCs are organic chemicals that have a low boiling point (Tk) and evaporate easily even at room temperature, the WHO has classified them into four groups (32):

- highly volatile organic compounds with Tk 50–100°C,
- volatile organic compounds with Tk 100–240°C,
- semi-volatile inorganic compounds with Tk 240–380°C,
- particles of organic matter with Tk >380°C.

Indoor concentrations are at least 10 times higher than outdoors, regardless of location. In general, indoor VOCs come from four main sources (30):

- human activities, including smoking tobacco, cooking and using products for cleaning and personal hygiene,
- releases from construction materials: paint, glue, furniture, detergents,
- creation in chemical reactions that take place indoor, external air that penetrates through the filtration and ventilation systems.

Threshold limit values: for benzene 0,1 ppm, for formaldehyde between 0,1 (for usually 8 hours) and 0,3 ppm (for usually 15 min) (21).

The concentration of VOCs in indoor air is influenced by the age, size and renovation of the building, their concentration outdoors and the rate of air exchange (opening doors and windows). Exposure to VOCs released from consumer products occurs in three main ways: inhalation, ingestion, or through the skin. As for semi-volatile inorganic compounds, intake through the skin directly from the air is more significant than intake by inhalation (33).

Adverse health effects. Many VOCs cannot be smelled. Short-term exposure to low concentrations of VOCs usually does not cause serious side effects and most people experience only sensory effects, olfactory perceptions and discomfort. However, in cases of long-term exposure, some VOCs can have harmful effects on human health, and can also cause cancer. Dizziness, headache, allergies, eye/nose/throat irritation, dyspnea, fatigue and attention deficit have been reported in school children exposed to VOCs (34).

Nitrogen dioxide, NO_2

The two main nitrogen oxides (NOx) are nitric oxide (NO) and nitrogen dioxide (NO_2). Outdoors, NO is rapidly oxidized to NO_2, so NO_2 is usually considered a primary pollutant. The reaction of NO_2 with water produces nitric acid (HNO_2), a strong oxidant and common indoor air pollutant. The concentration of NO_2 in indoor air is determined by both external (combustion products or motor vehicles) and internal sources (tobacco smoking, devices for burning wood, gas, oil, coal and kerosene such as gas stoves, heaters, boilers and fireplaces) (1).
The average concentration of NO_2 in buildings without combustion activity is half that of the outdoor concentration, but when gas stoves and heaters are used, the indoor NO_2 concentration often exceeds the outdoor concentration.

Threshold limit value: 3 ppm, or 100 ppb (for 1-hour) (21).
According to the EEA, in 2020, exposure to nitrogen dioxide above the 2021 WHO level led to 49,000 premature deaths In EU-27. NO_2 causes respiratory problems in school children, namely exacerbation of asthma, increased susceptibility to viral infections, but also negatively affects attention and memory abilities (35).

Ozone, O3

Ozone is a strong oxidizing agent that is mainly formed by photochemical reactions of O_2, NOx and VOCs in the air. The main sources of ozone in indoor air are mainly outdoor air and the operation of electrical devices. Devices that commonly release ozone are photocopiers, disinfectants, air purifiers and other office equipment (36).
The indoor ozone concentration usually varies between 20–80% of the outdoor concentration, and changes according to the air exchange rate.

People are exposed to ozone primarily through inhalation, but skin exposure is also not negligible (37). Ozone reacts rapidly with several indoor air pollutants, and the products of this reaction can be irritating to humans and can damage materials.
According to EEA, in 2020, acute exposure to ozone above the 2021 WHO level caused 24,000 premature deaths in EU-27.

Sulfur dioxide, SO_2

Indoor sources of sulfur dioxide (SO_2) are outdoor air (a product of fossil fuel combustion and in combination with aerosols and PM particles) and the release of SO_2 from vented gas appliances, coal, wood or heating oil stoves, kerosene heaters, and tobacco smoke (38). The release of SO_2 in indoor air is usually small and in a concentration that can be easily absorbed by indoor surfaces, so the concentration of SO_2 in indoor air is often lower than outside. The hourly concentration of SO_2 in buildings is often below 50 µg/m^3.
Human exposure to SO_2, which can weaken respiratory function and cause COPD and cardiovascular disease, is possible only through inhalation.

Carbon dioxide, CO_2

Characterization and sources. Carbon dioxide (CO_2), colorless and odorless gas. Sources of CO_2 in indoor air are (6):

- its concentration in the outdoor air (around 400 mg/m^3, mainly caused by burning fuel, from traffic, and other human activities) and
- people in the room, so its concentration depends on the number of people in the room. Namely, CO_2 is produced by breathing, proportional to the rate of metabolism. With normal breathing, a child aged 7–9 years produces 14 liters of CO_2 per hour, which is 50% lower than the amount produced by a teenager.

CO_2 concentration in indoor air has recently been defined as a basic indicator of indoor air quality and ventilation control. In addition to poor or no ventilation, the concentration of CO_2 in the indoor air can also be negatively affected by inappropriate orientation. CO_2 concentration is a serious problem mainly in classrooms where it increases rapidly, especially in winter, when it is not possible to provide long-term ventilation due to energy savings and unpleasant outside temperatures.
The German Board for Indoor Air Quality has set the following guidelines for CO_2 (39):

- concentrations below 1,000 mg/m^3 are considered harmless and no measures are necessary,
- concentrations between 1,000 and 2,000 mg/m^3 are suspicious and ventilation must be improved,
- concentrations above 2,000 mg/m^3 are unacceptable; if improved ventilation is not sufficient, other organizational or structural measures and/or mechanical ventilation are recommended.

The occupational limits: 5,000 ppm (for usually 8 hours) and 30,000 ppm (for usually 15 min) (21).

Adverse health effects. A high concentration of CO_2 (in overcrowded and poorly ventilated classrooms) is associated with an increase in children's absences from school, negatively affects health (increases bacterial infections) and reduces the academic results of school children. When the concentration of CO2 increases above 1,000 mg/m^3, children's absences from school increase by about 10–20%. With a further increase in concentration above 1,500 mg/m^3, the air becomes stagnant and unpleasant, and such high concentrations can negatively affect the circulatory, cardiovascular, autonomic nervous system, including psychomotor and cognitive performance, i.e. decision-making, problem solving, as well as concentration tests (40, 41, 42). The increased concentration of CO_2 also reduces the short-term attention span of students. The most common symptoms are fatigue and headache, followed by nausea and dizziness, tachycardia, memory impairment, lack of concentration, blurred vision, sweating, restlessness, vomiting, reddened skin, and even panic attacks (43). Although an unpleasant smell occurs in classrooms with a CO_2 concentration higher than 1,500 mg/m^3, students who are already in the classroom are not aware of it because the sense of smell quickly adapts (44). However, the children seem to be concentrating CO_2 is better described through the perception of fresh air than the perception of smell (45).

Exceeding the concentration of CO_2 above 5,000 mg/m^3 leads to health complications for most people (40). Students staying in classrooms where higher concentrations of PM particles and CO_2 were measured showed reduced cognitive performance, and high concentrations of CO_2 caused deterioration of individual test results in reading, writing and arithmetic, as well as reduction of students' short-term attention span.

Prevention. As the concentration of CO_2 in the classroom is directly and significantly related to the number of students, overcrowded classrooms should be avoided. Also, adequate and constant ventilation is necessary to reduce the concentration of CO_2 indoor. Reducing CO_2 concentration below 800 mg/m^3 can reduce the risk of some symptoms of sick object syndrome such as headache, fatigue or eye and throat irritation.

Carbon monoxide, CO

Sources. The main source of carbon monoxide (CO) indoors is combustion processes such as cooking or heating, including unvented kerosene and gas heaters, chimneys and stoves that emit CO, smoke returns from stoves, gas boilers, wood stoves and fireplaces, gas stoves, generators and other gasoline-powered equipment, and tobacco smoke. In addition, CO can also enter indoor spaces by infiltration from outside air (from car exhaust from nearby garages, roads or parking lots, power generators, industries using gas and fuel oil) (46). The average concentration of CO in indoor space without gas stoves is about 0,5–5 mg/m^3, while the concentration in indoor space near the gas stoves ranges from 5–15 mg/m3, and even 30 mg/m3 or more.

Threshold limit value: 35 ppm (21).

Adverse health effects. Due to its influence on tissue oxygenation through the production of carboxyhemoglobin, CO leads to harmful health effects, and at low concentrations it affects cardiovascular and neurobehavioral processes, while at high concentrations fainting or death occur. CO can negatively affect even the intrauterine development of the lungs (47).

Heavy metals

Sources. In indoor air from the external environment (dust and soil), smoking tobacco, products that consume fuel and building materials (48). Heavy metals in indoor dust enter the human body by inhalation, ingestion or through the skin.

Adverse health effects. International Agency for Research on Cancer (IARC) has classified heavy metals as(49):

- non-carcinogenic elements: cobalt Co, aluminum Al, copper Cu, nickel Ni, iron Fe and zinc Zn and
- frequent heavy metals that probably cause cancer: arsenic As, chromium Cr, cadmium Cd and lead Pb.

Cd and Pb, along with others, can cause cardiovascular disease, slow growth and development, and damage the nervous system. Exposure to PAH and Pb increases oxidative damage, stimulates the renin-angiotensin system and reduces nitric oxide concentrations. These mechanisms can cause increased vascular tone and peripheral vascular resistance (46).

Radon (Rn)

Sources. Primary sources of radon in indoor air include building materials, natural gas, and tap water. Wall construction materials (i.e. stone, concrete and brick) are the main sources of radon release in indoor air, because tons of such materials are used in construction activity. Radon can be released into indoor air by using water from underground sources containing granite or other rock that emits radioactivity, and such water sources usually contain radon concentrations above 10,000 pCi/L. Finally, the source of radon in the indoor air is also the outdoor air.
Human exposure to radon in buildings occurs mainly through the penetration of natural gas from the ground. Radon is not detectable by smell and usually accumulates in poorly ventilated classrooms.
Radon is the only pollutant for which mandatory concentration limits in indoor air are legally defined in the EU. The average annual concentration of radon activity must not be higher than 300 Bq/m^3, but some countries, e.g. Germany, allow higher concentrations of radon in the indoor air if it turns out that the applied measures have proven to be inappropriate (50).

Threshold limit value: No evidence of a threshold with no risk (21).

Adverse health effects. Radon can affect lung function, including causing lung cancer in case of chronic exposure. The risk of lung cancer increases by 3–14%, depending on the average radon concentration (51).

Pesticides

Pesticides in indoor air are usually semi-volatile compounds that, depending on vapor pressure, viscosity and solubility in water, can exist in gas or particulate form.

Sources. Wood building materials where pesticides are used as protection through impregnation or surface coating of wood, pest control and removal products including bacteria, fungi, insects, rodents and other organisms, carpets, textiles and upholstered furniture, and outdoor sources (52). Once they reach the indoor air, they can be maintained there for months or years due to their resistance to sunlight, extreme temperatures, rain and other factors.

The routes of exposure to pesticides in indoor air are skin, ingestion and inhalation.
Adverse health effects. Include short-term skin and eye irritation, dizziness, headache and nausea, while long-term effects include asthma, diabetes and cancers (53).

Biological pollutants

Biological pollutants in indoor air are biological allergens and microorganisms.

Sources. Biological allergens, known as antigens, originate from numerous insects, animals, mites, plants, pollen, house dust or fungi and cause allergy in reaction with specific immunoglobulin E (IgE) antibodies. Indoor sources of allergens mainly include furry pets (dogs and cats), dust mites, molds, plants, cockroaches and rodents, and there are also outdoor sources (54). Microorganisms, viruses and bacteria, often originate from humans or are transmitted by humans and animals.

Adverse health effects. Exposure to biological allergens in indoor air can result in sensitization, respiratory infections, respiratory allergic diseases and snoring, while exposure to viruses and bacteria probably causes both non-infectious and infectious side effects (55).

3. INDOOR AIR QUALITY AND ITS IMPACT ON SCHOOL-AGE CHILDREN' HEALTH AND ACADEMIC ACTIVITIES

Children, especially children under the age of 5, are the most sensitive population to the health effects of air pollution. The sensitivity of children, especially their sensitive subgroups, is most often a consequence of the immaturity of their respiratory, immune, reproductive, central nervous and digestive systems (56, 57). Children differ from adults in their physiological and physical status. Physiologically, the respiratory rate per kilogram of body weight is approximately twice as high in children and up to three times as high in newborns compared to adults. This means that children, due to their size, physiology and physical activity, have a breathing cycle twice as fast as adults, and therefore show a higher rate of oxygen consumption and metabolism per unit of body weight (58). Physically, children also take in more air and have a larger lung absorptive surface, which is why during breathing, and in proportion to their body weight, they absorb significantly more pollutants than adults. In addition, in children, the contribution of the nose in the breathing process is smaller compared to adults, making the retention of particles in the nasal airways less effective, and increasing the chance of their greater deposition in the lower airways (59).

School-age children (usually 4–12 years old) spend more time (about 80%) indoors (e.g. in schools and their homes) than outdoors. After the home, the school/classroom is the second most important environment for a child where, mostly indoors, he spends about 25–30% of his life (up to 10 hours a day). Therefore, adequate air quality in schools is an important determinant of the healthy life and well-being of school children.

The health effects of poor indoor air quality in the school population are primarily related to problems with the respiratory system, including exacerbation of asthma (60), the cardiovascular system, the onset of cancer and other diseases caused by an unfavorable environment, as well as effects on the attention and academic success of school children. Moreover, data suggest that early exposure to polluted air during intrauterine development (47) and childhood may play an important role in the development of chronic diseases in adulthood (4).

3.1 The effect of indoor air pollution on school-age children' respiratory and cardiovascular system

The harmful effects of poor IAQ in the school population are primarily related to problems with the respiratory systems. The classrooms are shown mainly to be overcrowded, poorly ventilated and overheated. This results in respiratory problems in addition to mild adverse events (e.g. headache, nausea, etc.) (4). The respiratory system is often the primary target of indoor air pollutants because they are most often introduced into the human body by inhalation. From respiratory diseases, the following are described: acute respiratory infection, in the form of upper respiratory tract infection – common symptoms are cough, sinus and middle ear inflammation, and acute lower respiratory tract infection and other allergic (asthma, atopic dermatitis and allergic rhinitis) and lung diseases including COPD and lung cancer (61).
Runny nose, sore throat, cough, breathing problems and snoring were most often reported by students staying in classrooms with air conditioning. Also, sore throat, cough and fatigue were often reported by students staying in classrooms with natural ventilation, where higher temperatures, higher relative humidity and higher concentrations of PM10 were measured. It is known that higher temperatures and higher relative humidity favor the growth and transmission of some viruses, which can be the basis for the mentioned symptoms.
Cardiovascular diseases are mostly associated with exposure to $PM_{2,5}$, PAH, CO_2, CO, and heavy metals, primarily lead and cadmium (46).

3.2 Effect of indoor air pollution on school-age children' academic activities

The IAQ affects the concentration and attention of students and their academic abilities. Standardized tests to assess reading and math ability applied to students who are exposed to poor indoor air quality repeatedly result in worse results compared to students who stay in healthy classroom environments. A study conducted in 1,000 schools in the USA, then a large cohort study of 8,000 children in Great Britain and systematic reviews of the literature confirm that the rate of ventilation in the classroom is directly related to the academic success of students, and that measurable progress in mathematics and reading (assessed through standardized tests) can observe when improving the quality of indoor air in classrooms (62).
Reduced cognitive performance of students staying in classrooms where higher concentrations of coarse and fine suspended particles (PM_{10}, $PM_{2,5}$) and CO_2 were measured were also documented in schools in Austrian urban areas. Cognitive development indicators, such as attention and memory capacity, had a better trend in other schools with the lowest concentrations of the finest PM_1 particles and NO_2 (63).
Studies on indoor air quality in classrooms in BiH indicated poor air quality with high concentrations of PM_{10} and $PM_{2,5}$, benzene, toluene, xylene, NO_2, CO_2 and suboptimal conditions of temperature and air humidity (64, 65).

4. CONCLUSION

The disease burden related to air pollution, even at low exposure, is estimated as one of the top five major public health problems with more than 4 million premature deaths worldwide in 2019 and 238,000 premature deaths in EU-27 in 2020. Recently, WHO recommended more strict limits of exposure for $PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2 and CO. The effect of PM particles on health is directly related to their heterogeneous physical and chemical characteristics and their ability to easily penetrate the human respiratory system, i.e. the smaller the size of the particles, the deeper their penetration into the blood and tissues resulting in greater cardio-respiratory and other toxicities. Moreover, their synergistic and cumulative effects with carcinogenic PAHs makes them even more dangerous. The most common health problems related to the exposure to the air pollution are higher risk of developing and/or worsening respiratory diseases, including COPD, exacerbation of asthma and cystic fibrosis, regular cough, respiratory infections, lung cancer and allergic diseases, cardiovascular diseases including hypertension, heart failure, myocardial infarction, cardiac arrhythmias, ischemic stroke, the onset of other cancer and autoimmune diseases, diabetes mellitus, skin diseases such as atopic dermatitis, eczema and skin aging, as well as effects on the neurocognitive development including attention and academic success of school-age children. Air pollution can even negatively affect the child's intrauterine development. The most sensitive populations are newborns and other children, pregnant women, elderly and patients with chronic diseases. To mitigate the harmful effects of air pollution, the EU adopted the clean air policy with the aims of setting up the ambient air quality standards, reducing air pollution emissions and setting up the emissions standards for key sources of pollution within the EU's zero pollution vision for 2050.

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The Impact of Climate Change on the Emergence and Spread of Zoonotic Diseases

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Abstract: Climate change significantly influences the emergence and spread of zoonotic diseases by altering ecosystems, increasing temperatures, changing precipitation patterns, and intensifying extreme weather events. These changes affect the habitats and migration patterns of wildlife, vectors, and pathogens, increasing human exposure to zoonoses. The warming climate extends the geographic range of disease vectors like mosquitoes and ticks, facilitating the spread of diseases such as malaria, dengue, Zika, and Lyme disease. Extreme weather events like floods and droughts disrupt ecosystems, leading to increased risks of diseases like cholera and hantavirus. Strategies like biodiversity conservation, habitat protection, and sustainable agricultural practices, along with enhanced surveillance and global cooperation, are necessary to prevent future zoonotic outbreaks in the context of climate change. The One Health approach, integrating human, animal, and environmental health, is crucial for mitigating these threats.

Keywords: Zoonosis, Climate, Emergence, One Health.

1. INTRODUCTION

Climate change refers to long-term alterations in average weather patterns, occurring on a global or regional level. These changes include variations in temperature, precipitation, winds, and other meteorological parameters over decades or longer periods. Climate changes can be caused by natural processes like volcanic eruptions and solar radiation variations, but increasing scientific consensus indicates that current changes are mainly a result of human activities. The most significant human-related causes of climate change include greenhouse gas emissions like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from burning fossil fuels, agricultural practices, deforestation, and industrial processes. These gases create a greenhouse effect, trapping heat in the Earth's atmosphere and leading to global temperature increases. According to World Meteorological Organization (WMO)[1] the global mean temperature in 2023 was about 1.45°C above the 1850-1900 average. The year 2023 was the warmest on record, because of long-term climate change and the effect of the 2023/2024 El Niño episode, the ocean absorbs approximately 90% of energy in the climate system, warming it to record levels in 2023 and global sea level increased to a new high in 2023 (110mm), since the beginning of the satellite altimetry measurement in 1993.

Climate change causes complex and often irreversible changes in ecosystems. Understanding and monitoring these changes is crucial, recognized by scientific communities alongside initiatives from international organizations, civil society, and some governments, to develop strategies for ecosystem conservation and mitigating the negative impacts of climate change. These initiatives generally include ecosystem protection, reduction of greenhouse gas emissions, and promotion of sustainable natural resource management practices. As temperature increases, changes in precipitation patterns and extreme weather events alter ecosystem structure and function. For example, rising temperatures can lead to earlier plant blooming, disrupting ecological interactions between plants and their pollinators. Some pollinating insects might appear later than usual, resulting in a mismatch between plant blooming and pollinator presence. This can reduce plant reproductive success and impact the entire ecosystem[2]. Moreover, climate change can promote the spread of invasive species (both plant and animal), further threatening and aggressively altering local ecosystems. Invasive species can take over habitats and resources of local species, reducing biodiversity. For instance, rising temperatures and changes in precipitation patterns can enable invasive plants and animals, including insects, to spread to areas where they previously could not survive (Sweco UK, 2023).

Extreme weather events like storms, droughts, and floods also have direct consequences on ecosystems. These events can destroy habitats, reduce water and food availability, and change species composition within ecosystems. For example, droughts can reduce fish populations in rivers and lakes due to lower water levels, while floods can destroy terrestrial habitats for many species.

Changes in precipitation patterns can also affect aquatic ecosystems. Reduced rainfall can decrease water availability in rivers and lakes, leading to higher pollutant concentrations and lower water quality. On the other hand, increased rainfall can enhance soil erosion and sediment runoff into water ecosystems, negatively affecting aquatic organisms.

In addition to direct impacts on species and their habitats, climate change also affects ecosystem services essential for human well-being. Ecosystems provide services like food

[1]https://wmo.int/topics/climate
[2]US Environmental Protection Agency. (2023). Ecosystems & Climate Change Research. Retrieved from https://www.epa.gov/climate-research/ecosystems-water-quality-climate-change-research

supply, climate regulation, water purification, and pollination. Changes in ecosystems can reduce these services' capacity, having far-reaching consequences for human communities and health (Harris, 2023).

"Health" refers to a state of complete physical, mental, and social well-being, not merely the absence of disease or infirmity. It encompasses how well the body functions, how we feel mentally and emotionally, and how we interact with others and our environment. Several factors can impact our health: lifestyle choices and nutrition, environmental factors, genetics, access to healthcare, social, cultural and economic factors, occupational hazards and infectious diseases. Infectious diseases remain a significant global health challenge, particularly as the rise of antimicrobial resistance (AMR) threatens to undermine the effectiveness of treatments, making it increasingly difficult to control infections, prevent disease spread, and protect vulnerable populations from life-threatening conditions.

This review aims to emphasize the multifaceted impact of climate change on the emergence and spread of zoonotic diseases. Specifically, it underlines how changes in temperature, precipitation patterns, and extreme weather events alter ecosystems and contribute to increased interactions between humans, wildlife, and vectors, facilitating zoonotic transmission. The objective of this review is threefold:

1. ***Understanding climate change as a driver:*** To elucidate how climate change drives the emergence and geographic redistribution of zoonotic diseases, emphasizing its role in creating favorable conditions for vectors and pathogens.
2. ***Impact assessment on health and economy:*** To assess the health, social, and economic consequences of zoonotic diseases influenced by climate change, utilizing historical and current examples from major zoonotic outbreaks.
3. ***Advancing mitigation strategies:*** To propose effective mitigation, prevention, and adaptation strategies by highlighting the importance of a One Health approach, integrating human, animal, and environmental health in response to climate-induced zoonotic threats.

A holistic understanding of the intersection between climate change and zoonotic diseases, and scientific advancements is essential for developing recommendations for policymakers, healthcare professionals, and stakeholders across various sectors in addressing this emerging issue.

2. ZOONOTIC DISEASES

Zoonotic diseases or zoonoses[3], are infectious diseases that can be transmitted from animals to humans and have been responsible for some of the most significant global health crises in our era (i.e. SARS, Ebola, Highly Pathogenic Avian Influenza, and COVID-19). Zoonoses can be classified into three distinct categories: (a) endemic zoonoses, which are widespread and affect both humans and animals, like Brucella and Rabies virus, b) epidemic zoonoses, which have sporadic temporal and spatial distributions, like the 2009 H1N1 influenza pandemic and (c) emerging and re-emerging zoonoses, which might occur as previously unknown or have already existed but are now rapidly expanding in prevalence or range, like MERS (Horefti, 2023). There are over 200 known types of zoonoses. It is estimated by the World Organization for Animal Health (WOAH) that 60 % of pathogens that cause human diseases originate from domestic animals or wildlife, and 75 % of emerging infectious human diseases have an animal

[3] *WHO: https://www.who.int/news-room/fact-sheets/detail/zoonoses*

origin[4].

The transmission of pathogens from wild animals to humans is called “zoonotic spillover”. Most human infectious diseases are derived from pathogens that originally circulated in non-human animal species. The connection between global warming, climate change and zoonotic diseases has become an important area of study, particularly as the frequency of zoonotic spillover events appears to be increasing. Understanding how climate change influences the emergence and spread of these diseases is essential for predicting and mitigating future outbreaks.

3. OVERVIEW OF HEALTH, SOCIAL, AND ECONOMIC CONSEQUENCES OF ZOONOTIC DISEASES FOR ANIMALS AND HUMANS

Zoonotic diseases pose significant global, regional, and national health challenges and burdens. However, their consequences extend beyond health, affecting social and economic spheres of life. This chapter analyzes the health, social, and economic consequences of zoonotic diseases using examples of major zoonoses.

3.1. Health Consequences

Zoonotic diseases can cause severe health problems in humans and animals. The zoonoses (Table 1) are responsible for nearly 2.5 billion cases of human infection and approximately 2.7 million human deaths annually (Horefti, 2023). Unlike any other zoonotic pathogen before it, Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has demonstrated the severe consequences that arise from disregarding pandemic risk factors and preventive hygiene measures. The significance of hygiene is most apparent in preventing the spread of zoonotic pathogens and addressing antimicrobial resistance (Kemper, 2023). Rabies is almost always fatal after symptom onset in humans, with an estimated 59,000 deaths annually, mostly in rural areas of Africa and Asia (De Luca, 2023). Highly Pathogenic Avian Influenza (HPAI) poses a significant public health threat due to the possibility of transmission to humans. HPAI has devastated wild bird colonies and raised concerns about a potential pandemic (McClaughlin et al. 2024).

Table 1. The timetable of major epidemics and pandemics caused by zoonoses (Horefti, 2023)

Year of Emergence	Location	Zoonosis	Fatalities
430 BC	Ancient Greece	Rickettsia (plague)	100,000
541 AD	Byzantine Empire	Yersinia Pestis	15-100 million
1345	Western Eurasia/North Africa	Yersinia pestis (Black Death)	75-200 million
1793	Philadelphia, USA	Yelow fever virus	25,000
1918	Europe	Influenza type A (Spanish flu)	20 million
1957	Asia, USA, Europe	Influenza type A (Asian flu)	1,1 million
1968	Hong Kong, Worldwide	Influenza type A	1 million
1976	Congo and Sudan	Ebola virus	280

[4]*WOAH: https://www.woah.org/en/what-we-do/global-initiatives/one-health/*

1980	Central Africa, world-wide	HIV - AIDS	40,1 million
1996	China – Hong Kong	Influenza type A (Avian Influenza)	6
2002	South China, Europe, North America	SARS	811
2009	Worldwide	Influenza type A (Swine Influenza)	151,700-575,400
2012	Saudi Arabia	MERS	866
2015	Brazil	Zika Virus	18
2016	China	Influenza type A	494
2018	Congo	Ebola	2287
2019	China	SARS COV2	7 million
2022	London	Monkeypox	146

3.2. Social Consequences

The social consequences of zoonotic diseases include lifestyle changes, stigmatization of patients, and changes in social norms. The COVID-19 pandemic led to global quarantines and social isolation, affecting the mental health of billions of people. In areas affected by diseases like Lyme borreliosis, people change their daily activities to avoid contact with disease vectors like ticks (de la Fuente et al. 2023). In some communities, zoonotic diseases have altered traditional practices. For instance, in regions where animal husbandry is closely tied to cultural identity, outbreaks such as Highly Pathogenic Avian Influenza (HPAI) or Foot-and-Mouth Disease (FMD) have forced changes in animal handling, farming practices, and even dietary customs. The social habits in these areas can be heavily impacted when entire livelihoods are threatened due to mandatory culling or restrictions on animal products. Major zoonotic disease outbreaks can also disrupt education systems, as seen during the COVID-19 pandemic when schools across the world were forced to close, leading to a massive shift to remote learning. This disproportionately affected children in low-resource settings who had limited access to the internet or remote learning tools, thereby exacerbating educational inequality.

Although there is growing evidence linking climate change to infectious diseases, our understanding of how human migration, climate change, and infectious diseases intersect remains limited. As climate change and related disasters increasingly disrupt populations, the resulting sudden displacements and long-term migrations may significantly alter the spread and burden of infectious diseases, potentially leading to severe public health challenges (Tsuie et al. 2024).

3.3. Economic Consequences

The economic impact of zoonotic diseases is enormous, including treatment costs, workforce loss, reduced productivity, and disease control costs. Zoonotic diseases increase healthcare costs due to the need for prolonged treatment and hospitalization. For example, the COVID-19 pandemic resulted in huge costs and will likely end up costing between $8.1 and $15.8 trillion globally[5]. Diseases like leptospirosis can significantly reduce productivity due to prolonged illness and recovery. A study in Colombia showed that leptospirosis has a significant negative impact on workforce productivity (Gutiérrez and Tapias-Rivera, 2024). Diseases affecting animals, like HPAI, can lead to mass culling of animals to prevent disease spread, resulting in enormous economic losses in the agricultural sector (McClaughlin et al., 2024). Bernstein et al. (2022) reported that the lives lost and economic costs of viral zoonotic pandemics have steadily increased over the past century. The baseline expected annual mortality from viral disease epidemics with the current world population is 3.3 million lives. Estimated willingness to pay (WTP) to prevent mortality can range from $107,000 to $6.4 million per life or more, depending on the country's wealth. Applying the more conservative range of WTP, authors find that avoiding this loss of life translates into a WTP of between $350 billion to $21 trillion annually. Economic analysis plays a crucial role in developing prevention programs against zoonotic diseases by providing insights into the cost-effectiveness, resource allocation, and overall financial impacts of different intervention strategies.

In conclusion, zoonotic diseases have profound health, social, and economic consequences. Effective control and prevention require coordinated global efforts, including a better understanding of the interconnections between human and animal health. Prevention and preparedness are crucial to minimize the impact of these diseases on global society. Recent approaches to this issue, particularly experiences from the COVID-19 pandemic, have led to treating the spread of zoonotic diseases as biological disasters, considering them events causing significant health, economic, and social consequences due to mass outbreaks of infectious diseases, bioterrorist attacks, or natural disasters promoting pathogen spread.

4. OVERVIEW OF MAJOR ZOONOSES

4.1. Bacterial Zoonoses

Bacterial zoonoses pose significant health problems due to their ability to cause severe illnesses in humans. The most important bacterial zoonoses, their characteristics, transmission routes, and basic preventive measures are listed below:

Disease	Pathogen	Transmission	Symptoms	Preventive measures
Salmonellosis	Bacteria of the genus Salmonella	Contaminated food, water, direct contact with infected animals or people	Fever, diarrhea, stomach pain, nausea, vomiting	Food hygiene, proper cooking of meat, hand washing after contact with animals
Brucellosis	Bacteria of the genus Brucella	Contaminated dairy products, direct contact with infected animals, inhalation of aerosols	Fever, sweating, muscle and joint pain	Milk pasteurization, use of protective equipment when handling animals

[5] *https://extranet.who.int/sph/fighting-covid-19-could-cost-500-times-much-pandemic-prevention-measures*

Disease	Pathogen	Transmission	Symptoms	Preventive measures
Listeriosis	Listeria monocytogenes	Contaminated food (unpasteurized dairy products, raw vegetables, undercooked meat)	Fever, muscle aches, vomiting; in pregnant women, it can cause miscarriage	Food hygiene, proper food storage and preparation
Leptospirosis	Bacteria of the genus Leptospira	Contaminated water, contact with urine of infected animals	Fever, headache, muscle aches, red eyes; in severe cases, kidney and liver damage	Avoiding contaminated water, use of protective equipment in risk areas
Tularemia	Francisella tularensis	Insect bites, contact with infected animals, contaminated water or food	Fever, skin ulcers, muscle pain, sore throat, swollen lymph nodes	Use of protective equipment, avoiding insect bites, rodent control
Anthrax	Bacillus anthracis	Contact with infected animals or their products, inhalation of spores, consumption of contaminated food	Skin ulcers, fever, chest pain, cough, breathing difficulties	Animal vaccination, proper handling of animal products, use of protective equipment

4.2. Viral Zoonoses

Viral zoonoses present a serious challenge to global public health. Their prevention requires public education, improved hygiene practices, vaccination, and vector control. Coordinated efforts of health, veterinary, and ecological experts are key to successfully combating these diseases.

Disease	Pathogen	Transmission	Symptoms	Preventive measures
Rabies	Rabies virus	Bite of an infected animal (usually dogs)	Fever, headache, anxiety, confusion, paralysis, hallucinations, hydrophobia	Vaccination of animals and people, avoiding contact with wild animals

Disease	Pathogen	Transmission	Symptoms	Preventive measures
Ebola virus disease	Ebola virus	Contact with bodily fluids of infected people or animals	Fever, head-ache, muscle pain, vomit-ing, diarrhea, bleeding	Isolation of infected, use of protective equipment, hygiene education
MERS (Middle East Respiratory Syndrome)	MERS-CoV (Middle East Respiratory Syndrome Coronavirus)	Close contact with infected people or camels	Fever, cough, shortness of breath; in severe cases, pneumonia	Hand hygiene, avoiding contact with infected individuals, proper handling of animals
Lassa fever	Lassa virus	Contact with urine or feces of infected rodents	Fever, weakness, headache, sore throat, chest pain, vomiting	Rodent control, household hygiene
Zika virus infection	Zika virus	Bite of infected mosquitoes (Aedes aegypti), sexual contact	Mild fever, rash, joint pain, conjunctivitis	Mosquito control, use of repellents, protection during sexual intercourse
SARS (Severe Acute Respiratory Syndrome)	SARS-CoV (Severe Acute Respiratory Syndrome Coronavirus)	Close contact with infected individuals, airborne droplets	Fever, headache, general weakness, cough, shortness of breath	Isolation of infected, hand hygiene, wearing protective masks
Nipah virus infection	Nipah virus	Contact with infected fruit bats or pigs, consumption of contaminated food	Fever, headache, respiratory problems, encephalitis	Avoiding contact with infected animals, avoiding consumption of contaminated food
Hantavirus Pulmonary Syndrome (HPS)	Hantaviruses	Contact with excreta of infected rodents, inhalation of contaminated air	Fever, muscle pain, cough, shortness of breath	Rodent control, hygiene measures

4.3. Prion Zoonoses

Prion diseases are rare but extremely serious and fatal neurodegenerative diseases affecting humans and animals. Prions are abnormal infectious proteins that can induce normal proteins in the brain to also transform into abnormal forms, causing damage. This overview analyzes the most significant zoonotic diseases caused by prions, their characteristics, transmission routes, and preventive measures.

Disease	Pathogen	Transmission	Symptoms	Preventive measures
Bovine Spongiform Encephalopathy (BSE) or "Mad Cow Disease"	Abnormal prions	Consumption of contaminated products from infected cattle, including nervous tissue and bone meal	In cattle: Behavioral changes, coordination difficulties, weight loss, death	Strict controls in the food industry, ban on the use of meat and bone meal as animal feed, removal of infected cattle from the food chain
Variant Creutzfeldt-Jakob Disease (vCJD)	Abnormal prions associated with BSE	Consumption of contaminated meat products from infected cattle, transmission via medical instruments	Psychiatric symptoms (depression, anxiety), sensory symptoms, ataxia, dementia, myoclonus, death	Strict controls in the food industry, single-use medical instruments for high-risk procedures, blood screening
Kuru	Abnormal prions	Endocannibalistic practice (ritual cannibalism) in the Fore tribe in Papua New Guinea	Tremor, ataxia, loss of coordination, laughter (known as "laughing death"), death	Cessation of ritual cannibalism, community education
Chronic Wasting Disease (CWD)	Abnormal prions	Direct contact with infected animals or contaminated environment via urine, feces, saliva	Symptoms in deer and elk: Weight loss, behavioral changes, ataxia, death	Wildlife population control, ban on export of infected animals, hunter education
Scrapie	Abnormal prions	Contact with infected sheep or goats, contaminated environment	Symptoms in sheep and goats: Tremor, itching, behavioral changes, ataxia, death	Removal of infected animals, genetic selection programs for resistance, animal movement control

4.4. Parasitic Zoonoses

Parasitic zoonoses pose significant health problems worldwide. Parasites can be protozoa, helminths, or ectoparasites transmitted from animals to humans through various mechanisms. This overview analyzes the most important zoonotic diseases caused by parasites, their characteristics, transmission routes, and preventive measures.

Disease	Pathogen	Transmission	Symptoms	Preventive measures
Toxoplasmosis	Toxoplasma gondii	Consumption of contaminated food or water, contact with cat feces, transplacental transmission	Mostly asymptomatic, but can cause mild flu-like symptoms in immunocompromised individuals and pregnant women, can lead to serious complications	Proper cooking of meat, hand washing after handling raw meat or cat feces, avoiding unpasteurized milk
Cysticercosis	Taenia solium (pork tapeworm)	Consumption of parasite eggs via contaminated food or water, autoinfection	Neurocysticercosis can cause seizures, headaches, neurological problems	Proper meat processing, hand hygiene, sanitation conditions
Echinococcosis	Echinococcus granulosus (cystic echinococcosis) and Echinococcus multilocularis (alveolar echinococcosis)	Consumption of parasite eggs via contaminated food, water, or contact with infected animals	Cystic echinococcosis causes cyst formation in the liver and lungs, while alveolar echinococcosis can cause severe liver damage	Hand hygiene, dog control, proper handling of animals
Trichinellosis	Trichinella spiralis	Consumption of undercooked meat from infected animals (usually pigs)	Fever, muscle pain, facial swelling, gastrointestinal problems	Proper cooking of meat, veterinary meat inspection
Giardiasis	Giardia lamblia	Consumption of contaminated water or food, fecal-oral transmission	Diarrhea, abdominal pain, nausea, vomiting	Proper water purification, hand hygiene

Disease	Pathogen	Transmission	Symptoms	Preventive measures
Leishmaniasis	Leishmania spp.	Bite of infected sand flies	Skin ulcers, fever, weight loss; in severe cases, visceral leishmaniasis can be fatal	Sand fly control, use of protective nets, insecticides
Schistosomiasis	Schistosoma spp	Contact with contaminated water containing cercariae (larval form of parasite)	Rash, fever, chills, muscle pain; in chronic cases, liver, intestinal, lung, and bladder damage	Avoiding swimming in contaminated water, improving sanitation conditions
Toxocariasis	Toxocara canis and Toxocara cati	Consumption of parasite eggs via contaminated food, water, or contact with infected animals	Visceral larva migrans causes fever, cough, abdominal pain, neurological symptoms in severe cases	Hand hygiene, deworming of pets

4.5. Fungal Zoonoses

Fungal zoonoses pose significant health problems, particularly for individuals with weakened immune systems. Fungal infections can be serious and sometimes fatal, transmitted from animals to humans through contact with contaminated environments or direct contact with infected animals. This overview analyzes the most important zoonotic diseases caused by fungi, their characteristics, transmission routes, and preventive measures.

Disease	Pathogen	Transmission	Symptoms	Preventive measures
Histoplasmosis	Histoplasma capsulatum	Inhalation of spores found in contaminated soil or bird droppings	Fever, cough, fatigue, chest pain; in severe cases, disseminated disease affecting multiple organs	Avoiding high-risk areas (e.g., caves, bird or bat droppings), use of protective masks and equipment
Coccidioidomycosis (Valley Fever)	Coccidioides immitis and Coccidioides posadasii	Inhalation of spores from soil in arid and semi-arid areas	Fever, cough, chest pain, fatigue; sometimes rash; in severe cases, disseminated disease	Avoiding dusty areas, use of masks and protective equipment in endemic areas

Disease	Pathogen	Transmission	Symptoms	Preventive measures
Sporo-trichosis	Sporothrix schenckii	Contamination of wounds through contact with contaminated soil, plants, or infected animals (especially cats)	Nodules on the skin that can ulcerate; in severe cases, infection can affect lungs, bones, or joints	Use of gloves and protective equipment when handling plants or soil, treatment of infected animals
Crypto-coccosis	Cryptococcus neoformans and Cryptococcus gattii	Inhalation of spores from soil contaminated with bird droppings or from environments infected with eucalyptus and other trees	Fever, headache, cough; cryptococcal meningitis in severe cases	Avoiding high-risk areas, especially for immunocompromised individuals, proper handling of bird droppings
Dermato-phytoses (Ring-worm)	Trichophyton, Microsporum, Epidermophyton spp.	Direct contact with infected animals or people, contaminated objects or surfaces	Red ring-shaped rash, itching, skin peeling; in severe cases, hair or nail loss	Hand hygiene, avoiding contact with infected animals or people, disinfecting contaminated objects

4.6. Zoonoses from Aquatic Animals

Zoonotic diseases transmitted from aquatic animals to humans pose significant health problems, especially for people frequently in contact with water and aquatic organisms, including fishermen, farmers, aquaculture workers, and water sports enthusiasts. This overview analyzes the most important zoonotic diseases from aquatic animals, their characteristics, transmission routes, and preventive measures.

Disease	Pathogen	Transmission	Symptoms	Preventive measures
Vibrio-sis	Bacteria of the genus Vibrio (e.g., Vibrio vulnificus, Vibrio parahaemolyticus)	Consumptionn of contaminated seafood, contact of open wounds with contaminated seawater	Gastrointestinal symptoms (diar-rhea, vomiting), wound infections, septicemia (espe-cially in immu-nocompromised individuals)	Proper cooking of seafood, avoiding contact of open wounds with seawater

Disease	Pathogen	Transmission	Symptoms	Preventive measures
Leptospirosis	Bacteria of the genus Leptospira	Contact with contaminated water or urine of infected animals	Fever, headache, muscle pain, red eyes; in severe cases, kidney and liver damage	Avoiding contaminated water, use of protective equipment in risk areas
Mycobacterium marinum infection	Mycobacterium marinum	Contact with contaminated water or infected fish, usually through open wounds	Skin lesions often on hands or fingers that can become ulcerated	Wearing gloves when handling fish, avoiding contact of open wounds with water
Schistosomiasis	Parasites of the genus Schistosoma	Contact of skin with contaminated freshwater containing cercariae (larval form of parasite)	Rash, fever, chills, muscle pain; in chronic cases, liver, intestinal, lung, and bladder damage	Avoiding swimming in contaminated water, improving sanitation conditions
Erysipeloid	Erysipelothrix rhusiopathiae	Contact with contaminated fish or shellfish	Red painful rash on hands or fingers, fever, joint pain	Wearing gloves when handling fish or shellfish, proper hand hygiene
Giardiasis	Giardia lamblia	Consumption of contaminated water	Diarrhea, abdominal pain, nausea, vomiting	Proper water purification, hand hygiene
Anisakiasis	Anisakis spp. (parasitic worms)	Consumption of raw or undercooked fish	Abdominal pain, nausea, vomiting, diarrhea	Proper cooking or freezing of fish before consumption
Opisthorchiasis	Opisthorchis viverrini, Opisthorchis felineus	Consumption of raw or undercooked fish	Abdominal pain, diarrhea; in chronic cases, liver and bile duct damage	Proper cooking of fish, avoiding consumption of raw fish

Disease	Pathogen	Transmission	Symptoms	Preventive measures
Norovirus	Noroviruses	Consumption of contaminated food or water, contact with contaminated surfaces	Nausea, vomiting, diarrhea, abdominal pain	Proper hand hygiene, avoiding contaminated food and water
Dioctophyme renale (giant kidney worm)	Dioctophyme renale	Consumption of raw or undercooked fish or frogs	Abdominal pain, hematuria, kidney insufficiency	Proper cooking of fish and frogs, avoiding consumption of raw aquatic animals

5. HOW CLIMATE CHANGE INFLUENCES ZOONOTIC DISEASE EMERGENCE AND EPIDEMIOLOGY

Climate change affects zoonotic diseases through a variety of mechanisms. These include changes in temperature, precipitation patterns, and the frequency of extreme weather events, all of which can alter the habitats and behaviors of both wildlife and disease vectors (such as mosquitoes and ticks).

As global temperatures rise, many species are forced to migrate to new areas to survive, often leading to increased contact between wildlife, livestock, and humans. This can facilitate the spillover of pathogens from animals to humans. Additionally, the destruction of natural habitats due to climate-driven events like wildfires or deforestation further exacerbates this issue by bringing wildlife into closer contact with human populations (Jones et al., 2008).
Climate change can extend the range of vectors that carry zoonotic diseases. For example, warmer temperatures and increased rainfall can create more suitable environments for mosquitoes that carry diseases like Zika, dengue, and malaria. As these vectors spread into new regions, the risk of zoonotic disease transmission increases (Kilpatrick and Randolph, 2012).

Climate change can also affect the survival and transmission of pathogens. Warmer temperatures may increase the survival rates of certain pathogens in the environment, thereby increasing the likelihood of human exposure. Additionally, changes in precipitation patterns can affect the availability of water sources, which can be breeding grounds for pathogens (Patz et al., 2005).

5.1. Impact of Climate Change on Zoonotic Diseases Occurrence and Distribution

Currently, the impact of climate change on the emergence of zoonotic diseases is already observable. However, climate change significantly affects the ecology and epidemiology of zoonotic diseases as well. Changes in temperature, precipitation, and extreme weather conditions can affect the distribution and dynamics of vector, reservoir, and pathogen populations. This chapter indicates how climate change affects the emergence of new and the spread of existing zoonotic diseases, emphasizing quantitative data and examples from relevant literature.

5.2. Impact of Temperature on Zoonotic Diseases

Increasing global temperatures directly impact the distribution of vectors such as mosquitoes, ticks, and rodents that transmit diseases like malaria, dengue fever, Zika virus, Lyme disease, and hantavirus. Warmer climates allow mosquitoes to colonize new areas. For example, the mosquito "Aedes aegypti", which transmits dengue fever, chikungunya, and Zika virus, is now present in parts of Europe where it did not previously exist. The global temperature increase of 1.5°C could increase the number of people exposed to dengue fever by 2.5 billion by 2050 (Rayan et al., 2019). Similarly, ticks of the genus "Ixodes", which transmit Lyme disease, are expanding their range northwards. A study by Ogden et al., (2015) shows that Lyme disease cases in the US increased by 320% from 1991 to 2013, partly due to the northward spread of ticks.

5.3. Impact of Precipitation and Humidity

Precipitation and humidity affect the life cycles of vectors and pathogens. Increased rainfall can create favorable conditions for mosquito breeding, while droughts can drive rodents into human dwellings in search of food and water. A study by Caminade et al., (2014) estimates that increased rainfall in Africa will result in a 50% higher incidence of malaria in high-altitude areas by 2080. In South America, increased rainfall associated with the El Niño phenomenon increases rodent populations, leading to more hantavirus pulmonary syndrome cases. The hantavirus outbreaks in Argentina correlate with years of high rainfall (Hjelle and Glass, 2000). There has been an expansion of tick-borne diseases like Lyme disease in North America, which has been linked to warmer winters and changes in precipitation (Ogden et al., 2014). Similarly, the spread of diseases like West Nile Virus in temperate regions has been associated with climate change-related shifts in bird migration patterns and mosquito populations (Semenza and Menne, 2009).

5.4. Extreme Weather Conditions

Extreme weather conditions like hurricanes, floods, and droughts can cause mass migrations and ecosystem disruptions, increasing the risk of zoonotic diseases. Floods can spread pathogens through contaminated water. For example, floods in Bangladesh often lead to cholera outbreaks, while floods in Germany in 2013 correlated with a 22% increase in leptospirosis cases. Droughts can reduce natural predators of rodents, leading to rodent population increases and higher risks of zoonotic diseases like hantavirus. A study shows that droughts in the southwestern United States were associated with hantavirus case increases (Hjelle and Glass, 2000).

In the future, the intersection of climate change and zoonotic diseases is likely to become even more critical. As climate change progresses, we can expect to be faced with:

- **Increased frequency of outbreaks**: With more frequent and severe climate events, there may be more opportunities for zoonotic pathogens to spill over into human populations. This is particularly concerning for regions that are currently undergoing rapid environmental changes.

- **Emergence of new diseases**: As ecosystems are altered, and species are forced into closer proximity, there is the potential for the emergence of new zoonotic diseases. These diseases may arise from previously unknown pathogens or from the adaptation of existing ones to new hosts (Daszak et al., 2001).
- **Geographical shifts in disease distribution**: Diseases that were once confined to specific regions may spread to new areas as climate conditions change. This will require global health systems to adapt and prepare for diseases in regions where they have not previously been endemic.

The connection between climate change and zoonotic diseases underscores the importance of an integrated approach to global health that considers environmental changes. As the climate continues to change, disease emergence and spread dynamics are likely to become increasingly complex, requiring enhanced surveillance, research, and collaboration across disciplines.

6. MITIGATION, PREVENTION, EMERGENCY RESPONSE AND ELIMINATION MEASURES

Mitigation, prevention, and elimination measures for zoonotic diseases are critical in protecting public health, animal health, and the environment. **Mitigation** reduces the impact of zoonotic outbreaks, limiting the spread and severity of infections. **Prevention** focuses on stopping the transmission of zoonotic pathogens from animals to humans, using strategies like vaccination, biosecurity, and public education. **Emergency response** in the context of a zoonotic disease outbreak refers to the coordinated actions and measures taken by health authorities, veterinary services, and relevant stakeholders to rapidly detect, contain, and mitigate the spread of a disease transmitted between animals and humans. This includes identifying the source of the outbreak, implementing biosecurity measures, deploying medical and veterinary resources, communicating with the public, and collaborating across sectors to protect both human and animal health while preventing further transmission. **Elimination** aims to completely remove the disease from affected populations, often through coordinated efforts such as mass vaccination, surveillance, and strict quarantine measures. Together, these approaches are essential for controlling and ultimately eradicating zoonotic diseases, and safeguarding global health. Strategies like biodiversity conservation, habitat protection, and sustainable agricultural practices, along with enhanced surveillance and global cooperation, are necessary to prevent future zoonotic outbreaks in the context of climate change.

6.1. Biodiversity Conservations

Biodiversity loss is not only an ecological issue but also poses a global threat to human survival and well-being. Despite increasing attention to climate change, biodiversity loss remains largely ignored, despite its essential role in global food production, clean water, and carbon sequestration. Numerous studies and data indicate that species like cheetahs, pandas, green turtles, Asian elephants, polar bears, and penguins are on the brink of extinction. Reduced pollinator numbers, like bees, can negatively impact agricultural production. Moreover, decreased biodiversity can reduce ecosystems' capacity to regulate climate and purify water, increasing human communities' vulnerability to extreme weather conditions and pollution (US EPA 2023). Given the complex relationships between causes and consequences, simple solutions to this problem no longer exist. Key strategies for biodiversity conservation include protecting and restoring natural habitats. Conserving forests, wetlands, and coral reefs can help mitigate climate change and preserve biodiversity. Enacting laws and policies to protect these ecosystems is vital (IFAW 2023).

6.2. Promotion of Sustainable Agricultural Practices and Natural Climate Solutions

Implementing sustainable agricultural practices can reduce the negative impact of intensive agricultural production on biodiversity. This includes protecting forests and agricultural land, using organic farming methods, and reducing pesticide and herbicide use. These practices can increase agricultural systems' resilience to climate change and support biodiversity conservation (2DII 2023). Natural climate solutions, like reforestation, wetland protection, and urban green spaces, can help combat climate change and preserve biodiversity. These measures not only reduce carbon emissions but also provide habitats for many species and improve air and water quality (The Nature Conservancy, 2024). Ecosystem adaptation to climate change involves measures that help ecosystems withstand and recover from the negative impacts of climate change. These measures include habitat conservation and restoration, creating wildlife corridors, and managing invasive species.

6.3. Strategies to Reduce the Risk of Zoonotic Diseases

Preventive measures to reduce the risk of zoonotic diseases include disease surveillance, vector control, animal vaccination, and public health campaigns to reduce contact between humans and potentially infected animals. It is also important to educate the public about zoonotic disease risks and promote hygiene practices that can reduce infection risk. Strategies to reduce the negative consequences of biological disasters include developing and implementing preparedness plans, establishing early warning systems, and strengthening health system capacities to respond to emergencies. Coordination between different sectors and international cooperation is crucial to effectively manage biological disasters.

Olson et al., (2023) emphasize the critical role of the One Health approach in addressing zoonotic diseases by integrating human, animal, and environmental health to prevent pandemics. One health approach advocates for greater environmental sector involvement, highlighting that current health security systems often overlook the environmental factors that drive zoonotic disease emergence. The One Health framework, now reinforced through the Quadripartite collaboration involving the UN Environment Programme (UNEP), the Food and Agriculture Organization (FAO), the World Health Organization (WHO), and the World Organisation for Animal Health (WOAH), reflects a deeper recognition of the interconnectedness between these sectors[6].

The inclusion of UNEP into the existing tripartite partnership underscores the growing need to address root causes like deforestation and wildlife market regulations. This collaboration aims to enhance surveillance, biosecurity, and early detection, recognizing the environment as a key player in pandemic prevention. By reducing human impact on nature, such as through improved wildlife monitoring and regulation, the One Health approach acts as a medical intervention with wide-reaching benefits.

6.4. Strengthening the One Health Approach: Case Studies and Global Collaboration

The One Health approach has become a cornerstone of global zoonotic disease prevention, as it integrates human, animal, and environmental health under a unified strategy. While its theoretical importance is well-recognized, practical applications of this approach demonstrate

[6] *https://www.who.int/news/item/29-04-2022-quadripartite-memorandum-of-understanding-(mou)-signed-for-a-new-era-of-one-health-collaboration*

its true potential in mitigating zoonotic outbreaks. For instance, the Nipah virus outbreak in India serves as a prime example of how the One Health framework helped reduce human exposure to zoonotic pathogens. By implementing community-based interventions to reduce human contact with fruit bats—the natural reservoir of the Nipah virus—public health officials, veterinarians, and environmental scientists worked collaboratively to control the outbreak (Singhai et al., 2021).

Another success story is the Highly Pathogenic Avian Influenza (HPAI) management program in Southeast Asia, where governments collaborated with international organizations such as the WHO, WOAH and FAO in using the One Health approach, this multi-sectoral effort focused on strengthening biosecurity measures in poultry farms, enhancing disease surveillance, and establishing early warning systems for avian influenza outbreaks. The program's success in reducing human cases of HPAI in the region highlights the importance of harmonized efforts across veterinary, public health, and environmental sectors (FAO, 2023).

Despite these successes, gaps remain in the global application of the One Health approach. For instance, many low-resource countries lack the infrastructure and trained personnel needed to implement robust One Health programs. Strengthening these capacities requires investment in cross-sectoral training, improving data-sharing mechanisms between environmental, animal, and human health systems, and ensuring global cooperation at both governmental and non-governmental levels. The One Health Joint Action Plan (OH JPA) for 2022-2026 outlines key strategies to address these gaps, including expanding intergovernmental collaborations and enhancing local capacities to detect and respond to zoonotic disease threats.

Incorporating environmental health more explicitly into pandemic prevention is another critical area where the One Health approach can advance. As reported by Olson et al. (2023), current health security systems often overlook environmental drivers, such as deforestation and biodiversity loss, that create the conditions for zoonotic spillover. Moving forward, integrated efforts that include environmental monitoring and regulation of wildlife trade, deforestation, and land use changes will be essential for reducing zoonotic disease risks.

These examples illustrate that One Health is not just a theoretical framework but a practical, evidence-based approach that has proven effective in various settings. Expanding its adoption globally will require political will, increased funding, and sustained collaboration between governments, international organizations, and local communities.

6.5. One Health Joint Action Plan (2022-2026)

The One Health Joint Action Plan (OH JPA)[7] for the period from 2022 to 2026 represents a coordinated effort of four key organizations: the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), the World Health Organization (WHO), and the World Organisation for Animal Health (WOAH). The goal of OH JPA is to improve the health of humans, animals, plants, and the environment through an integrated and holistic approach.

OH JPA emphasizes the importance of multisectoral cooperation and coordination to effectively respond to complex health threats that arise at the interface between humans, animals, plants, and the environment. The plan is based on the theory of change, which emphasizes the need for changes at three key levels: policy and legislation, organizational development and implementation, and data and evidence. Each of these areas has specific

[7]FAO, UNEP, WHO, and WOAH. (2022). One Health Joint Plan of Action (2022–2026). Working together for the health of humans, animals, plants, and the environment. Rome. https://doi.org/10.4060/cc2289en

activities and goals to be achieved within six action tracks:

1. ***Strengthening capacities for the One Health approach:*** This includes training and workforce development, creating an environment that supports One Health initiatives, and developing tools and mechanisms for effectively implementing the One Health approach.
2. ***Reducing the risk of zoonotic epidemics and pandemics:*** The focus is on understanding the causes and factors that lead to zoonotic disease emergence and establishing early warning and response systems for epidemics.
3. ***Controlling endemic zoonotic, neglected tropical, and vector-borne diseases:*** The goal is to reduce the burden of these diseases through the application of jointly targeted, risk-adjusted solutions and strengthening political engagement and investment.
4. ***Enhancing food safety risk assessments***: This includes improving national food control systems, enhancing risk analyses and assessments, and promoting the One Health approach in foodborne disease surveillance.
5. ***Combating antimicrobial resistance (AMR):*** Actions include strengthening country capacities for AMR control, supporting global and regional initiatives to respond to AMR, and strengthening global governance structures for AMR.
6. ***Integrating the environment into One Health***: The goal is to protect, restore, and prevent ecosystem and environmental degradation, and integrate ecological data and knowledge into decision-making processes.

OH JPA is designed as a flexible document that can be adapted to reflect progress, new challenges, and available resources. Implementation will take place through a multi-year plan with a special focus on national contexts and priorities. Through multisectoral cooperation, OH JPA will enable better understanding and addressing of health threats, promoting sustainable solutions that support the health of humans, animals, plants, and the environment. Key success elements include political will, adequate funding, strong legislative frameworks, and continuous education and community engagement.

7. CONCLUSION

Climate change profoundly impacts environmental health, the emergence of zoonotic diseases, and the frequency and severity of biological disasters. Understanding this dynamic of changes in ecosystems and the epidemiology of zoonotic disease is crucial for developing effective strategies for adaptation, prevention, and risk reduction. However, this will be a demanding task for the scientific and professional communities, especially in communicating new approaches and recommendations to decision-makers. Integrating approaches that connect human, animal, and environmental health, such as One Health, is key to addressing the challenges posed by climate change. The One Health Joint Action Plan represents an ambitious and comprehensive approach to addressing global health challenges. By integrating human, animal, plant, and environmental health, OH JPA has the potential to significantly improve global health systems, reduce the risk of epidemics and pandemics, and support sustainable development.

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Greenhouse Gas Emissions From Agriculture with a Focus on Animal-Based Food Production Systems

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Abstract: According to the latest data (Crippa et al., 2023), global greenhouse gas emissions in 2022 reached 53.8 Gt CO2 eq. The share of the food production sector in global greenhouse gas emissions differs depending on the literature source, making more than 25% of total GHG emissions. Animal-based food production chain generates about 7.5 Gt CO_2 eq (FAO, 2022), contributing to about 15% of total GHG emissions). Livestock production generates several emissions into the air (methane, carbon dioxide, ammonia, and nitrous oxide), primarily from enteric fermentation in ruminants and from manure in all classes of animals. Options to reduce methane emission from enteric fermentation include different nutritional and breeding strategies based on the introduction of methane inhibitors, both biological and chemical, with animal feed to reduce the activity of the methanogenic microorganisms in the gut. Mitigation of GHG emissions from manure is based on decreasing emissions of CH_4, N_2O, and NH_3 through animal feed management and proper manipulation (collection, storage, and use) of the manure.

Keywords: GHG emissions, Agriculture, Livestock, Enteric fermentation, Manure, Mitigation

1. INTRODUCTION

According to recent data, global greenhouse gas emissions of anthropogenic origin amounted to 53.8 Gt CO_2 eq in 2022. The share of the food production sector in total emissions is significant and amounted to 26%. In the last 60 years, global production of ADFs (animal-derived foods) significantly increased: meat and meat products by 403%, milk and milk products by 167%, fish and seafood by 355%, and eggs by 513% (FAO, 2021). The increase in population and the expansion of the consumption of agricultural products have contributed to and still contribute to the increased pressure on ecosystems and natural resources - air, land, water, and biodiversity. The paper focuses on this sector and its impact on GHG emission, considering that animal production in the total GHG emission participates with 14.5%. The paper also deals with various methods and practices that mitigate the emission of gases from animal production and reduce air pollution.

2. GREENHOUSE GAS EMISSIONS FROM THE FOOD PRODUCTION CHAIN

According to the latest data (Crippa et al., 2023), global greenhouse gas emissions in 2022 reached 53.8 Gt CO_2 eq (without LULUCF - land use and land use change), which is 2.3% more than in 2019. CO_2 emissions account for 71.6% of total emissions, methane emissions 21%, N2O 4.8%, and F gases 2.6%. In addition to the use (consumption) of energy as the most significant source of GHG gases, which participates with 74%, the global food production system, which includes pre-farm processes, production on the farm, and post-farm processes, such as processing and distribution, is one of the key emitters. The share of the food production sector in global greenhouse gas emissions amounts to 13.6 billion tons of CO_2 eq or 26% (Poore & Nemecek, 2018), while according to Crippa et al. (2021) and Mbow et al. (2019), emissions from the agrifood sector amount to as much as 17.9 billion tons of CO_2 eq or 34% and 37%, respectively, of the total emission of GHG gases.

According to the EDGAR database for 2015, greenhouse gas emissions from the food production chain amounted to 18 Gt CO_2 eq, i.e., 34% of all GHG gas emissions (considering CO_2, CH_4, N_2O, and F-gases) expressed as CO_2 eq and calculated using GWP100 IPCC AR5, with values of 28 for CH4 and 265 for N_2O. According to FAO (2023a) indicators, the share of the food production sector in the total GHG emissions in 2021 was 30% (Figure 1).

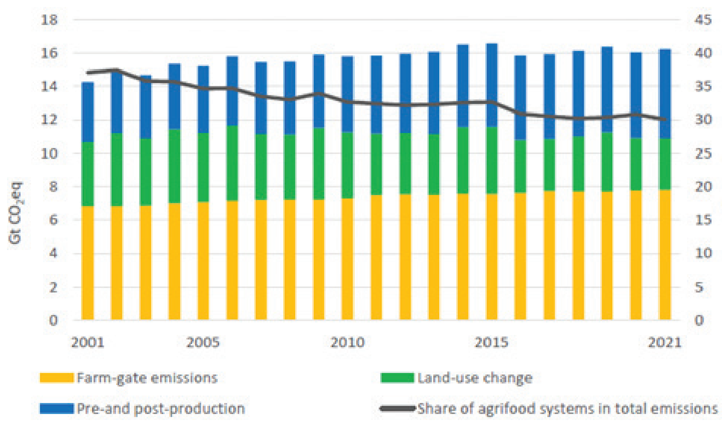

Figure 1. Global agrifood systems emissions (FAO, 2023a)

The reasons for the evident differences in the estimation of greenhouse gas emissions in the food production chain mentioned in the literature are mainly related to the inclusion or non-inclusion in the calculation of specific activities related to the production and consumption of food (cooking and waste, deforestation, exclusion of non-food products such as cotton, wool). Expectations are that a direct consequence of the increase in the global population, estimated at around 9.7 billion in 2050, will increase the demand for food and thus the expansion of agricultural production. Increased food production and increasing GHG emissions will inevitably increase water consumption and negatively affect biodiversity.
In 2015, 71% of global greenhouse gas emissions from the food production sector were directly related to agricultural production and activities related to land use and land use change (LULUC), with livestock and crop production responsible for more than half of emissions GHG gases, while the source of the remaining is land and changes in land use. This statement primarily refers to developing countries where emissions from agricultural production and LULUC are dominant and amounted to 73%, while in developed countries, the share of GHG emissions associated with energy consumption in the food production chain was higher and amounted to 53 % (Crippa. et al., 2021).

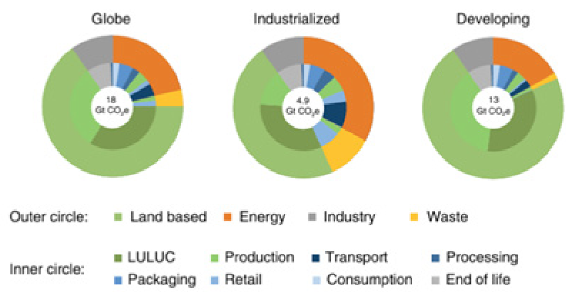

Figure 2. GHG emissions (including CO_2, CH_4, N_2O, and F-gases) at the global level, developed and developing countries from the food system in different sectors in 2015 (Crippa et al., 2021)

Taking into account the life cycle of the product (Figure 2), greenhouse gas emissions from agricultural production, including fishing, aquaculture and fertilizer production at the global level, in developed and developing countries amounted to 39% (7.1 Gt CO_2 eq), the emission related to LULUC 32% (5.7 Gt CO_2 eq), while emissions are related to transport (5%), packaging (5%), retail (4%), processing (4%), consumption (3%) and end-of-life disposal (8%) accounted for a total of 29% (5.2 Gt CO_2 eq) of the total greenhouse gas emissions generated from the food production chain.

Poore and Nemeck (2018) consider four vital elements for quantifying greenhouse gas emissions from the food production chain: (a) supply chain, (b) livestock and fisheries, (c) crop production, and (d) land use. According to the mentioned authors, in the total emission of greenhouse gases, the supply chain participates with 18% (retail 3%, packaging 5%, transport 6%, food processing 4%), livestock and fisheries with 31% (methane from enteric fermentation, manure management, pasture management, fuel use in fisheries), crop production with 27% (crop for human food 21% of food emission, crop for animal feed 6% of food emission) and land use 24% (land use change 18%, cultivated organic soils 4%, savannah burning 2%) where land use for livestock production participates with 16%. In comparison, the participation of land use for human food is 8%. Similar indicators are given by FAO (2023b), where the agrifood chain is divided into three components, where emissions from the farm contribute about half of the total emissions from the sector (7.8 Gt CO_2 eq), emissions before and after production activities 5.3 Gt CO_2 eq and emissions created by changing land use 3.1 Gt CO_2 eq.

Regarding the emission of individual greenhouse gases in the food production chain, CO_2 is the dominant gas, and the share of this gas in the total emissions from the sector in 2015 was 52%. CO_2 emissions in the food production chain are mostly related to energy use, i.e., the consumption of fossil fuels (in production, transport, processing), land use, and changes in land use. In second place is methane, whose participation in the total emission from the sector is estimated at 35%, and the primary source is animal production, that is, enteric fermentation and manure management, waste treatment, and rice production. N_2O emission from the food production sector is estimated at around 10% and is mainly related to animal manure and mineral fertilizers. The emission of F gases accounts for 2%, and the primary source is industry and cooling devices in retail (Crippa et al., 2021). In terms of GHG emissions that are directly related to agricultural production at the farm level (within the farm gate) (excluding emissions generated before and after the farm gate), the most significant emission of greenhouse gases is related to animal production (Figure 3).

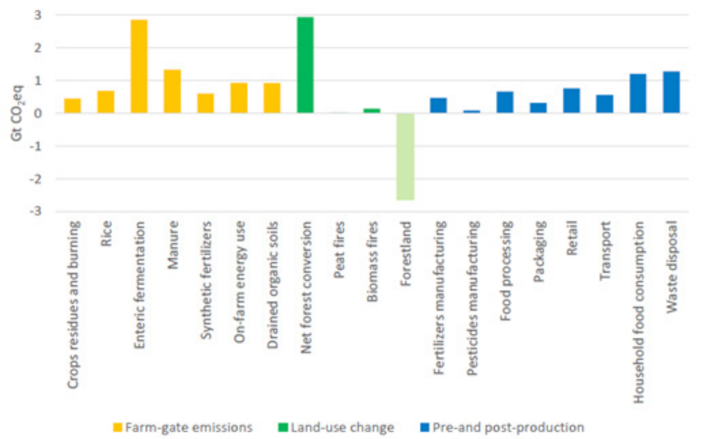

Figure 3. Agrifood systems emissions u 2021 (FAO, 2023b)

Due to the significant share of animal production in the total emission of GHG gases from agricultural production and, in general, the emission of gases of anthropogenic origin, and bearing in mind the expected increased demand for products of animal origin as well as the trend of increasing the total number of domestic animals (cattle, sheep, goats, pigs, and poultry) which in the period from 1970 - 2019 increased by about three times, which is expressed per capita an increase from 2.6 to 4.3 animals (Barthelmie, 2022), in the following text the primary sources of greenhouse gas emissions from animal production will be presented as well as potential measures to reduce the volume of emissions from this sector.

3. EMISSION OF GREENHOUSE GASES FROM ANIMAL PRODUCTION

At the global level, the emission of greenhouse gases from animal production amounts to 14.5% or 7.5 Gt CO_2 eq (FAO, 2023c), whereby about two-thirds (67%) of the gases are emitted from meat production, 30% from milk production, and 3% from egg production. According to

FAO (2022) for 2015, the dominant source of GHG was cattle production, which accounted for 62% of the total emissions from the sector, namely 42% (2.9 Gt CO_2 eq) from meat production and 20% (1.4 Gt CO2 eq) from milk production. The contribution of other types of domestic animals to the total gas emissions was significantly lower and ranged between 7 and 14%, with pig farming contributing 14%, buffalo meat and milk production 8%, poultry (chicken) 9%, and small ruminants 7%.

When considering the share of individual greenhouse gases in the total emission from the livestock sector, methane participates with 54%, CO_2 with 31%, and N_2O with 15% (FAO, 2023c). According to FAO GLEAM 3.0 calculations, methane emissions from enteric fermentation, manure, and animal feed production amounted to 46%, 7.8%, and 0.32%, respectively.

The emission of N_2O related to animal feed production amounted to 9.8%, and from manure to 5%. The most significant CO_2 emissions are associated with the production of animal feed (12%), LUC (land use change) due to the expansion of pasture areas (9.3%), post-farm activities (5.4%), and direct and embedded on-farm energy (3%) (FAO, 2022).

Excluding animal feed as an indirect source of emissions, direct greenhouse gas emissions from animal production are linked to CH_4 emissions from enteric fermentation and manure and N_2O emissions from manure (manure management, manure applied to the soil, and manure left on pastures). In 2021, these emissions amounted to 4.2 Gt CO_2 eq, or 54% of total emissions from agricultural production (FAO, 2023b).

Significant differences can be observed in the emission sources of different species of ruminants and non-ruminants. In ruminant meat and milk production, methane from enteric fermentation accounts for the largest share of total emissions. In pig and poultry production, the primary sources of emissions are feed production, LUC, and manure management. The following table describes the primary sources of CO_2, CH_4, and N_2O emissions in the animal production chain.

Table 1. Emission sources in animal production (FAO, 2022)

Source of emissions		Description
Feed CO_2	Field operations	CO_2 emissions arising from the use of fossil fuels during field operations
	Fertilizer production	CO_2 emissions from the manufacture and transport of synthetic nitrogenous, phosphate, and potash fertilizers
	Pesticide production	CO_2 emissions from the manufacture, transport, and application of pesticides
	Processing and transport	CO_2 generated during the processing of crops for feed and the transport by land and/or sea
	Blending and pelleting	CO_2 arising from the blending of concentrate feed

Source of emissions		Description
Feed land-use change CO_2	Soybean cultivation	CO2 emissions due to LUC associated with the expansion of soybean
	Palm kernel cake	CO2 emissions due to LUC associated with the expansion of palm oil plantations
	Pasture expansion	CO2 emissions due to LUC associated with the expansion of pastures
Feed N_2O	Applied and deposited manure	Direct and indirect N_2O emissions from manure deposited on the fields and used as organic fertilizer
	Fertilizer and crop residues	Direct and indirect N_2O emissions from applied synthetic nitrogenous fertilizer and crop residue decomposition
Feed CH_4	Rice production	CH_4 emissions arising from the cultivation of rice used as feed
Enteric fermentation CH_4		CH_4 emissions caused by enteric fermentation
Manure management CH_4		CH_4 emissions arising from manure storage and management
Manure management N_2O		N_2O emissions arising from manure storage and management
Direct energy use CO_2		CO_2 emissions arising from energy use on-farm for ventilation, heating, etc.
Embedded energy use CO_2		CO_2 emissions arising from energy use during the construction of farm buildings and equipment
Postfarm CO_2		CO_2 emissions from the processing and transport of livestock products

Figure 4 and Table 2 show significantly higher greenhouse gas production from animal production than from plant production. The production of GHGs expressed in kg CO_2 eq for producing some plant and animal products is shown. The “carbon footprint” for a kilogram of beef, sheep, pork, and poultry is 99, 39, 12, and 9 kg CO_2 eq, while for a kilogram of milk, it is 3.15 kg CO_2 eq.

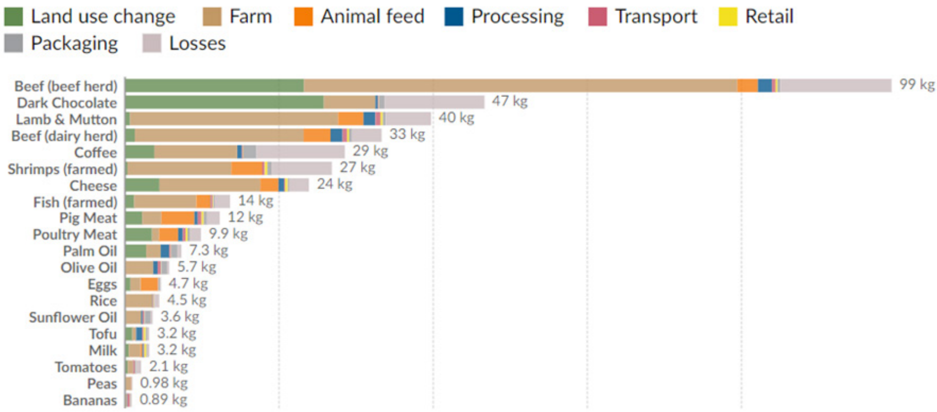

Figure 4. The enviromental impact of food - greenhouse gas emissions across the supply chain, CO2 eq/ kg of food (Poore & Nemecek, 2018).

Table 2. The share of certain activities in the animal production chain in producing greenhouse gases expressed in kg CO_2 eq/kg product (adapted according to Poore and Nemecek, 2018).

	Beef (beef herd)	Beef (dairy herd)	Lamb & mut-ton	Milk	Pig meat	Poul-try meat	Eggs	Fish (farmed)	Shrimps (farmed)
Land use change	23.24	1.27	0.65	0.51	2.24	3.51	0.71	1.19	0.33
Farm	56.23	21.92	27.03	1.51	2.48	0.93	1.32	8.06	13.45
Animal feed	2.68	3.5	3.28	0.24	4.30	2.45	2.21	1.83	4.03
Processing	1.81	1.55	1.54	0.15	0.42	0.61	0.00	0.04	0.00
Transport	0.49	0.59	0.68	0.09	0.50	0.38	0.08	0.25	0.33
Retail	0.23	0.25	0.30	0.27	0.28	0.24	0.04	0.09	0.35
Packaging	0.35	0.37	0.35	0.10	0.43	0.29	0.16	0.14	0.54
Loses	14.44	3.85	5.9	0.27	1.66	1.45	0.15	2.03	7.83
Total	99.48	33.30	39.72	3.15	12.31	9.87	4.67	13.63	26.87

4. METHANE EMISSION FROM ANIMAL PRODUCTION

Methane has a 28 times more substantial thermal effect than CO_2 and remains in the atmosphere for about twelve years on average. Globally, 50-60% of methane emissions originate from the agricultural sector, primarily from animal and rice production. Methane is a natural final product of rumen digestion of feed, and about 90% of the methane emitted by ruminants is synthesized in the rumen. The rest is synthesized in the large intestine. Methane synthesis in non-ruminants takes place in the large intestine.

Ruminants, as the most significant emitters, annually produce 86 million tons or 86 teragrams (Tg) of methane, with dairy cattle emitting 18.9 Tg, fattening cattle 55.9 Tg, sheep and goats 9.5 Tg, buffaloes 6.2-8.1 Tg, camels 0.9-1.1 Tg. Methane production in the large intestine of non-ruminants is significantly lower, so the methane emission from pig farming amounts to 0.9-1.0 Tg, while horses emit 1.7 Tg of methane annually.

4.1 Methane emission from enteric fermentation

Methane synthesis in the rumen is a normal physiological process for which the presence of methanogenic bacteria and an anaerobic environment is necessary. About 200 different microorganisms participate in the breakdown of feed in the rumen, which provides the host animal with nutrients necessary for survival, growth, and development. The rumen is inhabited by various microorganisms, among which the most important are bacteria, protozoa, fungi, and viruses. Bacteria and protozoa participate in the breakdown of carbohydrates (fiber, starch, and sugar), fungi in the breakdown of fibers, and viruses generally do not participate in fermentative processes. Methanogenic bacteria belong to the domain *Archaea*, kingdom *Euryarchaeota*. The central role of methanogenic microorganisms is the synthesis of methane.

Methanogens produce methane mostly from hydrogen and carbon dioxide, produced during the fermentation of structural and non-structural carbohydrates. The presence of hydrogen in the rumen inhibits fermentation processes. If hydrogen was not used for methane synthesis and thus removed from the rumen, its presence would inhibit the metabolism of microorganisms and thereby prevent the optimal flow of feed digestion in the rumen. Oxidation and synthesis of methane removes hydrogen from the rumen, which provides optimal conditions for microbiological decomposition of feed. Hydrogen release occurs during the production process of volatile fatty acids, namely acetic and butyric acids, from carbohydrates. In addition to methane synthesis, the released hydrogen is also eliminated during the propionate synthesis process and by biohydrogenation of diet fat. It is also used as a substrate for acetogenic bacteria, sulfur-reducing bacteria, and nitrogen-reducing microorganisms.

By releasing methane, animals lose 2-12% of the energy of the consumed feed, which is about 6% of global GHG emissions of anthropogenic origin. Several factors influence the amount of energy loss, and the most significant could be the quality and method of feed processing, level of feed consumption, species, animal age, animal body weight, direction of production, and geographical location. Diet energy losses in the form of methane in dairy cattle amount to 5.5-8%, fattening cattle 3.0-6.5%, buffalo 7.5-9%, and camels 7-9%.

4.2 Methane emission from manure

Methane is also produced during the anaerobic microbiological decomposition of manure organic matter. The amount of methane originating from manure is significantly smaller. It depends primarily on how the animals are kept, the length of time the manure is stored, and the ambient temperature. It is estimated that the total annual methane production from manure amounts to 17.5 million tons. More significant amounts of methane are produced when manure is stored in liquid form, which enables anaerobic microbiological decomposition compared to storage in solid form and an aerobic environment. Higher environmental temperatures, as well as higher moisture content in the substrate, also favor methane production. The average methane emission from the covered slurry is 6.5 kg/m^3 per year; in uncovered slurry, 5.4 kg/m^3, while solid manure emissions are 2.3 kg/m^3 (Hristov et al., 2013).

5. MITIGATION OF METHANE EMISSIONS FROM ENTERIC FERMENTATION

Reducing methane emissions is one of the ways to quickly limit global warming to 1.5^{0}C above preindustrial levels, precisely because of its relatively short stay in the atmosphere and high global warming potential. If methane emissions, determined in 2020, were to be reduced by 30% by 2030, the increase in the average global temperature by 2050 would be reduced by more than 0.2^{0}C (FAO, 2023d).

Strategies to reduce enteric methane emissions in ruminants can be divided into three categories: (i) strategies aimed at improving the quality of feed and changing the structure of the diet, (ii) the application of various additives to the diet that inhibit methanogens or reduce the amount of substrate necessary for methanogenesis and (iii) application of various biotechnological methods. Some of the strategies have been well-researched and are already in use, while some are still in the experimental phase, and additional research is necessary. Strategies differ in how they operate, and applying a particular strategy depends on the production system and local conditions. Extensive production systems that include grazing are challenging and require a particular approach because many strategies cannot be applied to such systems. The effectiveness of the application of individual strategies in reducing methane emissions ranges from weak (reduction of less than 1%) to moderate (reduction of CH_4 emissions by 15-25%) and high (reduction of CH_4 emissions by more than 25%). By applying specific dietary strategies or combining strategies that differ in their mode of action, it is possible to reduce methane emissions by 40% and, in some cases, even by 75%.

5.1. Strategies aimed at improving feed quality and changing ration structure

Forage. Due to the high content of cellulose, hemicellulose, and lignin, a diet based on a predominantly forage directs the fermentation in the rumen to the production of a larger amount of acetic acid, which also increases the production of methane.

The quality of forage significantly impacts the level of methane emissions in ruminants. Feeding animals with high-quality and digestible feed generally increases feed consumption and animal production. In contrast, the conversion of diet energy into methane and methane production per unit of product decreases. By increasing the quality of feed, manure production is reduced, and therefore, the emission of CH_4 and NH_3 from manure.

When ruminants are fed low-quality feed, 12% of the consumed energy is converted into methane (with highly digestible diets, the conversion is only 2%). To reduce methane production, the fiber content in forage should be lower, and the content of soluble carbohydrates should be higher. In the case of pasture feeding, livestock should be grazed only in the period when the plants are in an earlier stage of development. A diet with legumes or a higher proportion of legumes reduces methane production in the rumen, partly due to the lower proportion of fiber and faster passage of feed through the digestive tract, but also the presence of tannins and saponins in these feeds. Legumes reduce methane production by 12 to 15% (expressed based on consumed dry matter), primarily due to the toxic effect on methanogens.

Increasing forage digestibility directly affects methane emissions caused by rumen fermentation and methane originating from manure.

Silages are generally more digestible than hay. Chemical treatment of poor quality forage, the addition of molasses or urea, proper balancing of rations, selection of cereals to obtain better quality straw, use of C3 grasses instead of C4, and use of high starch forages (whole plant cereals, sorghum, and maize) are pretty effective strategies by which methane emission is reduced or maintained at a certain level. An increased level of nutrition accelerates the passage of feed through the digestive tract, which reduces methane production in the rumen. By changing the cation-anion ratio of the voluminous diet, methane production in the rumen is reduced, while other aspects of rumen fermentation remain unchanged.

Concentrate feeds. By increasing the proportion of concentrate feed in rations for ruminants, methane production per unit of product (meat, milk) is reduced. Losses of energy consumed by methane amounted to 6-7% when feeding diets containing 30-40% concentrate feed. A sudden drop in methanogenesis, i.e., the decreasing loss of total energy consumed to 2-3%, was determined when feeding with rations in which the share of concentrate feed amounted to 80 to 90%.

A high proportion of concentrate feed in diets increases the consumption of feed and non-structural carbohydrates (starch and sugar), the volume of fermentation in the rumen, and accelerates the passage of feed. This change in the structure of the diet is accompanied by a change in the microbial population in the rumen in the direction of an increase in the number of microorganisms that participate in the fermentation of starch, which results in an increased production of propionic acid. With this flow of fermentative processes in the rumen, the amount of free hydrogen entering the methanogenesis process decreases, reducing methane production. Due to the increased volume of fermentation, the pH of the rumen is lowered, which creates unfavorable conditions for the growth of protozoa, methanogens, and cellulolytic bacteria. To significantly reduce methane production in the rumen, the proportion of concentrate feed in the diets should be greater than 50%; that is, the proportion of starch in the diet should be at least 45%.

Animals' feeding systems also affect methane production. Methane production is lower when fed total mixed rations (TMR) than in separate forage and concentrate feeds.

Dietary supplementation of lipids. Traditionally, the main goal of adding fat to ruminant rations is to meet the increased energy needs of high-yielding animals. More recently, adding fat and oil to ruminant diets is one way to reduce the rumen's methanogenesis. Fats do not affect starch fermentation. The decrease in methanogenesis directly results from the toxic effect of fatty acids on protozoa and methanogenic bacteria. Biohydrogenation of unsaturated fatty acids directly inhibits methanogens. The extent to which such an effect will manifest itself depends primarily on the type of fatty acids and the amount of fat added to the rations, the number of carbon atoms in the fatty acid chain and the composition of the basal ration.
Fatty acids of medium-long chains (C_8-C_{14}), originating from palm and coconut oil, most effectively reduce methane production. When adding oil to defaunate the rumen, the influence of oil on the extent of protein and fiber degradation in the rumen should be considered.
Fatty acids have multiple mechanisms of action on methanogenesis. Medium-chain fatty acids directly affect the number of methanogens. Polyunsaturated fatty acids have a toxic effect on cellulolytic bacteria, and protozoa. In this way, the fermentation flow is directed towards the synthesis of propionic acid, and only a small amount of hydrogen is used to hydrogenate polyunsaturated fatty acids.

Rumen manipulation – application of various supplements to diets

Ionophores. Adding ionophores to feed ruminants, in addition to the positive effect on milk and meat production, significantly reduces methane production in the rumen. The mechanism of action of the ionophore is manifested through a change in the bacterial population from Gram-positive to Gram-negative bacteria, which directly affects the change in the course of fermentation in the rumen in the direction of propionic acid synthesis. Higher propionic acid production reduces the availability of hydrogen necessary for methane synthesis. Ionophores also reduce protozoa populations in the rumen. Usual amounts of monensin, which do not exceed 20 mg/kg diet, only slightly reduce methane production. The addition of monensin in the amount of 24 to 35 mg/kg diet reduces methane production by 4% to 10%, and over a shorter period of time, even by 30%.

The short effect of ionophores, the ban on the use of antibiotics as additives in animal feed in EU countries, and the general negative attitude of consumers towards adding antibiotics to animal feed are the main reasons that exclude the use of ionophores as inhibitors of methanogenesis.

Adding nitrates and sulfates to rations. By adding nitrates and sulfates to ruminants' rations, methane production in the rumen is significantly reduced. Due to the potentially toxic effect of nitrates or nitrites (formed by the reduction of nitrates), the addition of nitrates to animal feed is prohibited in some EU countries. Since adding nitrates to diets in small amounts does not have a toxic effect on the animal, future research should focus on determining the optimal amounts of nitrates in diets for different domestic animals.

Chemical inhibitors of methanogenesis. Some chemical compounds added to diets in small concentrations effectively reduce methanogenesis in the rumen. The best effect was shown when using bromochloromethane (BCM), 2-bromoethanesulfonate (BES), chloroform and 3-nitrooxypropanol (3-NOP). 3-NOP is also commercially available in some countries. By chemically inhibiting protozoa and archaea, methane production is reduced by up to 90%. Despite the pronounced reduction of methanogenesis, the mentioned compounds are not accepted in practice due to their potentially toxic effect on humans, animals and the environment. A potential problem is the adaptation of microorganisms to some of the mentioned compounds.

Essential oils. The addition of essential oils (secondary plant metabolites) to ruminant rations inhibits the growth of some Gram-positive and, to a lesser extent, Gram-negative bacteria, which reduces the extent of deamination and methanogenesis in the rumen and, thus, the production of ammonia nitrogen, methane and acetate. The mode of action varies and depends on the composition of the essential oil. In a limited number of in vivo trials, the addition of commercial products containing essential oils (commercial mixture of coriander, eugenol, geranyl acetate and geraniol, oregano oil, citrus extract and allicin) to the rations of dairy cows and feedlot steers, reduced CH_4 yield by 10, 22 and 23% (Belanche et al., 2020; Kolling et al., 2018; Roque et al., 2019).

Tannins (Tannin extracts). The mechanism of action of tannins on rumen methanogens still needs to be completely clear. Tannins slow down the growth and activity of both methanogenic bacteria and protozoa. By feeding ruminants with fodder rich in tannins, such as red clover (Trifolium pratense), birdsfoot trefoil (Lotus corniculatus) and white clover (Trifolium repens), it is possible to reduce methane production by up to 55%. However, tannins in higher diet concentrations negatively affect fiber digestibility and animal productivity. The poor digestibility of fibers is a consequence of the toxic effect of tannins on the bacteria that participate in the breakdown of fibers in the rumen. Tannins reduce methanogenesis by directly acting on methanogenic bacteria and protozoa and indirectly through reduced hydrogen production due to weaker fiber digestion. In addition to the negative impact on fiber digestibility, tannins also reduce the absorption of amino acids. Research by Grainger et al. (2009) showed that adding tannins to the rations of dairy cows reduces methane production by 30% and milk production by 10%. For the dosage and use of tannin, which would achieve a balance between the reduction of methanogenesis and the antinutritional effect, it is necessary to carry out additional research.

Saponins. Saponins are surface-active glycosides (natural detergents) present in many plant species. They have a suppressive effect or eliminate protozoa populations in the rumen. CH4 mitigating effect depends on the saponin source, chemical structure, concentration and composition of the diet. The mechanism of action of saponin is manifested by limiting the availability of hydrogen for methane synthesis. It was found that saponins can reduce methane production by up to 50%. Commercial sources of saponin are Yucca schidigera and Quillaja saponaria. The biggest problem with the routine use of saponins and tannins is the price of the plant-derived saponins and tannins on the market.

Prebiotics. Prebiotics stimulate the growth of certain groups of microorganisms - Selenomonas, Succinomonas, and Megasphaera - and direct fermentation in the rumen towards the production of propionic acid. At the same time, they inhibit the growth of bacteria of the genera Ruminococcus and Butyrivibrio, which direct fermentation in the rumen towards the production of acetic acid. Adding galactooligosaccharides (GOS) reduces methane emissions by 11%.

Immunization against methanogens. In recent years, research has focused on the application of various biotechnological strategies to reduce rumen methanogens. Administration of vaccines against three rumen methanogens reduced methane production in Australian sheep by 8%. On the other hand, tests of the effect of immunization in other geographical areas did not give the desired results. The main reason for the weak effect of immunization lies in the high diversity of methanogens that inhabit the rumen; that is, excluding certain types of methanogens enables the reproduction of other species. Vaccines should act on all methanogenic bacteria in the rumen to achieve the desired effect.

Bromoform-containing seaweeds (Asparagopsis spp.). By adding macroalgae to the diets of ruminants, it is possible to reduce rumen methanogenesis significantly. In the conducted in vivo and in vitro research, the best results were obtained with two red macroalgae Asparagopsis taxiformis and Asparagopsis armata, due to the ability of the algae to synthesize and accumulate bromoform and dibromochloromethane (Machado et al., 2016). Depending on the applied dose, methane production can be reduced from 9 to 98%. Adding 1% and less than 1% algae to diets reduces methane production by over 50%. Red and brown algae exhibit more significant methane production mitigation potential than green algae. The use of algae to mitigate methane emissions is still in the experimental phase, and additional research is necessary to overcome potential safety risks for humans, animals, and the environment.

Defaunation. The role of protozoa in methane production is related to hydrogen transfer by methanogenic bacteria. Methanogens bound to ciliates intracellularly and extracellularly produce from 9% to 37% of methane in the rumen. By reducing the population of protozoa in the rumen, the number of methanogens associated with protozoa also decreases, which ultimately results in reduced methane production. It is possible to reduce the protozoa population by using copper sulfate, acids, surfactants, fats, tannins, ionophores, and saponins. The best results are achieved when feeding animals with highly concentrated rations. Defaunation can reduce methane production by up to 13% when feeding ruminants with starch-based diets. The effect of defaunation on methane production can last longer than two years.

Animal breeding and management. Increasing animal productivity reduces the intensity of methane emission expressed per product unit, but in most cases, the absolute daily emission (g CH_4/day) increases. Increased animal productivity results from implementing various feeding and breeding practices (balanced nutrition, disease prevention, and selection). It is essential to point out that the increased productivity of animals will increase methane emissions if the efficiency of feed conversion is not increased or the number of animals in the herd is reduced.

It was found that animals with the same nutritional conditions show significant variations in methane production. In an experiment with sheep on a pasture diet, individual differences in methane emissions per unit of consumed feed were determined. The cause of the observed differences in methane emissions is still not clear. The possible influence of genetic factors on methane production is not excluded. If confirmed, selection could produce animals that emit significantly lower amounts of methane than the average, while the animal's production would remain unchanged. On the other hand, the different number of methanogens in the rumen of animals could explain these differences.

6. GREENHAUS GAS EMISSIONS FROM MANURE

Manure is a source of methane, N_2O, and NH_3 emissions, and the amount of emitted gases depends on the method of manure management, environmental conditions, and manure composition. Manure management includes a process that begins with the excretion of feces and urine, continues with the storage and treatment of manure, and ends with the spreading of manure on agricultural land. Emission of CH_4 and N_2O can occur in each of the mentioned phases. The GHG emission from the manure of different types of domestic animals is shown in Figure 5.

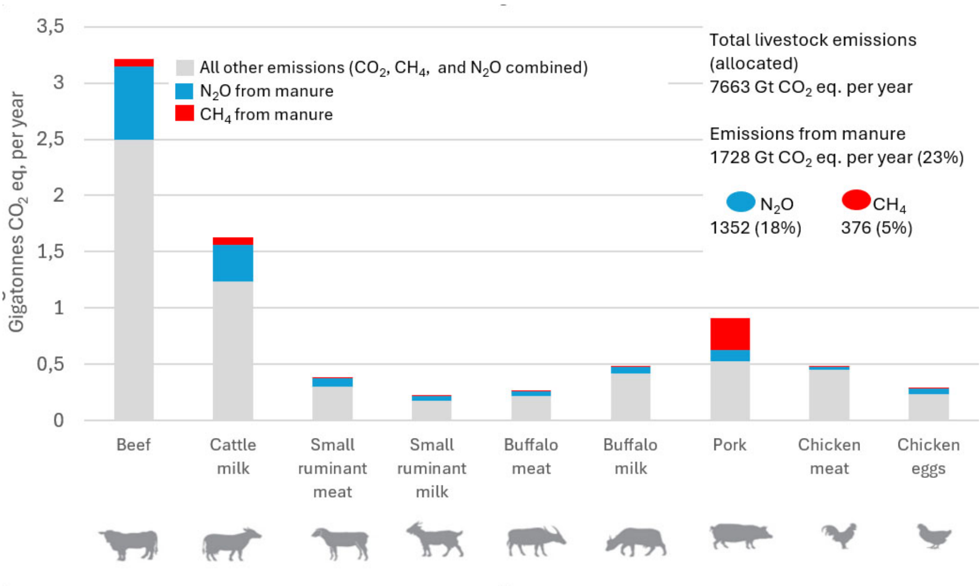

Figure 5. Emission from manure by animal species (UNFCCC, 2019)

6.1 Methane emission from manure

It is estimated that the total annual methane production from manure amounts to 17.5 million tons (FAO, 2023d). Most methane is produced during manure storage, especially during liquid manure storage. Methane is produced during the anaerobic microbiological decomposition of manure organic matter. Methane production begins with anaerobic microbiological hydrolysis and degradation of manure organic matter to long-chain acids, proteins, or alcohol. Further fermentation leads to the formation of short-chain acids that methanogens (Archaea) transform into CH_4 and CO_2 (Sommer et al., 2013). The methane from manure is significantly lower than the emission from enteric fermentation. It depends primarily on animal housing, the chemical composition of manure, manure storage and management, the length of storage, and the ambient temperature. More extended storage periods, warm and humid storage conditions, liquid manure (slurry) processing in lagoons or tanks, and anaerobic environments increase methane production. The production of CH_4 at a temperature lower than 15^{0}C is negligible, and significant amounts of methane are produced only after a few months. Methane production starts immediately at a temperature of 20^{0}C if the channel or pit contains residual slurry. The start of production is postponed for 20 days if the channel or pit is empty. The optimal pH for methane production ranges from 6 to 8. More significant amounts of methane are produced when manure is stored in liquid form, which enables anaerobic microbiological decomposition compared to storage in solid form and an aerobic environment. The average methane emission from the covered slurry is 6.5 kg/m^3 per year, in uncovered slurry 5.4 kg/m^3, while solid manure emissions are 2.3 kg/m^3 (Hristov et al., 2013). Animal nutrition also significantly affects the volume of methane emissions. A higher proportion of concentrate feed in diets increases methane emissions compared to feeding with roughage, i.e., feeding with less digestible diets. Regarding storage outside the facility,

CH_4 emissions vary depending on the ambient temperature and the storage method. Storage of more significant amounts of slurry over extended periods increases methane emissions.

The methane emission during manure application to the soil lasts for a short time due to oxygen diffusion into the manure.

6.2 N2O emission from manure

There are three primary sources of N_2O emission from the agricultural sector: (i) direct emission from agricultural land, (ii) direct emission from animal husbandry, and (iii) indirect emission because of various agricultural activities. Excessive use of mineral and organic fertilizers is the most significant source of N_2O of anthropogenic origin. Nitrification and denitrification processes produce N_2O during storage, manipulation, and manure application in aerobic and anaerobic environments. The amount of N_2O emitted from manure depends on animal nutrition, the chemical composition of manure (C:N ratio), method of manure storage, length of manure storage, climatic conditions during storage, and manure application.

Nitrification is an aerobic process for which, in addition to oxygen, a group of autotrophic bacteria and Archaea is necessary. Some bacteria belong to the genera Pseudomonas, Thiobacillus, and Micrococcus. During nitrification, NH_4+ is converted into nitrate, whereby N_2O is formed as a byproduct (Figure 6). Denitrification is a process in which N_2 is formed from nitrates under anaerobic conditions. During the entire process, N_2O is released as an intermediate gas. The denitrification process is entirely dependent on the nitrification process. Due to the lack or smaller amount of oxygen, the production of N_2O in liquid manure is lower than in manure stored in a solid state. Higher production of N_2O, compared to N_2, is favored by a lower pH value and lower humidity of the environment.

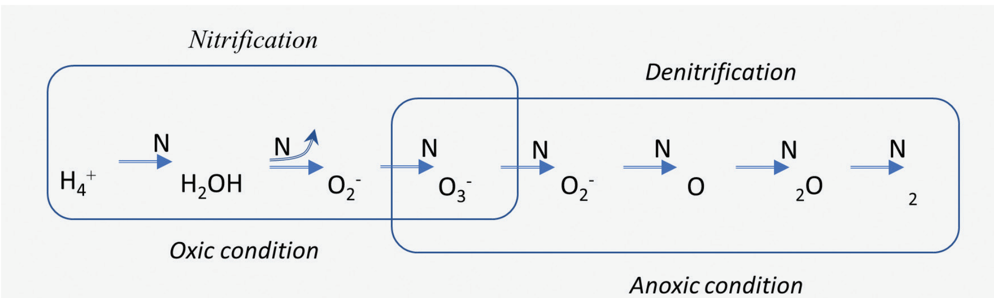

Figure 6. Chemical processes responsible for N2O production (Chadwick et al., 2011)

Direct production includes the emission of N_2O from domestic animal feces and urine, while indirect production includes N_2O created from NH_3 and NOx or from nitrogen runoff and leaching into the soil.

The volume of N_2O emissions increases with increasing N concentration in the manure. Most of the nitrogen in manure is in organic form, which needs to be mineralized to NH_4+ to turn into N_2O. An increase in temperature also increases the emission of N_2O. A temperature of 40 to 45^{0}C inactivates microorganisms and stops the production of N_2O. The most significant $N2_O$ is emitted from manure applied to the field, while a more minor part is emitted during solid manure storage.

6.3 NH3 emission from manure

Manure, urea, and NH4-fertilizers are the primary sources of ammonia emissions. NH_3 participates in acidification, eutrophication, and the formation of particles with a diameter of 2.5 µg (PM2.5). Ammonia is released by microbiological and chemical decomposition of animal excreta (protein from feces, urea, and uric acid). Under favorable ambient conditions, urea excreted from the animal's body is converted to NH_4+ under the action of the urease enzyme of microbial origin. NH_4+ is a precursor for NH_3, NO_3- and N_2O. The most significant loss of nitrogen from manure is ammonia, which amounts to 30-70% of the total content of NH_4+ in manure. NH_3 emissions from animal milk, and beef production contribute 54%, poultry 33%, and pig farming 12%. Most ammonia is emitted during the storage and spreading of manure on arable land and pastures. After manure application, about 1.5 times more ammonia is emitted from pastures than from arable land emissions.

The amount of ammonia emission is affected by the moisture content in the manure, nitrogen content, temperature, aeration conditions, pH of the manure, and chemical and microbiological activities. Ammonia emission occurs on the surface of manure. Fast airflow significantly increases ammonia emissions. Over half of the nitrogen from manure stored in anaerobic lagoons and open manure pits can be lost in this gas.

Ammonia remains in the atmosphere for a short time. It is usually returned by precipitation or in the form of dry particles and deposited in the soil and water, causing soil acidification and eutrophication of surface waters. In the air, it easily binds with sulfuric and nitric acid, creating particles of harmful aerosols – (NH_4)2SO4 and NH_4NO_3. Ammonium aerosols account for 47% of suspended PM2.5 particles (particles ≤ 2.5 microns in diameter) (Silvern et al., 2017). Unlike ammonia, aerosols have a longer lifetime (up to 15 days) and can be deposited over greater distances. Fine aerosol particles can create fog and affect visibility. Also, they can penetrate the human and animal respiratory systems and cause health problems.

7. MITIGATION OF CH4, N2O AND NH3 EMISSIONS FROM MANURE

Inadequate manure management represents a potential environmental and human and animal health risk. Nitrate leaching, eutrophication of surface waters, accumulation of heavy metals in the soil, and emissions of NH_3, CH_4, and N_2O gases are just some of the consequences of uncontrolled manure accumulation. Reducing CH_4, N_2O, and NH_3 emissions can be achieved by applying different strategies that include activities related to animal feeding, animal housing, manure storage, grazing, and application of manure as fertilizer.

The application of different nutritional techniques, which improves the digestibility and utilization of feed, significantly reduces the excretion of nutrients through feces and urine. Techniques that most effectively reduce the excretion of nutrients, primarily nitrogen, include feeding animals using balanced diets, increasing feed digestibility by using additives (synthetic amino acids, enzymes, probiotics), increasing digestibility feed processing, application of multiphase nutrition, use of specific feeds like hybrids (oily or lysine corn hybrids), proper rationing of protein as the primary source of nitrogen, etc. By reducing the protein content in diets to an optimal level, the emission of N_2O and NH_3 from manure decreased by 30% and 42%, respectively (Sajeev et al., 2018).

Implementing certain practices involving storing and manipulating manure has shown promising results. Daily or weekly manure removal from facilities reduces methane emissions by 55%, N_2O by 41%, and NH_3 by 22%. Frequent displacement of liquid manure (slurry) from the facility and exposure to lower external temperatures reduces methane emissions. The outdoor storage facility must be emptied during the summer, and slurry must be applied to the fields. In this way, CH_4 emissions are reduced by 9-10% (Sommer et al., 2013).

Animal stalls in which straw-based bedding is applied and stalls in which solid manure is stored have higher N_2O emissions than facilities with liquid manure. Also, the highest concentration of ammonia on dairy farms was determined in facilities where the gravity-flow system is applied, in which manure accumulates in the facility and is collected several times during the year, compared to flush and daily scrape manure. The lowest methane emissions were also found with the flush compared to the gravity-flow system. On pig farms, GHG emissions were determined to be 20% higher in facilities with a straw-based deep litter housing system compared to slatted floors housing for CH_4 16.3 and 16.0 g/swine per day, for N_2O 0.54 and 1.11 g/pig per day, and for NH_3 6.2 and 13.1 g/swine per day (Philippe et al. (2007).

Shortening the storage time of manure reduces GHG emissions.

A decrease in the temperature of the manure slows down microbiological activity and, thus, the emission of gases. Reducing the temperature of the manure below 10^0C and exposing the manure to lower external temperatures reduces methane emissions.

One of the options for reducing GHG emissions is the application of different storage covers. Covering manure during storage reduces the emission of NH_3 by 65% and CH_4 by 12% but also increases the emission of N_2O by more than 500% due to the creation of aerobic and anaerobic zones that enable nitrification and denitrification (Sajeev et al., 2018). Semi-permeable storage covers reduce the emission of NH_3 and CH_4 but increase the emission of N_2O due to oxygen passing under the cover. On the other hand, closed plastic covers reduce the emission of all three mentioned gases. It is important to note that when using impermeable covers, it is necessary to capture the released methane, which can then be used to produce electricity. Otherwise, there could be an explosion and a rupture of the cover (Montes et al., 2013)

GHG emissions reduction can also be achieved by processing (treatment) manure through anaerobic digestion, acidification, and composting. Anaerobic digestion produces CH_4 and CO_2. Anaerobic digestion is a process in which Archaea produce methane, CO_2, and other gases from the organic matter of manure. Methane obtained by anaerobic digestion is used as a renewable source of energy. Anaerobic digestion reduces methane emissions by 29% and N_2O emissions by 23% (Sajeev et al., 2018). Digesters of different capacities are in use, from smaller ones adapted to a smaller number of animals (10 cows, up to 5 pigs) to industrial ones designed for commercial farms. The application of this system requires high initial investments. Using anaerobic digestion is not recommended in geographical areas with an average temperature below 15^0C.

Acidification of manure lowers the pH and inhibits the emission of GHG and NH_3. Many studies have shown that better effects are achieved using strong acids (sulfuric, hydrochloric, phosphoric acid). However, due to the risk of potential danger when handling these acids, it is recommended to use weaker acids and acidifying salts. In a three-month experiment with cattle manure in which the pH of the manure was lowered to 5.5 using sulfuric acid, methane emissions were reduced by up to 87%, and ammonia was almost eliminated (Montes et al., 2013).

An efficient strategy for reducing N_2O emissions is using nitrification inhibitors that deactivate the enzymes responsible for the first step of nitrification. Using inhibitors reduces the emission of N_2O but increases the emission of NH_3. If NH_4+ is not converted to ammonia, it can increase the emission of N_2O in the soil. Adding urease inhibitors to urine at least 5 to 10 days before mixing urine with feces or applying them to the soil effectively reduces urea degradation and gas emissions.

The addition of ionophores (monensin and narasin) and tannins directly to manure inhibits methanogenic microorganisms and, thus, methane production.

Shallow manure injection below the soil surface also reduces ammonia emissions. In this way, the emission of NH3 is reduced by 71%, but the emission of N_2O increases by 259% (FAO, 2023c). The shallow injection method is more efficient if combined with anaerobic digestion and separation of solid manure.

Biofilters have proven effective in reducing NH_3 on pig and poultry farms. When biofilters are used for NH3 and GHG reduction, the production of N_2O in biofilter scrubbers must be taken into account. The use of biofilters is justified when storing manure in liquid form.

Composting is an aerobic process that significantly reduces methane emissions, but NH_3 and N_2O emissions can increase. By separating pork slurry and subsequent aeration of the solid fraction, methane emissions can be reduced by 99% and N2O by 75%, but NH_3 emissions can also be increased (Vanotti et al., 2008).

Conclusion

Agricultural production is facing the challenges brought by climate change. The negative impact of agricultural production on land, air, water, and climate requires identifying and applying innovative practices to mitigate such impact and ensure sustainable agricultural production. Implementing the concept of smart agricultural production (CSA) and the concept of smart animal production (CSL) can help mitigate the negative impact of agricultural production on the environment. Application of precision agriculture, improvement of feed efficiency, efficient management of manure, use of renewable energy sources, selection of varieties and species resistant to climate change, and application of other innovative practices enables the achievement of a sustainable system of agricultural production, increases productivity and profitability of production and reduces greenhouse gas emissions from the sector and generally negative impact on the environment.

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Climate Change and Water Resources

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Abstract: Water is one of the most important compounds in the world, essential for the survival of people and all living things. Of the total amount of water on Earth, only 2.5% is freshwater, and less than 1% is water in rivers and lakes that is directly available. Due to the growing population, economic development, and increasing needs for food and energy, the water demand is constantly increasing, while the reserves are limited. Climate change and increasing pollution further worsen the situation, challenging preserving water resources and ensuring their sustainable use.

Climate change has multiple consequences on water resources, significantly affecting the availability of water for drinking, agriculture and industry. The rise in global temperatures is disrupting the hydrological cycle, leading to shifts in the quantity, spatial and temporal distribution of water, and precipitation intensity. These changes, when combined with human activities, are causing disturbing precipitation infiltration, surface runoff, and water evaporation. The most alarming aspect is the surge in extreme weather events, such as droughts and heavy rainfall, now occurring with alarming frequency. These events reduce water availability in some regions while others grapple with devastating floods.

This study investigates the main impacts of climate change on water resources, proposes mitigation and adaptation measures, and gives examples of successful adaptation.

Keywords: climate change, water resources, sustainable water management, mitigation measures

1. INTRODUCTION

Water is an invaluable resource for economic development and human well-being. Despite this crucial fact, on which the survival of life on the planet as we know it largely depends, it is not used rationally or protected promptly. Water is spatially and temporally "irregularly" distributed, of limited quantity, and of "increasingly unfavorable" quality for human use. In contrast, water needs are growing year by year. The increase in the number of inhabitants in general, economic development, and the processes of intensive urbanization set demands for increasing amounts of drinking water in a particular area. Most often, it is necessary to build complex and expensive water management systems to provide the necessary quantities in the long term. However, the changes that take place within a society, especially when we are talking about developing countries where the implementation of the already adopted legal legislation is very weak, also lead to an increase in the total amount of waste materials, wastewater, and ultimately to a continuous deterioration of the qualitative characteristics of water resources a certain area.

The water crisis is reaching a critical point, as we face mounting challenges in providing sufficient water for various needs. This crisis is exacerbating issues of water protection and the need to safeguard against waterborne threats, posing an increasing risk to human health and the environment due to water pollution and the degradation of aquatic ecosystems. The main aspects of the water crisis are not equally distributed spatially and temporally, nor represented with equal intensity. While on one part of the planet, we struggle with floods, landslides, torrents, and storms accompanied by vast amounts of precipitation, on the other side, we have severe droughts and water shortages accompanied by deterioration of the quality of water. Although today's civilization has knowledge that points to the problem and ways to solve it and relatively effective technologies, the state of use, water protection, and protection from water is not improving but is drastically deteriorating globally. According to Bonacci (2003), the way out of the crisis can be found in the interdisciplinary cooperation of scientists who deal with water in any way. Since water is the unifying element for all human activities, water resource management should be a critical factor in encouraging cooperation and a holistic approach to society's general development and preserving water resources.

2. WATER RESOURCES AND AVAILABILITY

Water can be found in nature in various aggregate states, such as liquid, solid, and gaseous states. Of the total amount of water on Earth, which, according to estimates, is about 1386 million km3, only 3.5% is freshwater; about 96.5% of water is salt water. Water in the atmosphere is mainly in the form of water vapor, and according to estimates, the total amount of water is 12,900 km3. If all the water were distributed evenly over the Earth's globe, a water envelope with a thickness of about 2000 m would be created. Of the total amount of fresh water, about 68.7% of the water is trapped in ice and glaciers, 30.1 % is underground water, while rivers and lakes account for 0.3%, or about 93,120 km3, which is about 0.0072% of the total amount of water on the planet. Surface water is of primary importance for all forms of life on Earth and groundwater recharge through infiltration. Figure 1 shows the global distribution of freshwater sources from glaciers and ice caps, rivers, lakes and wetlands, and groundwater by continent. A distinct spatial unevenness is noticeable.

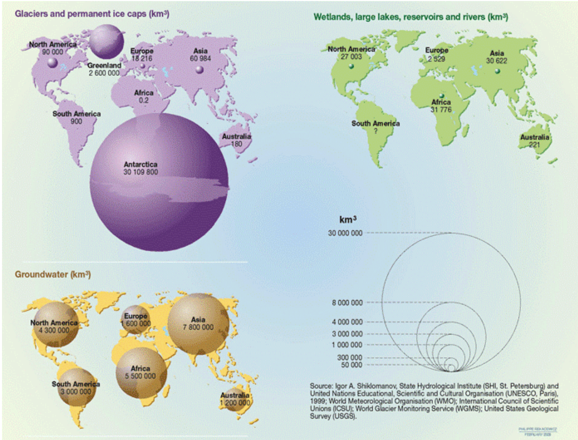

Fig. 1. Global waterfresh sources distribution from glaciers, rivers, lakes and wetlands, and underground sources, [2]

Water, in all its forms, is in a perpetual state of motion, thanks to the influence of solar energy. It evaporates from water surfaces and land, ascends into the atmosphere as steam, where it condenses, and then, under the pull of gravity, returns to the Earth's surface as precipitation. This unceasing journey of water, involving evaporation, moisture transport, condensation, precipitation, infiltration, percolation, runoff, concentration of water in larger water reservoirs, and re-evaporation (see Fig. 2), underscores the dynamic nature of the water cycle.

The global hydrological cycle is not unique and comprehensive but consists of several interconnected continental, regional, or local cycles. It occurs in an amplitude of about 13 km, that is, in the atmosphere up to 12 km high and in the lithosphere up to about 1 km deep. Water distribution on continents and within catchment areas constantly changes, manifested through spatial and temporal variations. The intensity and return period of the hydrological cycle, in addition to the effect of solar energy, are certainly influenced by numerous climatic factors and physical and geographical characteristics.

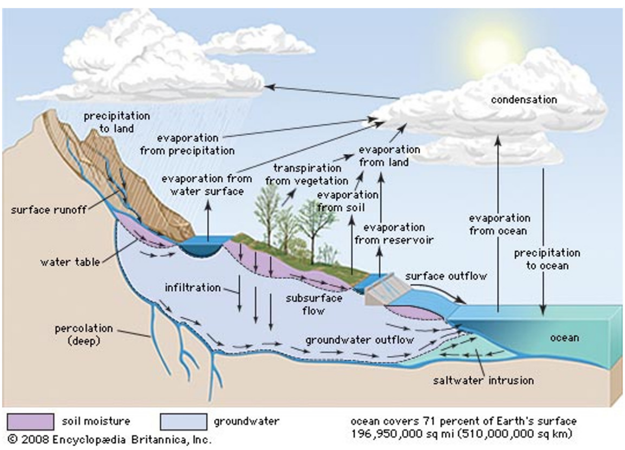

Fig. 2. The major components of the water cycle/hydrological cycle, [3]

Although the water content on land and in the atmosphere at any one time is relatively small, huge amounts of water pass through them throughout the year. In general, it can be observed that about 57% of the precipitation that falls on land evaporates, while the remaining 43% forms a runoff towards the oceans, mostly as surface water. In the total evaporation that forms atmospheric moisture, 90% is evaporation from the ocean and only 10% from the land. [4]

The speed of the water exchange process is different for surface, underground, or atmospheric water. While changing water in the atmosphere and on the Earth's surface happens quite quickly, this process is slowed down in the Earth's crust especially as we go into deeper layers. Thus, according to estimates, underground water sometimes needs as much as 1,000 years for one change cycle to occur, while the water in rivers changes in a few months. The average time of water exchange in the atmosphere is significantly shorter and amounts to about nine days, or 42 times a year.

The following figure (see Fig. 3) shows the precipitation, evaporation, and river runoff values, displaying the annual amplitude of water storage on land. This display is very illustrative because it shows how water on land changes during the year. The average precipitation on the entire planet is about 1130 mm. Still, it varies in an extremely wide range from desert zones with practically no precipitation to some zones in the tropical belt with precipitation over 10,000 mm.

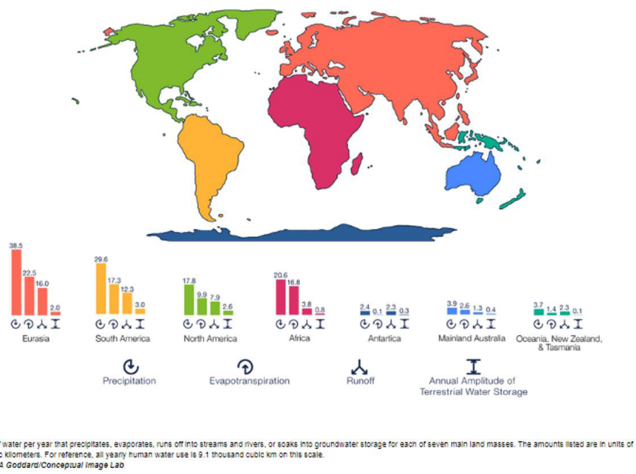

Fig. 3. Mean annual values of precipitation, evapotranspiration, runoff and annual amplitude, [5]

On its way through the atmosphere, water dissolves various gases present in the air, such as oxygen and carbon dioxide, then sulfur and nitrogen oxides, and collects various impurities, such as particles of soot, dust, and bacteria, in the atmosphere. When it reaches the ground, a part of the precipitation remains on the field's surface, as surface water, while a part seeps into the ground. Of the part of the precipitation that infiltrates into the soil, one part can occur on the surface of the terrain, in the form of springs in places where the geological-hydrogeological conditions allow it, or it can be drained into surface waters. In contrast, the other part moves towards underground aquifers, which infiltrates deeper into the underground. When passing through different layers of the soil to a waterproof layer, water dissolves different salts, such as salts of sodium, calcium, magnesium, iron, and manganese, as well as some organic matter, so that there is never pure water in nature. The percentage of water sinks into the soil depends mainly on the amount and intensity of precipitation, the porosity and geological structure of the soil, geographical and topological features, vegetation, season and weather, and other natural or artificial factors. Through his activities, man can significantly impact the runoff regime of surface and underground water, as well as infiltration and evapotranspiration. Therefore, the human influence is most felt precisely when the water comes into contact with the soil and is further redistributed through natural processes.

In order to assess the water wealth of an area, a quantitative description of the hydrological cycle, which is carried out through the water balance, is necessary. The water balance, in turn, is a crucial tool for determining the water quantities that enter, leave, or remain in an area over a specific period. The input components of the water balance, such as precipitation, and the output components, including evaporation and runoff, play a pivotal role in this assessment. Understanding the climatic characteristics that directly influence these components is therefore essential for a comprehensive water wealth evaluation.

It is a matter of grave concern that the available quantities of fresh water, estimated to be between 12,500 km3 and 14,000 km3 per year [6] are rapidly decreasing due to the exponential growth of the global population. The potential available quantities per inhabitant have seen a significant decline: from 12,900 m3 in 1970, to less than 7,000 m3 in 2000, with a projected further decrease to 5,100 m3 by 2025. This alarming trend could lead to a staggering 3 billion people facing water shortage, with less than 1,700 m3 of water per capita per year [7]

Although renewable water resources, which represent the amount of renewable water resources available annually, are important indicators of the state of water, they are insufficient. A comprehensive understanding of an area's water wealth requires a deeper knowledge of the time-varying nature of these resources. This understanding is crucial for effective water resource management and conservation efforts.

Renewable resources per inhabitant depend on the total amount of renewable flows and the size of the population. If renewable resources are declining - as is often the case in countries with high annual rainfall variability, such as monsoon seasons - then the per capita drawdown of renewable energy sources will also decline. Similarly, if total renewables remain constant, per capita levels may fall if a country's population grows. The chart (see Fig.4) shows the level of renewable internal freshwater resources per capita.

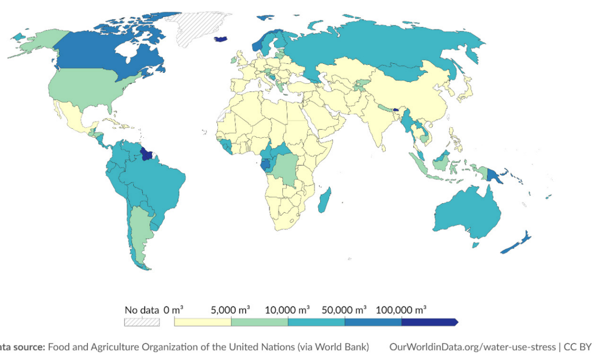

Fig. 4. Renewable internal freshwater resources per per person in 2020, [8]

The picture is even more disturbing if we look at the last thirty years only regarding the decrease in water availability per inhabitant per year. While in 1975, the availability was about 13,000 cubic meters per person per year, now it has fallen to 6,000 cubic meters. Given that the water quality has also significantly deteriorated, it nevertheless points to the seriousness of the situation. This situation is likely to exacerbate the expected effects of climate change further.

As the global population grows and the demand for water increases, water problems and the risk of water shortages are common concerns. This will be especially true for specific regions with smaller water resources and/or higher population pressures.
Water stress is defined based on the ratio of pumped fresh water to renewable freshwater resources. Water stress does not insinuate that a country is short of water, but it does indicate how close it is to exceeding the renewable resources of water. If water withdrawal exceeds available resources (ie, greater than 100 percent), then is either drawing beyond the rate at which the aquifers can be renewed.

The Food and Agriculture Organization of the United Nations categorizes water scarcity in the following ways: if the withdrawal is less than 25 percent of the resource, then there is no water scarcity in the country; 25-50 % is low stress; 50-75 % is medium; 75-100 % high stress; and greater than 100 % is critical stress.

Water withdrawal rates must be below freshwater renewal rates to maintain sustainable water resources. Freshwater witdrawawals refer to total water withdrawals from agriculture, industry and municipal/domestic uses.

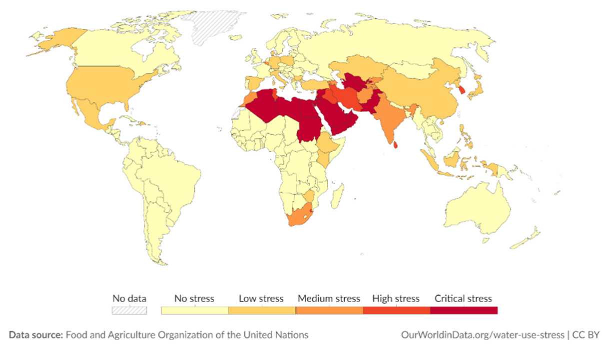

Fig. 5. Freshwater withdrawals as a share of internal resources in 2020, [9]

It is evident from the picture that the areas of the Middle East and North Africa have an extremely high level of water shortage.

A growing global population and an economic shift towards resource-intensive consumption patterns means that global freshwater use has increased approximately sixfold since 1900. Freshwater use includes pumping fresh water for agriculture, industry, and municipal purposes. This is shown in the graph. Rates of global freshwater use increased rapidly from the 1950s onwards, but since 2000 they appear to have leveled off or slowed down, [9, 10]. As we can see, renewable resources are declining by region, mainly due to population growth.

While the world's population tripled in the 20th century, the use of renewable water resources increased sixfold. Forecasts are that the world population will increase by another 40 to 50% within the next fifty years. This population growth, industrial development, and urbanization will result in increased water demand and serious consequences for the environment and water resources. The world population in 2100 is slightly more than 11 billion people.

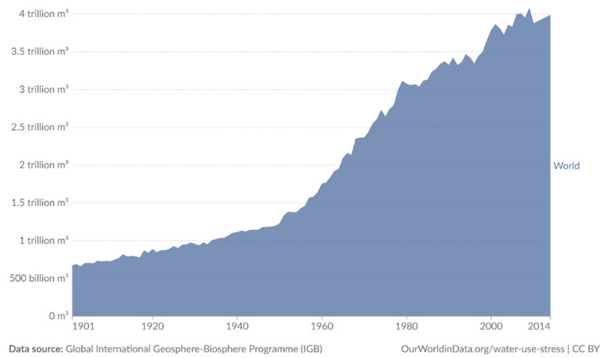

Fig.6. Global freshwater use over the long-run, [11]

The significant growth of the human population - especially when half of humanity already lives in urban areas - and the consequent expansion of agricultural and industrial activities with a high water demand only increased the problems of water availability, quality - and in many areas - Waterborne diseases, [11]. Data on the scale of deforestation with subsequent land conversion, soil erosion, desertification, urban sprawl, loss of genetic diversity, climate change, and the insecurity of irrigated food production reveal the growing severity of the problem.

3. THE INFLUENCE OF CLIMATE CHANGE ON THE HYDROLOGICAL CYCLE

One of the most important and complex concerns of the present and future centuries is climate change and finding ways to mitigate its impact and for timely adaptation. However, even a small change in climate conditions can lead to tangible changes in water resources. The negative effects of this phenomenon on water resources can cause irreparable damage. Therefore, recognizing these effects and their causes is crucial. Investigating such changes can facilitate the study of a number of hydroclimatic, economic, and social problems, such as droughts and floods, but also related problems of food shortages and human migration. Recent climate models predict that for each degree Celsius of warming, the water cycle could intensify by up to 7%. In practical terms, this means that wet areas could become, on average, 7% wetter and dry areas 7% drier. The only way to ensure that heat waves, droughts, and storms do not intensify in the future is to limit global warming - and there is still much humanity can do. The latest report of the International Panel on Climate Change estimates that if we manage to keep global warming to 2 °C, extreme weather events will be 14% stronger than in the late 18th and early 19th centuries. This underscores the potential for positive change through human action.

The impacts of climate change on water resources include changes in rainfall and runoff patterns, sea levels, land use, water demand, and many other aspects. As air temperatures increase, there is more evaporation and less precipitation in some regions, which reduces the amount of water that flows into rivers and lakes and directly reduces water availability for people, agriculture, and ecosystems. On the other hand, in wetter areas, intense rainfall can cause floods because rivers cannot carry huge amounts of water quickly, [12]. Floods change the structure of riverbeds and can increase river erosion. The river beds become insufficient to accommodate the water wave, and floods occur, [13]. The growth of the urban population and the expansion of impervious surfaces, combined with climate change, are direct factors that significantly contribute to increasing the threat, exposure, and vulnerability of urban environments to flooding events.

Changes in surface runoff patterns can affect the capacity of riverbeds and lakes, which affects water availability and quality, [14]. Increased temperatures and changes in precipitation can lead to land degradation and erosion, which reduces the soil's water-holding capacity. In that case, it may cause groundwater levels to decrease and increase the risk of flash floods. Degraded soil filters water less efficiently, affecting the water quality available for human use. Sea-level rise, caused by the melting of the polar ice caps and the thermal expansion of the oceans, can lead to the salinization of coastal freshwater sources, [15]. Drinking water in coastal communities and agricultural areas that use freshwater from rivers and underground sources should be treatened. Soil salinization can also reduce the productivity of agricultural lands.

When runoff patterns change due to heavy rains or dry spells, the water becomes polluted with various chemicals and sediment. Heavy rainfall can also cause sewage to overflow, leading to increased pathogenic microorganisms. This significantly affects water quality, reducing its suitability for human use and ecosystems. After extreme weather events, water supply systems are often interrupted. Very often, inadequate disinfection of the water supply system during heavy rains also significantly pollutes the water. These disturbances can alter the ecological balance in rivers and lakes, decreasing biodiversity and endangering species that depend on stable water resources.

Reduced water availability can have severe socioeconomic consequences, including conflicts over water resources, population migration, and reduced agricultural production. That can increase poverty and food insecurity, especially in regions already vulnerable to climate change. Climate change may increase water-related public health risks. Changes in temperature and precipitation patterns can affect the spread of waterborne diseases such as cholera and malaria. Water contamination during floods or droughts can further endanger human health, especially in areas with limited access to health care.

The correlation between air temperature and lake water temperature is linear, [16], and warming will significantly affect deep lakes due to their heat storage capacity, which is why it is expected that there will be an increase in surface temperature, and the most significant increases are expected in the winter months [17]. Another of the problems exemplified by rising temperatures is the increase in the transport of pollutants, such as ammonia, mercury, pesticides, etc., from surface and waste waters into the atmosphere [18, 19].

Since water is a crucial resource for the energy sector, especially for hydroelectric and thermal power plants that use water for cooling, climate change affecting water availability can seriously threaten energy production. That can lead to energy shortages and increased costs, emphasizing the need for an integrated water and energy management approach. Snowfall is crucial in maintaining water resources in mountainous regions during warmer months. Climate change reduces snowfall and accelerates snow melting, which can lead to a lack of water in periods when it is most needed.

According to studies, ocean salinity is directly related to changes in the global hydrological cycle, and scientists predict that these changes will intensify with further warming of the Earth [20]. Namely, global warming causes more substantial evaporation in warmer areas and increased rainfall in wetter parts of the world. As a result, the oceans become saltier in dry regions, while freshwater becomes less salty in wetter regions. This pattern accelerates the cycle of evaporation and precipitation, which can lead to more intense rainstorms and other extreme weather events.

As a consequence of climate change, more frequent occurrences of solid heat waves and long-term dry periods are expected in the future, which may result in a lowering of the groundwater level and consolidation (subsidence) of the soil, [21]. As a result of soil subsidence and changes in its properties, the underground infrastructure of the water supply network may be damaged. Recently, a geographic information system model was presented that can estimate the probability of damage to the water supply network due to ground subsidence that occurred as a result of various events caused by climate change, [22].

4. ADAPTATION TO CLIMATE CHANGE

Because of the above, it is essential to plan and implement adaptation measures to mitigate climate change's effects on water resources. Although adaptation and mitigation differ in approach, they complement each other. In an ideal scenario, both strategies are used together: mitigation reduces the long-term risks of climate change, while adaptation enables societies to cope with immediate and inevitable changes. Adaptation refers to adapting systems, policies, and infrastructure to mitigate the negative impacts of climate change on water resources and increase resilience to change. Mitigation refers to activities that reduce or prevent the emission of greenhouse gases, reducing the speed and extent of climate change and, thus, its impact on water resources.

Reducing the impact of climate change on water resources is essential for preserving water availability and quality. Technical, managerial, political, and educational measures can achieve this.

So, for example, when talking about floods, damage from floods has shown a rapid increase worldwide and in Europe.

Therefore, effective adaptation strategies to the consequences of climate change are needed. These strategies combine flood protection infrastructure, natural solutions (green infrastructure), and financing to manage flood risks and mitigate their economic impact.

Creating a hazard map and a flood risk map, as well as implementing measures to avoid human and material losses, proved to be a very effective measure in reducing the risk of floods—also, the introduction of early flood warning systems to enable timely response. Using green roofs, permeable surfaces, and urban parks to reduce runoff and improve rainwater infiltration is also an effective measure. Improving water distribution and treatment infrastructure to reduce losses and increase resistance to extreme weather conditions is a measure that produces excellent results, according to the experiences of the cities that apply it. Using GIS and smart technology in managing water resources and applying integral management is considered necessary, [11].

5. CITIES AND URBAN FLOODING

The total urban area exposed to flooding in Europe has increased by 1000% in the last 150 years, [14]. The total reported economic losses caused by extreme weather events in the European Economic Area (EEA) member countries from 1980 to 2017 were about 453 billion euros.

The expansion of urban areas results in a change in the natural hydrological characteristics of the land, i.e., the proportion of impervious surfaces increases compared to the state before urbanization, and the part of the water that seeps into the ground decreases, which ultimately leads to an increase in surface runoff that needs to be managed [13].

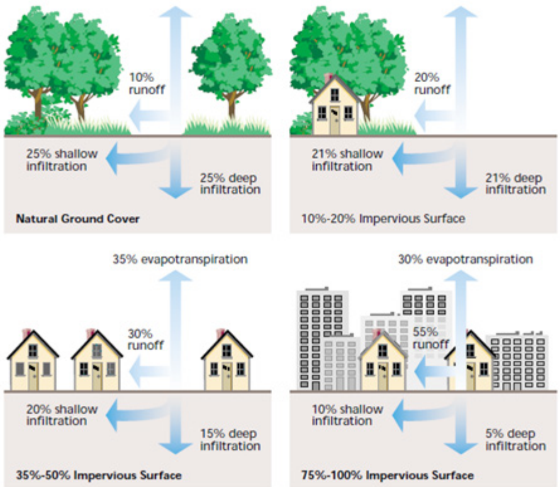

Fig. 7. Changes in runoff on natural and urbanized catchment areas, [23].

Figure 7 compares typical changes in the runoff hydrograph for an urban area and an area with natural cover. When about 75-100% of the surface is impervious, about 55% of total precipitation falls on surface runoff, 30% evaporates, and only 15% infiltrates. In the natural state of the surface, 10% of precipitation forms runoff, 40% is evapotranspiration, and 50% infiltrates into the soil.

It is estimated that the area of one city block generates five times more runoff than an identical forest area. Analyses have shown that increasing impervious surfaces by 30% results in a double increase in the flood of the 100-year return period [24]. Changes in land use due to urbanization cause significant changes in the volume and peak flows of stormwater.

The approach to flood management has changed significantly in recent times, especially after the entry into force of the Water Framework Directive and the Flood Directive. It was realized that, within economically realistic limits, it is impossible to provide complete flood protection for people and property due to anthropogenic activities/changes in catchment areas, changes in ecosystems, or climate variability, especially because all these changes are causally related. The “flood defense” approach has been replaced by an approach based on a cost-benefit analysis of flood risk.

The development of advanced technologies, the ICT sector, and detailed computer models for predicting floods have contributed to greater awareness of possible dangers, increased general public animation, and the importance that each individual or community can have in increasing mitigation capacities.

Integrated flood management, as part of integrated urban water management, is essential for resolving the complex processes associated with floods synergistically.

However, integration implies a complete, holistic approach that starts with the right political decisions and strategies, including institutional changes and changes in financing, changes in legislation, scientific understanding and knowledge, continuous progress, technological capability and innovation, and adequate social systems capable of accepting changes.

With an integral approach, different professions must be included to define the best possible solutions. In addition to experts in hydrotechnics, spatial planners and experts in urban planning, architecture, agronomy, horticulture, hydrogeology, transport, environment, sanitary engineering, and others should be included [25].

6. A NEW APPROACH TO WATER MANAGEMENT - URBAN FLOOD REDUCTION

New approaches to urban water management that have developed somewhat in response to climate change include “greater respect” for natural laws, i.e. returning to the natural hydrological cycle through natural solutions. The goal is to imitate the natural hydrological regime of a certain area in such a way that as much rainwater is retained in the catchment area as possible to reduce runoff and increase infiltration, which results in a reduction of the water wave and a reduction of the total amount of rainwater while achieving additional environmental, economic and cultural benefits.

Water drainage should be planned and designed following the natural way of runoff by evenly directing it to decentralized micro-systems of drainage, that is, using design techniques that foresee retention, infiltration into the subsoil, evaporation, and filtration. Such “green” technical solutions include the construction of grassed channels, accumulation and retention lagoons, infiltration channels, bioretention, underground retention, rain tanks, rain gardens, green roofs, green walls, etc.

By introducing elements of the so-called green infrastructure within conventional systems, new integral approaches to water management in urban areas called “Sustainable Urban Drainage Systems” (English SUDS - Sustainable Urban Drainage Systems) have been developed. In the literature, such systems are also called “runoff best management practices,” “urban development with a reduced negative impact on the water regime and environment” (LID - Low-Impact Development), or “urban drainage sensitive to water resources (WSUD - Water-Sensitive Urban Design) [13]

In the aforementioned stormwater management systems, facilities are used to mitigate the maximum and extend the runoff concentration of the direct runoff hydrograph (see Fig. 8), but they are also facilities for the treatment of stormwater pollution [8]. Therefore, these approaches allow control of both the quantity and quality of water at the source and at the point of discharge.

The basic goal of new trends in stormwater management is the use of facilities/elements that serve to slow down and treat surface runoff at the source, that is, before it reaches the sewerage system [26].

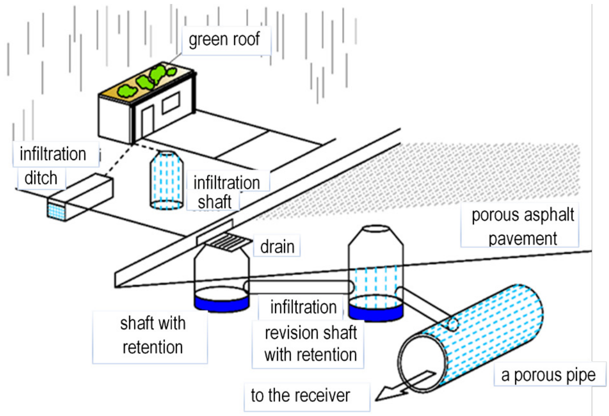

Fig. 8. Basic elements of the modern stormwater management system in urban areas, [26]

The goal is to keep stormwater out of the sewer system to reduce flooding, as well as the amount of "untreated" stormwater that is discharged into surface waters. By using these systems, mechanical and biological mechanisms ensure flow control, retention, filtration, infiltration, and water treatment (Figure 6). All the mentioned procedures can be successfully applied in newly designed and existing rainwater drainage systems. In Europe and the world, programs are continuously launched at the national and local levels, the goal of which is the implementation of the so-called "green infrastructure" in combination with conventional drainage systems. This aims to achieve additional benefits in the form of more effective protection of the environment and human health, improved landscaping, increased living standards, and new entrepreneurial opportunities in the green sector [26].

This innovative approach relies on the ecological principles that drainage should be planned and designed according to the natural way of runoff at the source using evenly distributed decentralized microsystems of drainage and purification (green roofs, grassed gutters, ditches, permeable paving, and asphalt, etc).

Although not yet proven to the required rigorous standards of scientific accuracy, increasing empirical evidence indicates that the hydrological cycle is accelerating while the amount of water remains the same over time. If this acceleration hypothesis is true, then it will increase the frequency and size of floods. At the other end of the spectrum, prevailing laws of continuity mean that drought severity and duration will also increase. These increased risks are likely to have serious regional implications.

7. CONCLUSION

Anthropogenic impacts on the hydrological cycle have numerous and complex consequences that require an integrated water resource management approach. That includes protecting and restoring natural habitats, integral and sustainable water management, pollution reduction, and climate change adaptation. Understanding and mitigating these impacts is critical to ensuring sustainable and healthy water resources for future generations.

The consequences of anthropogenic influence on the hydrological cycle can be far-reaching and complex. They include water quantity and quality changes, ecosystem impacts, and socioeconomic consequences. Overexploitation of groundwater for agriculture, industry, and urban use can lead to the depletion of aquifers, reducing water availability for future needs. The construction of dams and the diversion of rivers can significantly change the natural flows and water flow downstream and affect the ecosystems dependent on these waters. Urbanization and agriculture can reduce water infiltration into the soil, reducing underground reservoirs' filling and increasing surface inundation. Using pesticides and fertilizers in agriculture, industrial waste, and inadequate wastewater treatment contribute to rivers, lakes, and groundwater pollution. Pollution can include heavy metals, organic pollutants, nutrients (e.g., nitrates and phosphates), and pathogens. Excessive introduction of nutrients (e.g., phosphorus and nitrogen) from agricultural and urban sources can lead to eutrophication of water bodies, which causes excessive growth of algae, reduction of oxygen levels in water, and death of aquatic organisms. Fragmentation of river courses by dams and barriers can also hinder the migration of fish and other aquatic organisms.

Changes in the hydrological cycle can increase the frequency and intensity of extreme weather events such as floods and droughts, [27]. This can cause property damage, agricultural losses, and increased costs for restoration and adaptation. Changes in the quantity and quality of water can destroy habitats and threaten the survival of many plant and animal species. Adaptation to climate change implies taking certain actions to reduce the vulnerability of natural and social systems to climate change, increase their ability to recover from its effects and exploit potential positive effects that may also be a consequence of climate change. There are a number of structural and non-structural measures that can contribute to better adaptation and mitigation of climate change's negative effects on water resources, but it is also a fact that in the future, we will all have to put in much more effort together.

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Climate Change and Forest Resources

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Abstract: Covering 63% of the country, forests are important natural resources of Bosnia and Herzegovina which provide several ecological, social and economic benefits. The role of forests in preserving biodiversity, mitigating climate extremes and ensuring the stability of water and land regimes is immeasurable. The basic facts on forest resources, the forestry sector and sustainable forest management are presented in this paper to indicate the complexity of the interaction between forest ecosystems and climate change. In the context of climate adaptation and mitigation, some key impacts of climate change on forest ecosystems are presented (natural migrations and areal projections for tree species caused by climate change, change on forest ecosystems, growth dynamics and productivity patterns, policy, economic and institutional aspects of climate change in the forestry and nature protection sector, etc.) but also the role of forest ecosystems in regulating climate processes. Two important aspects of forest-climate change interaction in Bosnia and Herzegovina are particularly discussed: forest fires and the role of forests in carbon cycle including the potentials of forest biomass for energy. Climate change strongly affects the dynamics of forest ecosystems and this must be taken into consideration when developing effective policies for the conservation and sustainable management of forest resources. Understanding the importance of forest resources in the fight against climate changes may help to recognizes the stability of forest ecosystems as an important prerequisite for achieving balanced economic development and human well-being.

Keywords: forestry, climate change, sustainable forest management, forest fires, forest biomass for energy

1. FOREST RESOURCES AND THE FORESTRY SECTOR IN BOSNIA AND HERZEGOVINA AND GLOBALLY

The permanent and unbreakable connection between man and the forest is best reflected in the views of the Italian philosopher Vico (Giambattista Vico), who in his work Scienza Nuova from 1725 claimed that "This was the order of human institutions: first the forests, after that the huts, then the villages, next the cities and finally the academies" (Harrison, 1992). The forest has always fascinated man, both in the sphere of rationality and in the sphere of his emotional existence and actions. The American naturalist Moore (John Muir) said that "And into the forest I go, to lose my mind and find my soul", while for Hesse (Hermann Hesse) "Trees are sanctuaries. Whoever knows how to speak to them, whoever knows how to listen to them, can learn the truth" (Quoteambition, 2022). The presence of different types of trees, shrubs and ground flora, the structure and dynamics of the forest, and the harmony of complex relationships between plants, animals and other life forms that inhabit forest ecosystems, make the forest a natural phenomenon suitable for establishing an analogy with the individual and collective life of man. Forest ecosystems are a unique natural phenomenon on the Earth that continuously and permanently provides numerous material and non-material benefits to people. The Food and Agriculture Organization of the United Nations (FAO) recognizes three key functions of forest ecosystems: (i) Social functions (recreation, tourism, education, art, spiritual aspects, etc.), (ii) Production functions (supply of wood and numerous other forest products) and (iii) Ecological functions (protection of biological diversity, ensuring the stability of land, air and water regimes, carbon storage, climate change mitigation and regulation of climatic extremes, etc.). Throughout history, there has been a constant interaction between man and the forest, while the changing demands of society towards forest resources well illustrate the evolution of these relationships, which today is reflected in the paradigmatic change from economic-production to ecological-social benefits and functions of forest ecosystems.

Together with hydrological potential and mineral wealth, forests represent one of the most important natural resources of Bosnia and Herzegovina, as a predominantly hilly and mountainous country. Due to their preserved naturalness and mainly mixed structure (deciduous and coniferous tree species), as well as significant potential for natural regeneration, forests represent a strategic resource for the development of Bosnia and Herzegovina. Considering their specific geographical position in terms of different climatic influences (Mediterranean, sub-Mediterranean and moderately continental climate zones), the forests of Bosnia and Herzegovina have a high level of biodiversity and provide numerous ecological, social and economic ecosystem services (benefits from forest ecosystems). The main types of trees are beech, fir and spruce, and in addition to them there are also various types of pines, oaks, noble deciduous trees (maple, elm and ash), forest fruit trees (wild cherry, wild apple and wild pear), and many other types of trees and shrubs. The diversity of forest ecosystems in Bosnia and Herzegovina (mixed, deciduous and coniferous forests) is shown in Figure 1.

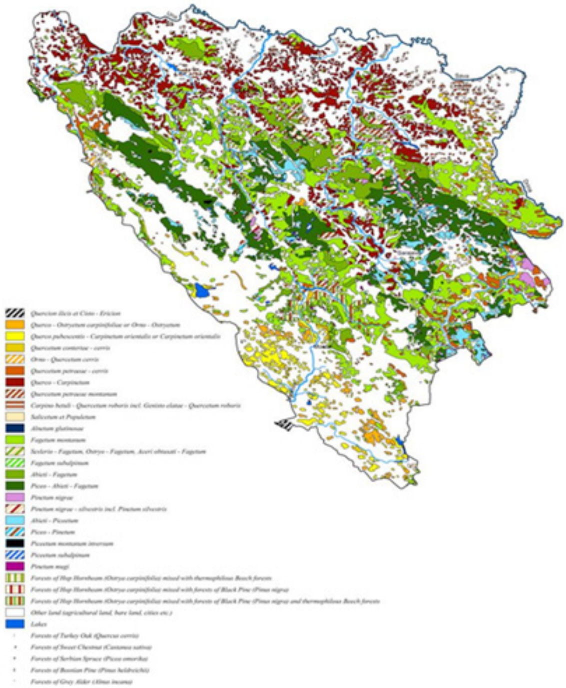

Fig. 1. The map of real forest vegetation in Bosnia and Herzegovina (UŠIT, 2014)

Organized forest management in Bosnia and Herzegovina has a long tradition and is based on the achievements of Central European forestry science and profession, which are characterized by multifunctionality, sustainable management and preservation of all important forest functions (economic justification, social responsibility and ecological acceptability). In the context of the development of an optimal system of organization and implementation of a consistent forest policy, the forestry sector in BiH is burdened by the current administrative-political arrangement of the State, according to which the key actors of forest policy are positioned at the entity and cantonal levels. In such conditions, the forestry sector is faced with the challenges of meeting the interests of various forest policy actors, the need to implement significant structural changes and the inevitability of technological modernization, in order to improve its competitive position on the global market of forestry products, while at the same time meeting the changing demands of society towards forest resources.

According to the data of the Second State Forest Inventory, which was carried out in the period 2006 - 2009, forests and forest land in Bosnia and Herzegovina cover an area of over 3.2 million ha, which represents about 63% of the total area of the country. These data place Bosnia and Herzegovina at the very top of Europe when it comes to the percentage of forest cover. However, this data must be understood in the context of the total area under forest and the distribution of forest ecosystems on a global scale. With a total area of over 160 million ha of forests in the EU member states and an average forest cover of about 40%, EU forests account for only 4% of the total world's forests, so the forests of BiH participate in the global forest area with a minor share. In terms of the area under forest, the "big players" in world forestry are countries with a large territory, so that only 5 countries (Russia, Canada, Brazil, USA and China) account for over 55% of the world's forests. If India, some large African, Asian, South American, and even Scandinavian countries (e.g. Sweden and Finland together have about 50 million ha of forest), with their huge forest resources are added to this, then it is clear that Bosnia and Herzegovina on the global forestry product market does not play a significant role, as it is sometimes presented to our public. On the other hand, the forests of Bosnia and Herzegovina are important for its citizens, both for economic reasons and perhaps even more for the ecological and social benefits they provide us. We have no other forests than ours, the forests of Bosnia and Herzegovina, and that is why they are extremely important to us. In addition, we should not ignore the fact that Bosnia and Herzegovina, superficially observed, has more forest than other neighbouring countries, which is an important precondition for achieving and maintaining a regional leadership position in the forestry, wood processing industry and nature protection sector.

When it comes to the ownership structure, it is generally considered that forests in BiH are dominated by state-owned forests (about 80%), and that only 20% of forests are owned by private individuals (in contrast to most Western European countries where private forest ownership dominates). In the last few decades, this ratio has been significantly changed in favour of private forests, i.e. new forests that spontaneously arose on abandoned and neglected private agricultural land, especially in rural areas. In the context of land use change, one can claim a general increase in forested areas in Bosnia and Herzegovina, which is in line with European growing trends, in contrast to the world average, where forested areas are constantly decreasing. In many cases, private forests in Bosnia and Herzegovina are small-scale, fragmented into several ownership parcels and are often coppice forests, so that their quality lags behind the quality of state-owned forests on average. Data on forest resources in Bosnia and Herzegovina (based on data from the Second State Forest Inventory) were published in the FIRMA study (USAID, 2012) and are shown in Table 1.

Table 1. The structure of forests and forest land in Bosnia and Herzegovina

Vegetation form	Available surface				Inaccessible area	Total
	Economic forests	Non-economic forests	Protective forests	Special purpose forests		
	Ha	Ha	Ha	Ha	Ha	Ha
High forests	1.329.500	46.300	5.200	8.800	262.600	1.652.400
Coppice	843.200	158.700	1.600	2.400	246.300	1.252.200
Shrubbery	52.700	41.100	0	100	36.700	130.600
Barren land	55.700	88.400	800	3.400	38.900	187.200
Other forest area	3.300	3.100	0	100	2.600	9.100
All forests/forest land	2.284.400	337.600	7.600	14.800	587.100	3.231.500

Compared to the First State Forest Inventory from the 1960s (when the total area under forest and forest land was determined to be 2.734 million hectares), there was a significant increase in the area under forest. The main reasons for these changes are to be found in the methodological differences between the First and Second State Forest Inventory and the actual increase in forested areas due to afforestation (to a lesser extent) and natural forest succession, most often on abandoned agricultural land in the previous 30 years or so (for the greater part). The same source (USAID, 2012) states that the total timber stock volume in the available forests of BiH is 435 million m3, or an average of 201 m^3/ha. Stocks are higher in high (average 266 m3/ha) than in coppice forests (average 97 m^3/ha), as well as in state (average 228 m^3/ha) compared to private forests (143 m^3/ha). Biomass stock (approx. 398 million tons) and stored carbon (approx. 187 million tons) in the forests of Bosnia and Herzegovina were also determined. Data on biomass stock and stored carbon should be taken with a grain of salt due to the methodological limitations of the Second State Forest Inventory.

The benefits (services, functions) that humans have from forest ecosystems are numerous and according to FAO can be classified into three large groups. 1.7 billion people in the world, mostly in rural areas, directly depend on forest resources. When it comes to the economic and social functions of forests in BiH, they are primarily reflected in the provision of jobs and raw materials for various branches of the processing industry. According to the data of the official agencies (Federal Statistical Office, 2021; Republic Statistical Office of the RS, 2021), there were over 10,000 employees in the forestry sector of Bosnia and Herzegovina in 2020 (5,224 in the Federation of Bosnia and Herzegovina and 4,849 in the Republic of Srpska). Following the logic of economic connection, the export-oriented domestic wood processing industry relies on forestry sector, so these two branches of the economy currently employ over 22,000 people. The former development of the wood processing industry in BiH is also indicated by the data that in 1992, it contributed 10% to the GDP (3 billion US dollars) and 11% to the total export value of the BiH economy. In that period, the timber complex (forestry and wood processing industry) employed 90,000 workers (18% of workers in the total industry and mining in BiH). Forestry and the wood processing industry were the driving forces behind the development and post-war reconstruction of Bosnia and Herzegovina. Already in 2015, the participation of the wood processing industry in the structure of the total industrial production of the Federation of Bosnia and Herzegovina amounted to 8.1% (processing and production of wood products 2.8%, furniture 2.9%, paper and pulp 2.4%) with a significant surplus (in 2015, exports of the domestic wood processing industry amounted to 625 million KM and imports to 177 million KM). The mentioned indicators gain even more importance having in mind that forestry, together with the wood processing industry, extensive agriculture and mining, represents the basic source of existence for the majority of the local population in rural areas. The possibility of diversification in the forestry sector (use of mushrooms, medicinal plants and forest fruits, development of hunting and eco-tourism, energy production from forest biomass, etc.), in addition to already existing jobs, represent a solid assumption for further development and economic growth.

As for ecological functions, the role of forests in preserving biodiversity, mitigating climatic extremes and ensuring the stability of water and land regimes is immeasurable. It is known that 80% of all terrestrial species on the planet live in forest ecosystems. As a country with a relatively small area, Bosnia and Herzegovina has a rich and preserved biodiversity, as evidenced by more than 5,000 species and subspecies of vascular plants, more than 100 species of fish and over 320 species of birds. Based on the estimates made during the creation of the preliminary list of species for the Red Book, and in compliance with the IUCN categorization, it was determined that over 600 species and subspecies of the flora of BiH belong to some degree of threat (Federal Ministry of Environment and Tourism, 2009). It was also determined that 30% of the total endemic flora of the Balkans (1,800 species) is found in Bosnia and Herzegovina (NEAP, 2003). According to the data of the Assessment of the State of Nature and Governance of Natural Resources, over 90 species of mammals, over 6,000 species and subspecies of invertebrates, over 70 species and subspecies of reptiles, over 600 species of lichens and over 500 species of fungi have been identified in Bosnia and Herzegovina (Barudanović et al. 2024). All these data confirm the regional importance of Bosnia and Herzegovina, when it comes to the biodiversity values, which is very often connected with the existing forest ecosystems. Therefore, it can be claimed that Bosnia and Herzegovina is a land of forests and biological diversity. The common ecological role of forest ecosystems in providing drinking water is extremely important. According to some projections, by the year 2050, every fourth person on the planet could be affected by a constant water shortage (Support to the preparation for the implementation of the Sustainable Development Goals and engagement of the private sector, 2022). It is important to encourage pioneering research related to payment modalities for the contribution of forest ecosystems to ensure drinking water in the countries of the region (Vuletić et al. 2020). Eventually, it is known that the degradation and disappearance of forests precedes soil erosion, the appearance of torrential flows and the disappearance of sources of drinking water, which is further complicated by extreme climate changes. The floods that hit some parts of Bosnia and Herzegovina in 2014 warn us that we still do not sufficiently understand and appreciate the ecological functions of forest ecosystems, especially those related to ensuring the stability of the water and soil regime.

2. SUSTAINABLE FOREST MANAGEMENT, SUSTAINABLE DEVELOPMENT GOALS AND FOREST-CLIMATE INTERACTIONS

The concept of sustainable forest management, which implies simultaneous and balanced satisfaction of the dynamic ecological, social-cultural and economic demands of society towards the forest, contains the essence of the concept of sustainable development as defined in the so-called "Brundtland" report[1] - meeting the current needs of the society without jeopardizing the ability of future generations to meet their needs as well. The concept of sustainability unites efforts to bridge the gap between the imperative of economic development and the necessity of environmental protection. The problem of the availability of natural resources, in constant population growth and unpredictable climate changes, leads to the question: *How much forest can/may we cut down for industrial needs, without questioning its continuous growth and the stability of forest ecosystems?* From the historical overview of the concept of sustainability in forestry (Marić, 2021), it can be seen that this term was first used by von Carlowitz (Hans Carl von Carlowitz) as early as 1713 in his work *Sylvicultura Oeconomica*, considering the problem of the reduction of areas under forest and growth of wood price due to increased demand, population growth and uncontrolled grazing. Von Carlowitz warned that people could *"suffer great difficulties"* in the absence of wood and called for the preservation of forests without their excessive exploitation. The essence of his doctrine is that only as much wood can be cut as the forest can be regrown, and that the ultimate goal is to manage forests in a sustainable manner, consistently and continuously over time. In the spirit of today's definition of sustainable development, Moser (Wilhelm Gottfried Moser) in his book *Grundsätze der Forst-Oeconomie*, published in 1757, claimed that *"a sustainable economy must be reasonable, just and wise, and that man must not live only for himself, but also for others and progeny"*. The German term *"Nachhaltigkeit"* (sustainability)

[1]In the document "Our Common Future", published in 1987, the concept of sustainable development was presented for the first time, as a strategic-political platform that recognizes the mutual connection between social equality, economic growth and environmental issues (https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf)

has been used for 300 years to explain the principles and fundamental goals of sustainable forest management (Schmithüsen and Rojas-Briales, 2012). The concept has evolved over time, so that the goals and strategies for achieving sustainable forest management have been adapted to changing ecological and social-economic realities. In this sense, forestry paved the way for other sectors dealing with the governance and management of natural resources (Schmithüsen, 2013). Multifunctional and sustainable forest management strives to respond flexibly to different interests and adapt management of forest resources to social and environmental conditions, in such a way as to provide more options for responding to market demands, trends and changing needs of the society, while not excluding the possibilities of use for future generations (Marić, 2021 Ibid). According to the definition of the Ministerial Conference on the Protection of Forests in Europe (Forest Europe), sustainable management means *"the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems"*[2]. In a similar way, the FAO definition of sustainable forest management was formulated as *"a dynamic and evolving concept that aims to maintain and improve the economic, social and ecological values of all types of forests for the benefit of current and future generations"* (FAO, 2022). It is clear from the above that the concept of sustainable forest management is constantly evolving, and that its main purpose is the long-term maintenance of all the values of forest ecosystems.

At the centre of the 2030 Agenda for Sustainable Development, as a global partnership platform for the development of all UN member states, are 17 universal sustainable development goals (SDGs). While respecting the differences in the priorities of individual countries, the sustainable development goals provide clear, common and global guidelines towards ending poverty, suppressing hunger, improving health and education, reducing inequality, ensuring peace and well-being, continuous economic growth, reducing energy uncertainty, combating climate change, preservation of all types of ecosystems on the planet and protection of biodiversity in them. The research of teaching staff attitudes at the Faculty of Forestry the University of Sarajevo (Avdibegović et al. 2023), regarding the contribution of the educational-research process to the sustainable development goals, showed that it contributes more or less to all of them, which clearly indicates a multidisciplinary character of forestry study. Bearing in mind the seriousness and consequences of the phenomenon of climate change, it is not surprising that almost one quarter of the respondents included in this research believe that the educational and research process at the Faculty of Forestry contributes the most to the achievement of SDG 13 (Climate Action).

Aware of the importance of the interaction between forest ecosystems and climate change, forestry experts and researchers in BiH realize various scientific and research activities on this topic. The results of these activities are, among other things, reflected in the description of possible scenarios of climate change for the Western Balkans, which includes areal projections for some typical tree species in BiH, conditioned by climate change. The results of these modelling are areal maps of tree species for individual countries (Slovenia, Croatia and BiH), with possible areal projections in the year 2080 (Vukelić et al. 2010). Research into the possibilities of In situ and *Ex situ* protection of genetic resources, in the context of the impact of climate change on forest ecosystems of Southeast Europe, is also in the focus of forestry experts, emphasizing the imperative of preserving the specific genetic structure of forest species for future forest ecosystem restoration processes (Cvjetković et al. 2019;

[2]Second Ministerial Conference on the Protection of Forests in Europe, 16-17.06.1993., Helsinki, Resolution H1: https://foresteurope.org/wp-content/uploads/2022/01/MC_helsinki_resolutionH1.pdf

Daničić et al. 2019). A significant number of scientific works on the topic of the impact of climate change on forest ecosystems and management planning refer to the assessment and monitoring of quantitative indicators of the CSF concept *(Climate-Smart Forestry)*, on permanent experimental plots in mixed beech, fir and spruce forests (del Río et al. 2022). The resistance of the most important tree species to climate change was analysed through the research of growth and productivity patterns, as an indicator of the dependence of individual species on the variability of habitat conditions in the previous period. It was understood that mixed forests of beech, fir and spruce should be given priority over monocultures when it comes to climate change mitigation in mountainous areas (del Rio et al. 2021). In the context of the influence of changing environmental conditions on the growth of trees in the mountain forests of Europe (including BiH), specific analyses were carried out on permanent test plots in the field. Observed in a spatial-time context, significant changes in the growth dynamics of individual species were observed, and potential causes (including climate change), consequences and possible implications for management measures were analysed (Pretzsch et al. 2020). Besides, the mentioned researches tried to shed additional light on the dynamics and growth patterns of trees and forest stands, in the context of global climate changes (Pretzsch et al. 2022). Some studies have analysed the effects of climate change on the recent state of forest vegetation at the local level (Vojniković et al. 2015) as well as the appearance of certain pests on plants as an indicator of global warming (Roques et al. 2015). In the analyses of the political-legislative, economic and institutional aspects of climate change in the forestry and nature protection sector, the need for intersectoral action, regional cooperation and the active involvement of all interest groups and actors of forest and environmental policy is emphasized (Nedeljković et al. 2019; Selmanagić Bajrović and Avdibegović, 2010). The possible options for preventing and mitigating climate changes indicate the necessity of forest policy reform, in the direction of respecting the principles of *"Forest Governance"* concept and orientation towards "green economy" and decarbonization as a strategic vision (Avdibegović et al. 2018).

3. IMPACT OF CLIMATE CHANGES ON FOREST ECOSYSTEMS

Climate factors and conditions are necessary for the growth and development of all living organisms, including forests. In addition to adequate moisture and temperature, CO_2 and light are necessary factors for the photosynthesis process in all plants. CO_2 plays an irreplaceable role in building the wood biomass of forest trees. Dry wood contains about 50% carbon and 43% oxygen, and only 6% hydrogen and 1% nitrogen (Mekić, 1998). By absorbing CO_2 and releasing oxygen in the process of photosynthesis, green plants maintain the optimal composition of the atmosphere, which is of vital importance for life on the Earth. It is estimated that organisms that carry out photosynthesis convert about 100 billion tons of carbon into biomass annually (Field et al. 1998). On the other hand, negative climatic phenomena (drought, stormy winds, heavy snowfall, etc.) have a negative impact on forest ecosystems, which manifests itself through the physiological stress of trees, forest dieback, the occurrence of forest fires and windstorms, after which, as a rule, the proliferation of harmful insects and the appearance of various phytopathogens occur. The interaction of forest ecosystems and climate conditions is also manifested through the influence of the forest on the microclimate. Regardless the influence of macroclimate factors, microclimatic conditions in the forest are different than outside it. The temperature in the forest is lower in summer and higher in winter (day differences are 2.5-5 °C and nighttime 0.5-1 °C), while the temperature fluctuations are less pronounced. On average, a smaller amount of precipitation penetrates to the soil in the forest (there is a saying that in the forest "rain falls twice"), snow stays longer, the wind speed is lower, soil evaporation is lower, and the relative humidity of the air is higher (Mekić, 1998 ibid). It is evident that climatic conditions and climate changes affect forest ecosystems, but also that the forest, due to its influence on the climate, can be seen as a specific climate factor.

Climate change, caused by excessive gas emissions and the greenhouse effect, represents one of the most serious global environmental problems. Around the world, climate change cause increase in the frequency and intensity of extreme weather events, such as heat waves, droughts and floods. Europe has been particularly affected by climate change, where average temperatures have risen almost twice as high as the global average. The living world changes in different ways and adapts to the changed dynamics of climate processes. One of the ways in which species and ecosystems react to climate change is reflected in the geographical (towards the north) and height (to higher altitudes) shifting of the boundaries of natural areal (natural migrations). It was established that the ranges of certain species are moving north by an average of 16.9 kilometres in 10 years and to higher altitudes by an average of 11 meters in 10 years. Naturally, animals migrate from their habitats faster than plants. Animals increase their upper areal limit by 47-91 meters per decade, and plants by 17-40 meters per decade (European Wilderness Society, 2024). The consequences of these changes are multiple. They are reflected in the risk of loss of biodiversity and even extinction of those species that cannot migrate or adapt quickly enough to changing climate conditions. On the other hand, species that are more flexible when it comes to expanding their range can become invasive and thus disrupt the stability of local ecosystems. Geographical and altitudinal changes in the range of species can affect the reduction or loss of certain ecosystem services such as water regulation, soil fertility and pollination, which are of essential importance for humans. Finally, changes in areal and populations of plants and animals, caused by climate disturbances, can strongly affect productivity in forestry and agriculture (food security).

The long lifespan of trees and the multi-year production cycle in forestry (often over 100 years) do not allow quick adaptation to changes in the environment, which makes forest ecosystems particularly sensitive when it comes to climate change. The mortality of trees and the amount of sanitary felling (most often caused by stormy winds, drought and bark beetles) have increased significantly in the previous period. In Europe, in the previous 40 years, the last decade was a record in terms of forest damage connected in a way or another to climate change. This especially applies to artificially raised spruce forests (Picea abies), which in areas with a relatively low altitude were exposed to long dry periods, what resulted in an overpopulation of bark beetles. It is estimated that such disturbances will be more and more frequent and intense in mountain forests and in Northern Europe, in conditions where the temperature conditions in the previous period were unfavourable (low temperatures) for the development of bark beetles. Physiological sensitivity to extremely dry conditions caused by climate change is also shown by other types of trees, especially beech (*Fagus sylvatica*) and some types of pine. Scientific models predict that in EU countries, oak forest habitats will increase from the current 11% to 30-40% of forest areas (depending on which climate scenario will come true in the future), while spruce forest habitats will decrease by approx. 50% (Sotirov et al. 2024).

Climate change and its impact on forest ecosystems is also evident in the Western Balkans. According to the data of the study published by the Council for Regional Cooperation, in the Western Balkans, a temperature increases of 1.2 °C could be expected by 2035, and even by 1.7-4.0 °C by the end of the century, depending on effects of global activities to reduce the emission of greenhouse gases (Vuković and Vujadinović-Mandić, 2018). The consequences of climate change are mostly reflected in agriculture (reduction of food production and loss of fertile land), forestry (degradation of forests and disappearance of certain species) and water management (disruptions in the water regime). In the publication Assessment of the State of Nature and Governance of Natural Resources in Bosnia and Herzegovina (Barudanović et al. *Ibid 2024*), the contribution of individual groups of ecosystems in Bosnia and Herzegovina on providing ecosystem services (benefits of nature which are defined for the needs of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) was presented. Among regulating ecosystem services are, among others, the benefits of regulating climate processes and the benefits of regulating air quality. The benefits of regulating climate processes include the effects that ecosystems have on the emission of greenhouse gases, the biophysical effects of the vegetation cover on the atmosphere, the recycling of moisture, and the regulation of the process of formation and decomposition of aerosols. In the context of benefits from nature related to regulating air quality, it is understood the ability of individual ecosystems to regulate the relations of various gases and their compounds in the atmosphere (O_2, CO_2, NO_X, harmful organic pollutants, etc.), as well as to purify the air and bind, break down and store various pollutants that directly affect human health or infrastructure. The highest ratings of importance for the benefits of regulating climate processes and the benefits of regulating air quality are given to forest ecosystems (mountain forests, lowland and hilly deciduous forests and shrubberies, and Mediterranean and sub-Mediterranean forests and shrubberies).

In addition to the mentioned results, the aforementioned publication pointed out the lack of scientific research activities regarding the impact of the ecosystems on regulating ecosystem services, which includes the regulation of climate change. It is necessary to establish a system of continuous monitoring of these impacts, through defining appropriate indicators and collecting data on the benefits of climate change regulation, and looking for adequate nature-based solutions for adaptation and mitigation of climate change. In the mentioned Assessment, it was also stated that BiH is rich in natural ecosystems that have positive effects in the process of climate change adaptation, but that due to the interplay of numerous direct and indirect pressures, the harmful effects of climate change are becoming increasingly pronounced, with negative impact on the ecosystem's ability to regulate these processes. It is necessary to implement transformative and strategic changes in climate-sensitive sectors, above all in forestry, in order to mitigate the negative consequences on society, nature and the economy in BiH.

When talking about options for dealing with climate change, two terms are commonly used in the media and scientific literature: "adaptation" and "mitigation". It is about two groups of activities, instruments and political measures, which are realized simultaneously but in a strategic sense have different character. "Adaptation" is focused on the consequences and effects of climate change and implies reaction, i.e. a posteriori action. Unlike it, "mitigation" deals with the causes of climate change and, according to a priori logic, tries to reduce the potential negative impact and acts before the actual manifestation of climate change. It is clear that "mitigation", in relation to "adaptation", implies prior and planned action, and that it is therefore more effective but also more difficult to implement. A classic example of "adaptation" measures to climate change in forestry sector is afforestation with species that have a known genetic origin and are more resistant to drought, especially in xerothermic habitats. In forestry practice, for the purpose of afforestation of extremely rocky and arid terrains, seedlings with a specially coated root system are used, in order to more easily adapt to the demanding habitat conditions. On the other hand, the use of forest biomass for energy represents a measure for "mitigation" of climate change, in order to promote renewable energy sources and reduce carbon emissions, which are largely a consequence of the use of fossil fuels. In addition, the application of appropriate planning and management systems (favouring mixed, semi-aged and "close-to-nature" forests), prohibition of clear-cutting, forest certification and the use of ecologically acceptable technological solutions, are also examples of measures for "mitigation" of climate change in the forestry sector. In the context of forest policy, it is important to emphasize that in most cases "adaptation" measures have a local or regional focus, unlike "mitigation" measures, which have a strategic and often global character.

4. FORESTRY SECTOR AND CLIMATE CHANGE: SELECTED ASPECTS

This chapter presents only two aspects of climate change that can be directly linked to the forestry sector in Bosnia and Herzegovina. One of them is forest fires, which in public perception, due to the ecological, economic and social consequences they cause, are often recognized as the main negative manifestation of climate change, both locally and globally. The second aspect refers to the importance and role of forest resources in the carbon cycle and the potential for energy production based on forest biomass. There are a number of other aspects that can be observed in the context of the interaction between the forestry sector and climate change, but their analysis is omitted here.

Forest fires

In the IUFRO (International Union of Forest Research Organizations) study entitled Europe's wood supply in disruptive times (Sotirov et al. 2024), it is stated that in southern Europe, droughts and fires will play an increasingly prominent role in shaping forest development in the future. In conditions of extreme climate change, it can be expected that the burnt area in Europe will reach 750 thousand hectares per year by the end of this century. Figure 2 shows projections of burned forest areas depending on different climate change scenarios (Representative Concentration Pathways - RCPs) in Europe. The projections clearly indicate an increase in the area affected by fires in the case of scenarios RCP4.5, RCP6.0 and RCP8.5 until the end of the XXI century.

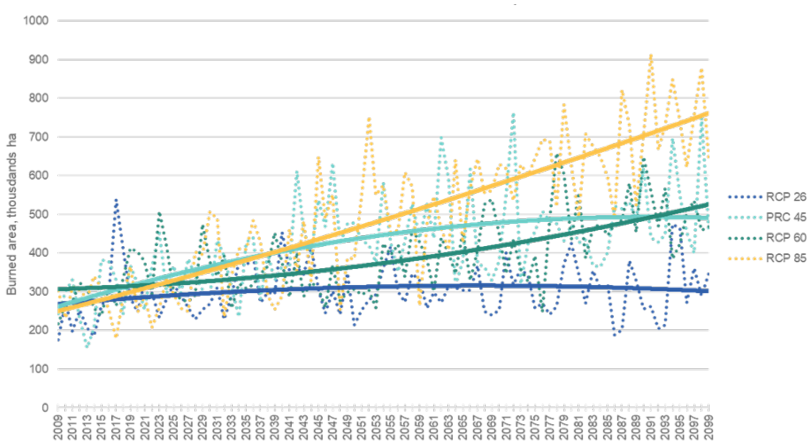

Fig. 2. Projected changes in burned forest areas in Europe under different climate change scenarios over time (2009-2099) (Sotirov et al. ibid 2024, based on IIASA, FLAM Model, Krasovskii et al. 2019)

The mentioned four climate change scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) were developed for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2013, and consider changes in different factors such as: population growth, gross domestic product, energy consumption, growth in average temperatures, changes in precipitation, etc. For example, an increase in world population to 12 billion people by 2100 is likely to lead to the most pessimistic scenario (RCP8.5), where the consumption of primary energy should be three times higher than the current one. According to this scenario, the global mean temperature by 2100 would increase for 4-8 °C compared to the reference pre-industrial period. At the same time, the share of coal in the energy mix would remain significantly high (almost 50%), and CO_2 emissions would increase from almost 10 GtC/year in the present to almost 30 GtC/year by the end of the century. On the other hand, the most optimistic scenario (RCP2.6) implies that the number of people would increase to "only" 9 billion by the end of the century, while the share of fossil fuels in the energy mix would be very low, and CO_2 emissions would fail to zero around 2080. In that scenario, the mean global temperature increase remains below 2 °C target under the Paris Agreement from 2015. Current trends do not leave much room for optimism regarding climate change and the global factors that affect it. In any case, forest fires around the world increasingly contribute to global greenhouse gas emissions and negatively affect human health and safety, the sustainability of economic activities, and the continuity of providing ecosystem services.
Climate changes are considered important generators of various natural disasters, which are increasingly manifested in Bosnia and Herzegovina. Considering their spatial distribution, forest ecosystems in Bosnia and Herzegovina are quite vulnerable in terms of being threatened by forest fires. Coniferous forests and forest areas in Herzegovina are certainly the most threatened. However, a high level of threat is also present in private forests, which are often abandoned, neglected and non-managed, with lot of dense and easily flammable low vegetation. Official data (burnt area and wood losses) shown in Table 2 show the growing trends of forest fires in Bosnia and Herzegovina.

Table 2. Forest fires in Bosnia and Herzegovina (2018-2021) (Federal Statistical Office, 2021; Republic Statistical Office of the Republic of Srpska, 2021)

Year	2018	2019	2020	2021
Burnt area (Ha) (state and private forests)	RS: 3.358	RS: 1.958	RS: 6.823	RS: 6.861
	FBiH: 1.467	FBiH: 4.099	FBiH: 21.732	FBiH: 18.062
Wood losses (m3) (state and private forests)	RS: 2.374	RS: 13.204	RS: 32.196	RS: 37.913
	FBiH: 87	FBiH: 775	FBiH: 16.966	FBiH: 20.764

The total financial damage in the Federation of Bosnia and Herzegovina caused by forest fires in 2020 was estimated at 15,434,534 KM (Federal Ministry of Agriculture, Water Management and Forestry, 2021). It is particularly worrying that fires occur in the same areas year after year, which significantly hampers the ability of forest ecosystems to recover after these natural disasters. It is indicative that lately forest fires have been occurring even in protected areas, so that in 2022 fires were recorded in Sutjeska National Park, Hutovo Blato Nature Park and Blidinje Nature Park.

There are many preconditions for a successful fight against forest fires, and the most important among them are: intersectoral cooperation, coordination and communication, inter-entity and cross-border (international) cooperation), educated and trained staff, technical and infrastructural prerequisites, increasing public awareness, available financial resources and adequate legal framework, including operational procedures, rules and regulations. The complexity of the causes and consequences of forest fires, as well as the large number of directly or indirectly interested actors involved in this issue, imposes the need to consider the role and development of intersectoral cooperation. The establishment of DRR platforms (Disaster Risk Reduction) at the local level in Bosnia and Herzegovina is a good example of positive practice regarding intersectoral cooperation in combating wildfires. These are initiatives that were implemented in the context of a broader approach (UNDRR), which aims to help decision makers at all levels to better understand and act effectively in reducing the risk of natural disasters. In addition, strengthening public awareness of the importance of natural resources and the need to fight against forest fires is extremely important. The fight against forest fires requires a specific combination of knowledge and skills from forestry, technology, economic-sociology, law, communication and other disciplines, which points to the need for multidisciplinary training of the forestry sector personnel. Prevention, suppression and fight against natural disasters caused by climate change, especially forest fires, require a high level of technical and infrastructural equipment. Nowadays, this implies the use of robust and modern IT and communication equipment, satellite images, GIS tools and the most modern technologies on land and in the air. The role of the early warning system is particularly important, which, based on a combination of different types of data from different sources, increases the readiness of all actors for a timely and quick reaction on natural disasters. Combating forest fires is expensive and involves the provision of considerable financial resources. For this, an adequate regulatory framework is necessary, which in the conditions of the complex administrative and political organization of Bosnia and Herzegovina implies the existence of harmonized laws that regulate the issues of forest management, nature protection, firefighting and civil protection. Forest fires do not recognize the administrative borders of entities and states and very often have a cross-border character. Responses to increasingly frequent natural disasters involve joint activities of actors from the affected countries, so there are numerous examples of coordinated international cooperation in the fight against fires. Such an approach, especially in the Mediterranean region, has been actualized in the last few years, due to increasingly frequent temperature extremes caused by global climate changes, but also as a result of coordinated activities at the level of the European Union. Perspectives for the improvement of forest management measures aimed at reducing the risk of fire occurrence and restoration of burned areas, have a strong basis in the latest strategic documents of the European Union dealing with nature protection and forest resource management.

The role of forests in carbon cycle and the potentials of forest biomass for energy

Although the significance and role of forest resources in the global carbon cycle, and therefore adaptation and mitigation to climate change, are well known, it should be noted that 14% of anthropogenically caused carbon emissions at the global level are the result of forest harvesting and degradation of forest ecosystem. At the same time, forests and forest lands, if properly managed, have the potential to store 29% of carbon from the atmosphere, which (along with the ocean) makes forests the most significant carbon sink. It is also important to emphasize that in times of global energy insecurity, wood is still the most important source of energy for over 2.5 billion people (for 90% of people in Africa). In the context of renewable energy sources and energy transition, forest biomass (in addition to solar and wind energy) plays a very important role. In many European countries, forest biomass is currently the most common renewable energy source. Achieving the goals of the Paris

Agreement implies a significant and urgent reduction of anthropogenic emissions of CO_2 and other greenhouse gases on a global scale. At the same time, an increase in the removal of CO_2 from the atmosphere is expected, in which forests play a key role. When it comes to European strategic documents, the European Green Deal relies heavily on forests and forestry to achieve climate neutrality in the EU by 2050. According to data from the European Forestry Institute (EFI), forests and wood products currently absorb a significant amount of carbon from the atmosphere (equivalent to 380 $MtCO_2$ per year), which compensates for about 10% of the total greenhouse gas emissions of the entire EU. In accordance with the ambitious political goals of the EU, the LULUCF (Land Use, Land-Use Change, and Forestry) sector, which includes forests and wood products, is expected to absorb an additional 50 $MtCO_2$ annually at the EU level until 2030., 100 $MtCO_2$ by 2035 and 170 $MtCO_2$ by 2050. Climate change mitigation activities in forestry, aimed at reducing carbon emissions from forest ecosystems and storing carbon in wood products, include measures of protection (degradation reduction and forest protection), management (sustainable use), restoration (afforestation) and improvement of wood use (transition on durable wood products and wood product recycling). It is estimated that the combined applying of all these measures at the EU level could provide an additional potential for mitigating the effects of climate change in the equivalent of 72 - 143 $MtCO_2$ per year until 2050, depending on the applied mix of forest policy measures (Verkerk et al. 2022). According to the First National Report of BiH under the United Nations Framework Convention on Climate Change, the potential of forest ecosystems as sinks for storing greenhouse gases amounted to -7,432.5 $GgCO_2$ in the base year of 1990. The total emission of greenhouse gases in Bosnia and Herzegovina (without sinks) amounted to 34,043.49 $GgCO_2$ in 1990, and in 2018 it decreased to 31,170.94 $GgCO_2$. According to the inventory of greenhouse gases in the forestry sector for 2015 and 2016 (Figure 3), the total balance of greenhouse gas sinks and emissions for forest areas, wood products and fires was -6,095.70 GgCO2 in 2015, and -5,836.68 $GgCO_2$ in 2016. These data were obtained by using the IPCC (*Intergovernmental Panel on Climate Change*) methodology for calculating the inventory of greenhouse gases in the forestry sector (UNDP/Ministry of Spatial Planning, Construction and Ecology RS, 2022). The measures to increase the potential of the carbon sink in the forestry sector, recognized in the national strategic documents (Integrated Energy and Climate Plan – NECP) are focused on consistent implementation of sustainable forest management measures, reforestation of barren and eroded areas, conversion of degraded forests, fight against forest fires, increasing the growth of forest stands and raising plantations of fast-growing species (energy plantations).

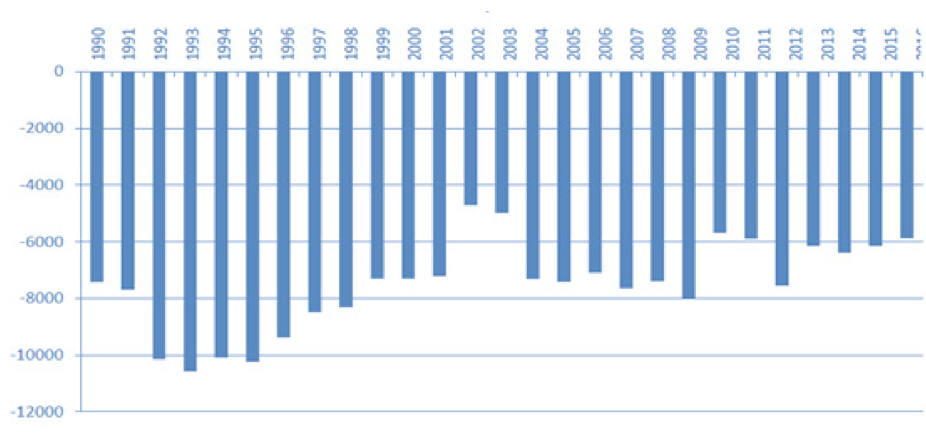

Fig. 3. Carbon sinks in forestry sector of Bosnia and Herzegovina (1990-2016) (GgCO2)

In conditions of constant population increasing, global economic growth, and orientation towards fossil fuels, the energy becomes an important political, economic and environmental issue. Conflicts around the world and interruptions in supply chains further complicate the current situation and lead to problems of energy insecurity, availability and sustainability. The use of alternative, so-called clean and renewable energy sources are accepted as the most effective answer to the mentioned problems, and the use of forest biomass for energy, especially in countries such as Bosnia and Herzegovina, has great potential. The amount of CO_2 emitted into the atmosphere during the burning of forest biomass energy sources (pellets and briquettes) is equal to or less than the amount of CO_2 absorbed during the growth of the trees whose biomass is burned. That is why forest biomass for energy (residues after felling, waste from the wood processing industry or agriculture, etc.) is considered "carbon neutral" and has great potential as a renewable source of energy, where coppice forests and energy plantations (Halilović et al. 2021) as well as private forests (Posavec et al. 2015) are especially important. In doing so, it is necessary to analyse the reliability of the supply chain of forest biomass for energy (Vasković et al. 2015) and the use of different technologies in the process of forest exploitation, in order to make the best possible use of the potential of forest habitats from the aspect of using wood for energy needs (Halilović, 2012). The use of firewood, as a retrograde way of obtaining energy from forest biomass, is still quite widespread in Bosnia and Herzegovina. Using the WISDOM (Wood fuel Integrated Supply/Demand Overview Mapping) methodology, it was determined that a significantly higher percentage of households in the Federation of BiH use wood as an energy source (mainly firewood), compared to official statistical data (Čomić et al. 2021). Several studies were also carried out with the aim of determining the potential for the use of forest biomass for energy, as well as technological, ecological, legal and political-legislative assumptions for the mobilization of forest biomass. The results of one of these studies (Pfeiffer et al. 2019) related to the assessment of forest biomass potential in Bosnia and Herzegovina are shown in Figure 4.

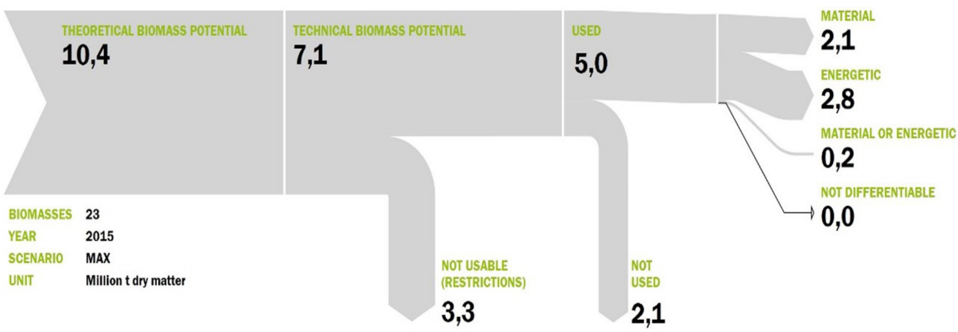

Fig. 4. Forest biomass potentials in Bosnia and Herzegovina in 2015 (maximum scenario)

One third of the total estimated theoretical potential of forest biomass (10.4 million tons dry matter), cannot be used, mainly due to ecological restrictions and the need to preserve the stability of forest ecosystems. The significant part of the technically available potential is already used in the wood processing industry and as firewood. So, this assessment takes into account the economic and social importance of the wood processing industry for the entire BiH economy in terms of providing a sufficient amount of raw materials, but also the current pattern of using wood as an energy source (firewood), especially in rural areas.

The remaining (unused) potential of forest biomass is estimated at 2.1 million tons of dry matter per year, which is equal to 716-907 ktoe (kilotons of oil equivalent). For the sake of comparison, in 2013 the total energy consumption in BiH was 4.6 million toe (tons of oil equivalent), of which traffic and transport accounted for 869,400 toe (Entity Action Plans for the Use of Renewable Energy Sources, 2014). The aforementioned traffic and transport were mainly based on imported oil derivatives, and the value of oil imports in 2013 was about 2.27 billion KM (BiH Statistics Agency, 2014). In order to fully mobilize the potential of forest biomass for energy, it is necessary to ensure the reliability of supply chains and a number of other political-economic and legal assumptions. In several studies carried out by the UNDP, an analysis of political aspects in the forestry and energy sectors in Bosnia and Herzegovina was carried out (Avdibegović, 2017) as well as an analysis of the mix of regulatory, economic, planning and informational instruments of forest policy in relation to this issue (Avdibegović and Čomić, 2019).

CONCLUSIONS

Forest resources are of exceptional importance for Bosna and Herzegovina and that is why their sustainable management should have an important place in the national political and economic agenda. Sustainable management of forest resources, based on a comprehensive understanding of forest multifunctionality, is an important factor in the sustainable development of the entire BiH society. Climate changes, above all the increase in mean temperatures and the changing pattern of precipitation, have a strong impact on the stability of forest ecosystems. On the other hand, current management measures cannot guarantee the control of the negative effects of climate change on forest ecosystems, such as the occurrence of forest fires and, in connection with this, the reduction of forest potential for carbon storage. Climate change strongly affects the dynamics of forest ecosystems and this fact must be taken into account when developing effective policies for the conservation and sustainable management of forest resources. It is necessary to apply adaptive management strategies, such as conversion to tree species that are more resistant to drought. Even under these conditions, due to increasingly pronounced climate changes and the long-term nature of forestry production, it is realistic to expect numerous challenges in forest management in the coming years. However, the proper implementation of forest resource management measures can significantly reduce the risk of unwanted effects of climate change.

The positive aspects of proper forest management (choice of adequate management systems, formation of a mixed and diverse structure of forest stands, supporting natural regeneration, afforestation, silviculture measures and sanitary harvesting, forest protection, construction and maintenance of forest roads, etc.) are recognized as good practices, which are used in the forestry of Bosnia and Herzegovina. In 2023, the European Commission adopted the Guidelines on Closer-to-Nature Forest Management. At the same time, the EU strategy for forests until 2030 defines the term "close-to-nature forest management" as a set of practices that ensure the multifunctional character of forests, while simultaneously preserving biodiversity in them, strengthening the carbon storage function and ensuring the continuity of income from wood. The fact that these are the same principles on which forestry science and the profession in Bosnia and Herzegovina have been based for many years is encouraging. The concept of plural, integral and multifunctional forestry, which includes the balance of various ecological, sociological and economic aspects, ensures the satisfaction of changing society's demands towards the forest in the long term and in a comprehensive manner. At the same time, the application of the concept of multifunctional and "close-to-nature" management of forest resources indicate strategic and structural changes that must be implemented in the forestry sector of Bosnia and Herzegovina. Understanding the importance of forest resources in the fight against climate changes is an important step towards what lies ahead and what nowadays we call the climate, energy and “green” transition. The forest resources of BiH gain additional importance in the circumstances of global energy poverty, insecurity and relations that prevail in the politically bipolar world in which we live. Changes in the political, economic and ecological environment require a different attitude towards forest resources. This is a key prerequisite for meeting the changing demands of society, which recognizes the stability and ecological integrity of forest ecosystems as an important prerequisite for achieving balanced economic development and human well-being.

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The Impact of Transportation and Communication on Environmental Pollution and Climate Change

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Abstract: Transportation and communication systems have a significant impact on the environment, environmental pollution, and climate change, as confirmed by statistical data from relevant institutions engaged in measurement and research. The transportation system includes various forms of transport, such as road, rail, water, air, and pipeline, each of which affects water, air, and soil pollution differently. This study pays special attention to road transport, as it is statistically one of the main sources of greenhouse gas emissions, primarily through the release of CO_2, NOx, PM particles, and others.

The introduction of sustainable transportation systems and communication technologies can reduce the negative impact of traffic and transport on the environment. Climate change, manifested through extreme weather conditions, requires the adaptation of existing traffic and communication systems and their infrastructure. Policies and regulations that encourage the reduction of emissions from transport vehicles and the promotion of sustainable mobility are key aspects of researching the impact of transportation and communication on the environment and climate change. Special attention is given to solutions, technological innovations, and the promotion and use of renewable energy sources, which can significantly reduce the negative impact of traffic and transport on the environment and climate change. The chapter concludes with examples of good practices that reduce the impact of transportation and communication on environmental pollution.

Keywords: Transportation and Communication Impact, Environmental Pollution, Climate Change, Greenhouse Gas Emissions, Sustainable Transportation.

1. INTRODUCTION TO TRANSPORTATION AND COMMUNICATION SYSTEMS

Transportation systems help people reach their destinations quickly and safely, while communication systems ensure that information (data) travels quickly and securely. Understanding how these systems work helps us improve them, making them safer and better for the environment, reducing traffic congestion, and increasing efficiency. By doing so, we can enhance the quality of life and support the sustainable development of communities. The transportation system, as a unified entity, affects its entire environment, as well as economic and social life. It has its function, structure, system elements and connections between them, subsystems, and more. The transportation system is viewed as a complex, integrated, and open system.

The function of the transportation system is to meet all movement needs in a society as effectively as possible, including the transportation of goods, and people, and the transmission of messages (information) between people who are spatially distant. These transportation needs vary spatially and temporally.

The basic structure of the transportation system consists of transport routes and vehicles across different branches (modes) of transport, such as road, rail, water, maritime, air, and pipeline transport.

Communication is the process of exchanging information through a specific communication system. This system includes elements like infrastructure, devices, technologies, and users, all of which interact to create a complex and integrated system. The purpose of a communication system is to make the transfer of information between people and devices as efficient and reliable as possible, no matter the distance between them. Just like two people need to understand the same language to talk to each other, communication systems require specific mechanisms to ensure information can be exchanged between different devices Communication systems provide a fast and efficient way to transfer information between people, companies, and societies. These systems encompass a wide range of different technologies and platforms that together form an integrated network, enabling people to connect. Like transportation systems, communication systems have their function of facilitating the exchange of information through various formats such as phone calls, text messages, audio and video calls, and more. With the increasing number of users of these systems, the need for fast, secure, and reliable information transmission also grows. Considering the rapid development of technology and digitalization, the ways in which people communicate today are significantly changing. For these reasons, communication systems are constantly adapting to new requirements such as information transmission volumes and speed. This rapid development of communication technologies enables the integration of different systems, which supports innovation in all segments of society and contributes to improving people's quality of life. Facilitated international cooperation and knowledge exchange further enable the implementation of these technologies in the economic and social systems of people. The function of transportation and communication systems is not only to meet the needs for movement and communication but also to support economic growth and societal development. However, despite their numerous advantages, transportation and communication systems have negative effects and consequences on the environment. Additionally, traffic noise has a harmful impact on human health and ecosystems in both urban and rural areas. The volume of goods transported by trucks has increased significantly due to the ongoing growth in freight transport activity, surpassing 120 billion ton-kilometers in 2017. This increase is mainly attributed to the growing demand for consumer goods transported by road freight and maritime transport. In 2017, the total global passenger transport activity amounted to 55 trillion passenger kilometers, with 78% coming from road transport [1]. Although rail is by far the most efficient mode of transport with the lowest CO_2 emissions per passenger, it accounted for less than 8% of passenger activity that year. Communication as a form of transportation enables the rapid and efficient transfer of information and data between different locations and people. With the help of various technologies and infrastructure such as telecommunications networks, satellite connections, and digital platforms, communication systems support global connectivity, facilitating the exchange of ideas, business messages, and personal information. The basic characteristics of this mode of transport are: speed of information transfer, global connectivity, flexibility and mobility, cost-effectiveness, and more.

2. TRANSPORTATION AND ENVIRONMENTAL POLLUTION

The impact of transportation on the environment is increasingly growing due to the heightened demand for movement of people and the rising number of personal vehicles, which inevitably leads to the construction of new transportation infrastructure. With the development and expansion of transportation, the negative impact on the environment also increases, particularly on air, soil, and water, directly endangering plant and animal life as well as human health. The transportation sector is considered a mobile source of emissions that pollute the environment. The transportation sector is closely tied to the use of fossil fuels such as gasoline and diesel.

Due to incomplete combustion of fuel, harmful gaseous substances are produced, which enter the atmosphere through the vehicle's exhaust system.
The two most commonly used fuels (diesel and gasoline) generate different mixtures of pollutants [2–5]:

- Gasoline vehicles are mainly responsible for emissions of carbon monoxide (CO), volatile organic compounds (VOC), ammonia (NH3), and heavy metals.
- Diesel vehicles produce most of the suspended particles that are 2.5 microns or smaller (PM2.5) and nitrogen oxides (NO_x).
- Emissions of carbon dioxide (CO_2), which contribute significantly to the effect of global warming, are produced by both diesel and gasoline engines.

Emissions of harmful substances from road vehicles are primarily limited by the mandatory reduction of total greenhouse gas emissions adopted in the Kyoto Protocol, followed by the binding targets set by the European Union based on it, and finally by the homologation regulations implemented through EU directives [3].

Natural and urban spaces are increasingly being visually degraded, animal habitats are being fragmented into smaller sections, and green areas in cities are shrinking. The transportation industry, particularly road transport, is considered one of the main sources of pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter, sulfur dioxide (SO_2), volatile organic compounds (VOC), as well as a significant source of carbon dioxide (CO_2) emissions. The damage to the environment caused by pollutants from the air as a result of traffic, and their impact, are presented in the table below. Table 1 presents the various pollutants emitted into the atmosphere as a result of transportation activities.
Table 1. Pollutants resulting from transportation and their source/cause

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Pollutant	Source/Cause
Carbon monoxide – CO	Incomplete combustion
Carbon dioxide – CO2	Combustion
Hydrocarbons – HC	Incomplete combustion, carburetion, evaporation
Nitrogen oxides (NOX)	Oxidation of N2 and nitrogen components in fuel
Particulates, soot (PM2.5 and PM10)	Incomplete combustion, road dust
Ozone formed by interaction with other pollutants	Photochemical oxidation with NOX and hydrocarbons
Lead and other heavy metals	Combustion
Krypton (Kr)	11.14 x10-4
Nitrous oxide (N_2O)	5x0-5
Xenon (Xe)	8.6x10-6
Hygrogen (H)	5x10-5
Nitrogen dioxide (NO_2)	2x10-8
Ozone (O_3)	2x10-6
Sulfurdioxide (SO_2)	2x10-8
carbon monoxide (CO)	2x10-5
Ammonia (NH_3)	1x10-6 - trace

The negative impacts of transportation on the environment (such as air and soil pollution, noise, transport of hazardous materials, consumption of natural resources, etc.) vary from one mode of transportation to another. However, it can be said that road and air transport are the main polluters, while other types of transportation are characterized by more favorable environmental performance. An overview of the impact of each mode of transportation on air, water, health, soil, and nature is provided in Table 2 below.

Table 2. Overview of the Environmental and Health Impacts of Different Modes of Transportation [6]

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Mode of Transportation	Impact on Air	Impact on Water	Impact on Soil/Land	Impact on Nature and Wildlife	Impact on Human Health
Road	CO2 emissions, NOx, PM particles, noise	Wastewater from road cleaning, chemicals from vehicles	Road construction, soil damage due to construction, noise	Exploitation of materials for road construction, endangerment of wildlife	Respiratory diseases, stress due to noise
Rail	Electricity production for propulsion, diesel locomotives	Possible oil and chemical spills from locomotives	Transport of hazardous materials	Lesser impact on habitats due to relatively narrow tracks	Lower health impact due to fewer emissions and less noise
Water	CO_2 emissions, wastewater from ships, noise	Discharge of ballast water, potential fuel leaks, sewage and wastewater from ships	Coastal erosion due to strong currents, engine noise	Impact on marine ecosystems, endangerment of aquatic specie	Health impacts in coastal areas due to emissions
Air	High CO2 emissions, NOx, water vapor, noise, effects on stratospheric ozone	Runoff water from airports containing oils, wastewater from airplanes	Soil erosion on airport grounds	Exploitation of materials for airport construction, destruction of ecological areas due to construction	Respiratory issues due to emissions, stress from noise
Pipeline	CO2 emissions from pumping stations, noise	Potential oil or gas leaks	Soil erosion due to pipeline laying	Impact on local habitats, especially during construction	Hazards from leaks for people and environment

Different modes of transportation have varying impacts on the environment. Road transport significantly pollutes the air with CO_2, NOx, and PM emissions [7] and causes noise pollution. It also affects water and soil through wastewater and construction activities, fragmenting habitats and endangering wildlife. As the most prevalent mode of transportation, road transport is the primary contributor [8] to environmental pollution. Of the total pollution from the transportation sector, road transport accounts for 75-95%, while the remaining types of transportation contribute to the rest of the pollution [6]. Rail transport has a smaller impact on air and habitats compared to road transport but can cause minor water and soil pollution. Water transport pollutes the air and water by discharging wastewater and fuel, negatively affecting marine ecosystems. Air transport is a major source of CO_2 emissions and noise, and it can impact the atmosphere and climate. Pipeline transport, although less visible, can cause air and soil pollution, especially during construction and in the event of leaks. All these factors highlight the need for sustainable practices and technologies in transportation to mitigate the negative impact on the environment.

Transport also creates another negative effect: noise. It is estimated that around 135 million people living in urban areas suffer from noise caused by transportation. The Figure below shows the noise levels produced by different sources, including vehicles such as motorcycles, trains (90 dB), aircraft during takeoff (120 dB), and others.

Noise Level in dB	Source	Level
120	Aircraft during takeoff	Extremely loud
110	Car horn	
100		Very loud
90	Truck, motorcycle, train	
80	Bus	
70	Noise near a highway	Loud
60		Moderate
50	City street	
40		Quiet or no noise
30		
20		
10		
0		

Fig. 1. Noise levels of various sources and their loudness in decibels.

3. EMISSIONS FROM DIFFERENT MODES OF TRANSPORTATION

Emissions from transportation are a significant source of pollution in urban and rural areas worldwide. Different modes of transportation, such as road, rail, air, water, and pipeline, have specific impacts on the environment, emitting varying amounts of CO_2, nitrogen oxides (NOx), particulates, sulfur dioxide, and other pollutants. In 2019, road transport accounted for 71.7% of the emissions from the transport sector in the EU-27[9].

Most greenhouse gas emissions from transportation are the result of fossil fuel combustion in vehicles like cars, trucks, ships, trains, and airplanes. More than 94% of the fuel utilized in transportation is derived from petroleum, primarily consisting of gasoline and diesel, which leads to direct emissions.

The figure below provides an overview of greenhouse gas (CO_2) emissions by sector in the EU-27 for the year 2022, offering insight into the diversity and impact of various industrial and sectoral activities on total emissions in this region.

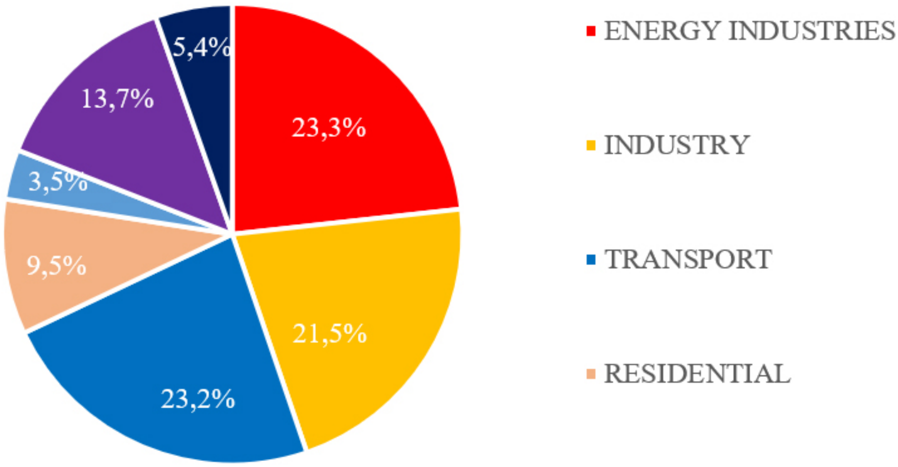

Fig. 2. Overview of greenhouse gas emissions in the EU-27 for the year 2022 [10]

Unlike other sectors, greenhouse gas emissions in the transport sector have increased over the past three decades. After a brief decline following the economic crisis of 2008-2009, emissions began to rise again. Preliminary data show that emissions in 2020 decreased as a result of the COVID-19 crisis. In road transportation, cars played a dominant role in 2019, responsible for 60.6% of emissions, with heavy trucks and buses together contributing 27.1% [9]. An overview of the share of greenhouse gas emissions from transport in the EU-27 by transport modes and their percentage share is provided in the figure below.

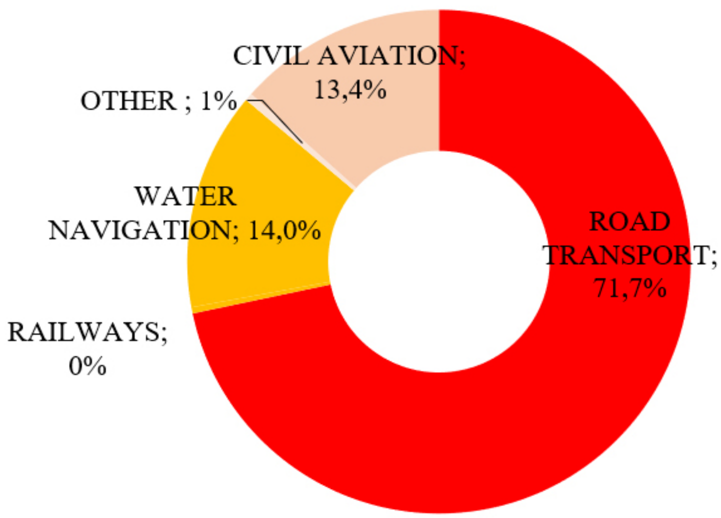

Fig. 3. Share of greenhouse gas emissions from transport in the EU-27 by transport modes [11]

The figure 3. illustrates the breakdown of greenhouse gas emissions by different categories within road transport in the EU-27.

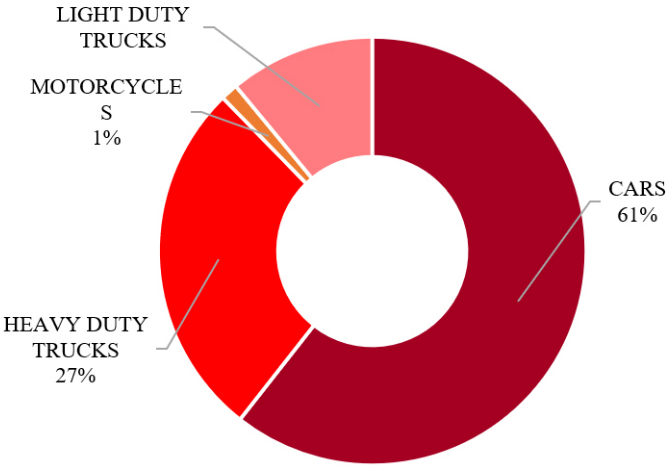

Fig. 4. Breakdown of greenhouse gas emissions by road transport categories in the EU-27[11]

CO2 emissions from passenger transport vary significantly depending on the mode of transport. Personal cars are the main polluters, accounting for 60.7 percent of total CO2 emissions from road transport in Europe, with an average occupancy rate of 1.6 people per car in Europe in 2018 [11]. Road transport (both passenger and freight combined) contributed nearly three-quarters (74%) of greenhouse gas emissions from transport that year, while rail accounted for only 5%. About 36% of CO2 emissions from transport occur in urban areas, with 31.6% coming from passenger transport and 4.7% from freight [1]. The increase in road traffic in recent decades has led to a significant rise in greenhouse gas emissions, particularly in developing countries where high-emission vehicles are commonly used. While passenger transport emissions dominate total emissions in urban areas, freight transport also plays a crucial role in air pollution, especially in cities with high levels of industrial activity.

4. COMMUNICATIONS AND THE ENVIRONMENT

As a human species, we are obligated and responsible not to disrupt the ecosystem through our overall approach to the environment, especially considering our role as innovators, drivers, and implementers of technological development. Our responsibility for the consequences that this development entails is extremely significant. The application of ICT technologies, with telecommunications traffic being considered part of the solution, leads to a reduction in the harmful impact of transportation on the human environment. The intensity of these phenomena and the very unfavorable forecasts for the future have influenced the creation of new development goals, including the once-unimaginable concept of "sustainable development" and the concept of "green," which implies a certain degree of guidance and limitation in favor of the development possibilities for future generations.

By integrating advanced communication technologies, it is possible to reduce greenhouse gas emissions and harmful substances in various aspects of society. When considering the use of communication technologies for teleconferences and video calls, the need for business travel is reduced, directly decreasing emissions from various modes of transportation. The use of advanced technologies such as smart grids and the Internet of Things allows for more efficient use of resources and energy, further reducing the negative impact on the environment [12].

5G network technology, which enables faster and more efficient communication, facilitates the development of smart cities [13]. Smart cities use sensors and advanced analytics tools to optimize vehicle movement, reduce traffic pollution, and improve the quality of life for city residents. In this way, communication technologies are one of the key tools in the fight against climate change and environmental protection.

Considering the rapid growth of data and the need for their processing and storage, the introduction of green ICT solutions and the use of renewable energy sources are crucial factors in reducing the negative impact of communication technologies on the environment. Applying such solutions allows for the reduction of the ICT sector's carbon footprint and contributes to more sustainable development. Modern society is quite aware of the need to change previous practices in favor of the environment, yet the technology sector still has negative impacts that need to be mitigated.

The constant increase in the production of technological devices such as phones, computers, routers, etc., requires a large amount of natural resources, including minerals, metals, and fossil fuels [14]. The extraction of these minerals significantly impacts deforestation, soil degradation, and water pollution. Moreover, the rapid obsolescence of technology and the constant introduction of new products create a large amount of electronic waste that requires proper disposal. These obsolete devices contain toxic substances, such as lead, mercury, and arsenic, which can pollute water if not properly disposed of. Improper dismantling of electronic devices, also known as electronic waste, can release hazardous substances and pose health risks to those working with such waste.

The energy required to power servers, data centers, and devices also contributes to greenhouse gas emissions, as seen in cryptocurrency mining [15], which further contributes to global warming. The lack of proper management of electronic waste, including the production of electronic components, often involves intensive industrial processes that emit pollutants into the air and water. These pollutants can degrade air and water quality, harm human health, and threaten the survival of various species. [16].

Technology has significant potential to protect the environment through a range of innovative applications. Renewable energy sources such as solar, wind, geothermal, and hydroelectric power are crucial in the transition to a sustainable energy system. Waste management is becoming more efficient thanks to technological innovations such as automated recycling systems and sensor-based waste monitoring. Smart building management systems reduce energy consumption through automatic control of lighting, heating, and cooling. Technologies like the Internet of Things (IoT) allow for precise monitoring and optimization of water, energy, and other resource consumption. 5G networks enhance the energy efficiency of telecommunications infrastructure, reducing overall energy consumption. Research shows that ICT can significantly contribute to reducing greenhouse gas emissions and increasing energy efficiency in households and industry. However, there is also a challenge in that increased use of ICT can, in some cases, increase overall energy consumption. The integration of artificial intelligence and machine learning optimizes agricultural production and reduces the need for pesticides[17].

CO_2 emissions caused by certain ICT services have already been estimated and compared to the emissions produced by corresponding conventional services in order to assess the reduced societal environmental burdens. The table below shows the estimated rate of CO2 reduction achieved through the use of ICT technologies.

Table 3 shows the percentage reduction in environmental impact achieved by using various ICT services compared to traditional services, such as business travel, training, and conventional study methods.

Table 3. Reduction of Environmental Impact through ICT Services

ICT Technologies	Conventional Services	Reduction in (%)
Videoconferencing	Business travel and meetings	60-90
e-Learning	Training and education	85
Online Study	Traditional study methods	30

According to research [18], the average smartphone emits 55-95 kg of CO_2 during its lifecycle. This includes emissions from the extraction of resources needed for production, manufacturing, distribution, usage, and finally recycling of the device. Just for charging and usage, an average of 12 kg of CO_2 is emitted per year [18]. Additionally, according to the same research, the average laptop is estimated to emit between 200-300 kg of CO_2 over its lifecycle. This includes emissions from resource extraction, manufacturing, energy use during operation, transportation, and ultimately recycling or disposal of the device. During usage alone (charging and use), around 50 kg of CO_2 is emitted per year.

5. CLIMATE CHANGE AND TRANSPORTATION

Climate change and transportation are interconnected in various ways, with transportation significantly contributing to climate change, while climate change simultaneously affects the efficiency and functionality of the transportation system. Transportation is responsible for approximately 25% of global greenhouse gas emissions, and in the European Union, this sector accounts for 23.2% of total CO_2 emissions [10]. Of these, road transport has the largest share, generating about 71.7% of emissions from the transport sector [11].

Emissions from transportation include carbon dioxide (CO_2), nitrogen oxides (NOx), particulate matter (PM), and sulfur dioxide (SO_2). CO_2 emissions are particularly problematic due to their contribution to global warming. Greenhouse gas emissions significantly contribute to global warming, air pollution, and negative effects on human health and nature [19]. For example, emissions from the transportation sector in the EU-27 increased by 33.5% between 1990 and 2019 [9]. Climate change, manifested through rising sea levels and extreme weather conditions, seriously affects all modes of transportation. Rising water levels complicate waterway transportation, while storms and floods disrupt road and rail traffic, increasing the need for infrastructure adaptation to maintain the efficiency of transport systems.

Due to climate change, many shipping routes are experiencing a drop in water levels, posing a significant challenge and risk for global logistics. Low water levels hinder navigation, reducing the capacity and number of ships that can safely pass through canals and rivers. The Panama Canal, one of the most important maritime routes in the world, has been particularly affected. Due to low water levels, the number of ships that can pass through the canal has been reduced, and the maximum load of ships has also been decreased. This situation has led to long queues of ships waiting to pass, which slows down global supply chains and directly impacts environmental pollution.

These changes in the movement of transport vehicles highlight the need for adapting transport strategies and infrastructural investments to mitigate the negative effects of climate change on global transport. Extreme weather conditions such as storms, floods, landslides, and droughts damage transport infrastructure and reduce the efficiency of the movement of goods and people. During the winter of 2019, snowstorms in Europe caused significant disruptions in air and road traffic, resulting in substantial economic losses [20].

Reduced transport capacity and longer waiting times increase transportation costs and cause delays in the delivery of goods. Such effects underscore the additional need for efficient and sustainable approaches in planning transportation routes and implementing measures that will reduce the negative impacts of climate change.

6. POLICIES AND REGULATIONS

The development of environmental protection policies in individual countries, especially in developed ones, has contributed to raising awareness about the limitations of natural resources. Managing environmental protection policies within society requires a serious and responsible approach to nature and the environment, with the goal of protecting and preserving them from pollution. Environmental protection policy provides answers to questions such as managing and directing ecological processes, protecting key resources necessary for the survival of life on Earth, and creating a sustainable future[21].

In the context of transportation, this policy includes strategies for reducing harmful gas emissions, promoting sustainable forms of transport, and improving infrastructure for low-emission vehicles. Sustainable mobility and responsible management of transportation systems are crucial for reducing the ecological footprint and achieving long-term environmental protection goals.

Policies and regulations related to the impact of transportation on pollution and environmental protection include a wide range of measures and initiatives implemented at local, national, and international levels. In this context, the following have been introduced:

- Emission standards for vehicles – the introduction and implementation of stricter emission standards for vehicles, aimed at limiting emissions of harmful gases such as CO2, NOx, SOx, and particulates (Directive 70/220/EEC, Euro 1 - Directive 91/441/EEC, Euro 2 - Directive 94/12/EC, Euro 3 - Directive 98/69/EC, Euro 4 - Directive 2002/80/EC, Euro 5 - Regulation (EC) No 715/2007, Euro 6 - Regulation (EU) No 459/2012)[22].
- Regulations governing fuel quality – aimed at reducing emissions of harmful gases during combustion in vehicle engines (Directive 98/70/EC on the quality of petrol and diesel fuels).
- Introduction of road tolls and special taxes for high-emission vehicles (Directive 1999/62/EC, known as the Eurovignette Directive, allows the collection of tolls based on vehicle emissions), as well as policies restricting access to certain urban areas to reduce congestion, noise, and pollution (Low Emission Zones - LEZ)[23].
- Policies promoting the use of public urban transport, walking, and cycling (The 2011 White Paper on Transport promotes sustainable urban development and emission reduction through integrated transport strategies).
- Policies and measures for financial incentives and subsidies for the use and purchase of low-emission vehicles (Directive 2014/94/EU of the European Parliament and of the

Council of 22 October 2014 on the deployment of alternative fuels infrastructure).

The strategic framework of the European Union (EU) aims to transform the EU into a climate-neutral society by 2050 through the European Green Deal [24]. This framework involves achieving net-zero greenhouse gas emissions and sustainable economic growth, while ensuring that the transition is fair and inclusive for all citizens and regions. The core objectives of the European Green Deal are[25]:

- Climate neutrality by 2050 through the reduction of greenhouse gas emissions and achieving net-zero emissions.
- Increasing the emission reduction target by 2030: At least a 55% reduction in emissions compared to 1990 levels.
- Economic growth decoupled from resource use by promoting a circular economy and sustainable industrial practices.
- Protection and restoration of ecosystems and biodiversity through the conservation of natural resources and biological diversity.

One of the elements of the strategic framework of the European Green Deal focuses on green transport, which includes stricter emission standards for vehicles, promoting the use of electric cars, and developing the necessary infrastructure. The plan also addresses sustainable urban mobility through the construction of bicycle lanes, improvement of public transportation, and reduction of pollution in urban areas.

The implementation of these policies and regulations contributes to Sustainable Development Goals (SDGs) efforts, particularly in the context of reducing greenhouse gas emissions and combating climate change. By enhancing public transportation and developing infrastructure that supports pedestrians and cyclists, as well as encouraging the use of renewable energy sources, these initiatives help create safer and more sustainable cities, reduce air pollution, and improve the quality of life for citizens. Moreover, the focus on sustainable mobility and the development of infrastructure for alternative fuels supports the transition to a more energy-efficient and environmentally friendly transportation system.

7. SOLUTIONS, TECHNOLOGICAL INNOVATIONS, AND SUSTAINABLE DEVELOPMENT

Solutions, technological innovations, and sustainable development play a crucial role in transforming transportation and communication to better overcome new challenges and reduce environmental pollution. Transportation is one of the main sources of greenhouse gas emissions and air pollution, creating a need for innovative solutions to mitigate these negative effects. Continuous efforts are being made to find ways to address these issues. Many large cities are developing a Sustainable Urban Mobility Plan (SUMP) [26] as a strategic document aimed at meeting the mobility needs of people and businesses in an environmentally sustainable way within urban areas and their surroundings. SUMP integrates different modes of transportation and promotes sustainability, which aligns with the Sustainable Development Goals (SDGs).

The introduction of practical and sustainable solutions in transportation and communication systems aims to reduce emissions and improve the quality of life in urban environments. Focusing on the improvement of public transportation, the construction of bicycle lanes, and the promotion of walking has shown significant results in reducing air pollution emissions compared to the use of private cars. Technological innovations in transportation and communication systems are used to modernize and increase efficiency, which can directly or indirectly reduce environmental pollution. The use of technological innovations can significantly reduce traffic congestion in cities, increase safety, and reduce harmful gas emissions. Some technological innovations in the field of transportation and communications that directly impact pollution reduction include electric[27] and hybrid vehicles, Intelligent Transport Systems (ITS), autonomous vehicles, mobile applications, virtual reality, optical networks, and more.

Sustainable development in transportation and communications requires the integration of environmental, economic, and social aspects. These initiatives contribute to reducing the ecological footprint and creating healthier, more resilient communities. Sustainable development in transportation and communication systems is achieved through: developing strategies to reduce greenhouse gas emissions, city planning that integrates various modes of transport and encourages urban mobility, building infrastructure projects that minimize the ecological footprint (such as green roofs on stations and the use of environmentally friendly materials), and through education and raising awareness among all participants. Every individual, company, and state should consider how they contribute to greenhouse gas emissions and develop strategies to reduce or completely eliminate them.

There are several general strategies that most people can adopt [4]:

Using renewable energy sources to power homes and buildings, which would reduce heat rising into the atmosphere. The most commonly used forms of renewable energy are solar and wind energy.
Using electric cars instead of those powered by fossil fuels.
Using public transport.
Improving the thermal insulation of houses and buildings.
Where possible, balancing annual carbon dioxide emissions by investing in commercial services that extract carbon dioxide from the atmosphere.
Encouraging local businesses that adopt and promote sustainable, climate-friendly practices.
Setting a cap on the amount of carbon dioxide that can be emitted into the atmosphere.

8. EXAMPLES OF BEST PRACTICES

Today, there are many examples of best practices that have had positive effects in reducing harmful gases. Below are some examples of good practices.

Copenhagen has become an example of the successful implementation of sustainable public transport. The city has made significant investments in the development of bicycle lanes, improvement of public transport, and the introduction of electric buses. Nearly half of Copenhagen's residents commute by bicycle, and 35% of those working in the city, including suburban commuters, choose cycling as their mode of transport. The city provides 390 km of designated bike lanes, contributing to a reduction of about 70,000 tons of CO_2 emissions each year [28].

London has implemented Low Emission Zones (LEZ) to limit access for high-emission vehicles in specific areas of the city. The primary goal of London's LEZ is to reduce PM_{10} emissions from older diesel vehicles. The introduction of this policy occurred in several stages, with each stage enforcing stricter emission standards for vehicles. The initial phase, which was less stringent, actually saw a temporary increase in PM10 emissions by approximately 14.8% within the zone. However, the subsequent, more stringent phase led to a significant decrease in PM10 emissions by 5.5%, demonstrating the varying impact of the policy across different stages [29].

Barcelona has installed smart street lighting that uses sensors to detect the presence of people and vehicles, adjusting the lighting accordingly. This technology has cut energy consumption by 30% and saves the city over 36 million euros annually[30].

Vienna takes an integrated approach to its transportation network by combining transport infrastructure with advanced communication technologies. The use of smart traffic lights, digital traffic signs, and traffic monitoring applications helps to optimize traffic flow.
In Vilnius, the capital of Lithuania, sustainable transport initiatives have been put into place, such as the creation of bicycle lanes, the enhancement of public transport, and the promotion of walking. The city utilizes Geographic Information Systems (GIS) to plan and manage its transportation infrastructure effectively. These efforts have led to a reduction in car usage, an increase in cycling and public transportation, and consequently, a decrease in CO_2 emissions and an improvement in air quality in urban areas[31].

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Climate Change and Air Pollution Mitigation

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Abstract: With the increasing negative impact of the consequences of climate change on the entire planet Earth, rules and restrictions are increasing with the aim of adapting and mitigating climate change. Thus, in December 2019, at a meeting within the European Council, the representatives of the European Union countries agreed that the European Union should achieve climate neutrality by 2050. This means that by 2050, the countries of the European Union will have to drastically reduce their greenhouse gas emissions and find ways to compensate for remaining and unavoidable emissions to reach net zero emissions. In its conclusions, the European Council concluded that the transition to climate neutrality brings significant opportunities for economic growth, markets, and jobs, as well as technological development.

Bosnia and Herzegovina signed Sofia Declaration in November 2020 and in this way joined to EU target to become climate neutral until 2050. The main source of GHG emissions and polluting substances in Bosnia and Herzegovina is electric energy, which has a share of about 60% in total GHG emissions. The key challenge in the process of climate change mitigation is to use the transition to a low-carbon (low-emission) economy for achieving the sustainable economic development and social cohesion goals, while taking account of the existing structure of the economy and the time required for its transition. The main cause of poor air quality is home fireplaces due to the high energy needs for heating and the poor quality of used stoves and boilers as well as poor fuel quality.

Keywords: GHG emission, air pollution, mitigation measures.

1. INTRODUCTION

1.1 Historical course of the issues of climate change and air pollution

After the beginning of the industrial revolution at the end of the 19th century, the negative impact of humankind on the environment begins. From year to year, the influence of humankind and its actions on Earth is felt more and more. It primarily manifests itself through changes in the environment, which, regardless of their underlying causes, result in natural imbalances, the extinction of numerous animal species, air and soil pollution, and a general decline in the quality of life. Although the effects of greenhouse gas (GHG) emissions on the global climate system first became apparent at the end of the 19th century, scientific research into this issue only began in the second half of the 20th century.

For a long period of time, neither countries nor companies did anything to reduce or bear responsibility for greenhouse gas emissions. The industrial and energy sectors are now considered to bear the greatest responsibility for adverse effects on the environment, both locally and globally.
Historically speaking, the issue of emissions of pollutants into the atmosphere has three characteristic phases:

- local pollution by products of incomplete combustion, characteristic of the period 1870-1970,
- regional (scale of continents) acid gas pollution, characteristic of the period 1950-2000, and
- global scale (climate changes) caused by anthropogenic emissions of greenhouse gases, as well as pollution by gases that deplete the ozone layer, especially characteristic of the period after the 1990s.

The approachs to air quality management to the noted three phases are:

- regulation of air pollution,
- air quality management and
- sustainable development.

Each phases' approach to the issue of air pollution contains the measures from the previous phases, but it works wider and deeper. The first phase is characterized by an ecological approach, the second by a technological approach, and the third by a social development approach. In the third phases, the ecological approach reappears in the function of the development of society on natural bases.

Regulation of air pollution as an approach to the problem of air pollution has a tradition of over 150 years. Ecologists and medics have established the effects of poor air quality and warned of the danger. The result is the limitation of air pollution, and to achieve this, at the same time, the limitation of air pollution. In this way, the first air protection strategy was created, which was based on limiting pollution, which is the basis of the modern approach.
Air quality management is a broader concept than air quality protection. In fact, the concept of protection of air quality is being expanded in such a way that pollution forecasting is carried out during the construction of new settlements or new plants that emit polluting substances. Construction is permitted only if all technical and technological measures have been taken to

keep pollution within the permitted limits, as well as to use modern technology that will allow the air to be as clean as technically possible, not as medically permitted.

Sustainable development raises the question of what satisfaction and which human needs the air is polluted for, and since air quality is also a human need, needs must be reconciled - biological-existential and those that are satisfied through production. Harmonization is carried out within several sectors, while not forgetting the application of modern technological measures, nor the basic concept of limiting pollution.

Air pollution manifests itself through:

- emission of products of incomplete combustion,
- acidification (soil acidification from the air) and eutrophication (excessive feeding of the soil from the air),
- air quality degradation (visibility, aesthetics),
- decomposition of the ozone layer,
- exposure of human health and ecosystems to high concentrations of pollutants.

The emission of carbon dioxide and other greenhouse gases into the air does not constitute air pollution, because even significantly higher concentrations in the atmosphere than today would not have direct consequences for human health and ecosystems. The problem is that due to anthropogenic emissions of greenhouse gases, there is an increase in atmospheric concentrations of greenhouse gases, which causes less emission of heat from the Sun into space. The result is the establishment of the equilibrium temperature of the atmosphere at a higher temperature level.

The use of coal, and then other fossil fuels, is the basis of the industrial (actually energy revolution) revolution, but also the basic pattern of air pollution and the environment in general. The problem of air pollution first appears at the local level in certain cities with intensive use of coal. In addition to energy, the products of energy conversion of coal were the products of incomplete combustion: carbon monoxide, soot, solid particles (fly ash) etc.. The presence of soot in the atmosphere of cities favored the creation of fog, and the fog hindered the heating of the soil and the creation of an upward flow of air, which would ventilate the ground layers of the city's atmosphere, resulting in the creation of smog (eng. smoke(smoke) + fog(fog)). If the stable atmosphere remained for more than three consecutive days, it was the occurrence of episodes of increased air pollution (known as London 1950-1955, Sarajevo 1965-1970). Then, measures are taken to reduce pollution, primarily through improving the efficiency of combustion (this not only reduces air pollution, but also reduces fuel consumption), through the introduction of improved stoves and boilers as well as district heating. These measures are also implemented in Sarajevo (in the period 1968-1978, the improvement of combustion efficiency and the replacement of coal with a high content of sulfur by coal with a lower content of sulfur, and since 1978, by natural gas, which does not contain sulfur and can be burned almost without emitting soot).

While the emission of soot and carbon monoxide could be easily avoided (with costs that were amortized in a few days or months), the emission of sulfur dioxide, which grew with the increase in energy consumption, could not be easily (with acceptable costs) avoided. The problem was solved by applying natural self-cleaning mechanisms of the atmosphere, which are enhanced by choosing a favorable plant location and building a (sufficiently) high chimney.

In this way, local dilution of flue gases is achieved (significantly due to sulfur dioxide), and on a larger scale, sulfur dioxide is washed onto the ground (dry deposition or in the form of acid rain). A well-known rule in 1970s was: the solution to pollution is dilution. However, the half-life of sulfur dioxide is about seven days, and during that time air masses containing significant amounts of sulfur dioxide can travel thousands of kilometers. The emission of sulfur dioxide increased in the period from the middle of the last century to the 1990s. After which it began to decrease, so that in 1990 the world emission of this pollutant amounted to 120 million tons per year (exactly what its natural emission was), and in 2010 the emission amounted to 100 million tons per year [1].

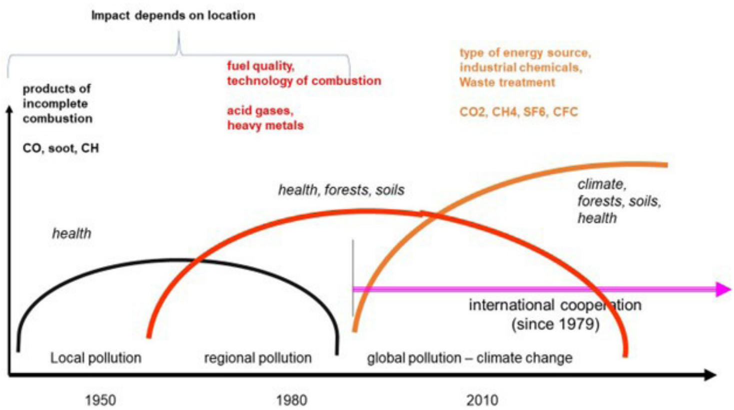

Fig. 1. Phases and impacts of air pollution [2].

While the natural emission of sulfur dioxide is distributed all over the planet, the emission originating from human activity was concentrated in Europe and North America, and to a lesser extent in Asia (China). Along with sulfur dioxide, another gas appears and acts together with it, which gives acid with rain - nitrogen dioxide. Some countries solved their problems by building high chimneys to pollute other countries with acid rain (very often with a pH value that corresponds to the acidity of vinegar), destroying their forests, reducing the yield from agriculture and increasing the corrosion of built structures (metals), i.e. the corrosion of buildings, especially historical ones (built of limestone). The Scandinavian countries were particularly affected by pollution from Great Britain, and most of Europe, from the former German Democratic Republic, former Czechoslovakia and Poland, socialist countries with very extensive energy. The former Yugoslavia was a net importer until 1990, and that year it became a net exporter of sulfur compounds. Thanks to international cooperation and the actions taken in accordance with it, the worldwide emission of sulfur dioxide has been decreasing since the end of the 20th century.

The main product of fossil fuels combustion is carbon dioxide. Its emission is proportional to the amount of energy that is to be obtained by burning carbon. The content of carbon dioxide in the atmosphere in the pre-industrial era was about 0.03%, and even an almost 100 times higher concentration would not be harmful to humans and animals. Therefore, carbon dioxide is not considered a pollutant. However, this gas, as well as other triatomic and polyatomic gases, cause climate change.

The problem that was hinted at in the ninth century was already evidently experienced in the last decade of the last century. Triatomic and polyatomic gases return to the earth's surface part of the infrared radiation, the solar energy that the earth returns to space. The average temperature on planet Earth is 15 oC, and if there were no carbon dioxide in the atmosphere it would be -18 °C, i.e. even 33 °C lower.

The increase in the concentration of carbon dioxide in the atmosphere observed in the second half of the last century, with a faster increase at the end of that century, leads to an increase in the average temperature on Earth, changing the climate (in some parts of the planet, the average temperature decreases, in others it increases, the precipitation regime changes, etc. .).

Climatic changes also occur due to changes in the use of space (areas under forests are decreasing - a carbon reservoir, the color of the soil is changing). The problem is global, because the cycle of carbon dioxide in the atmosphere is about 60 years. This phenomenon threatens to cause significant consequences firstly for ecosystems, and thus also for the economies of individual countries. Human civilization is facing its biggest environmental problem so far, for which there is still no complete solution. The problem is that reducing carbon dioxide emissions requires a radical change in the economic system. The transition to a low-carbon economy is necessary. The only practical way to reduce anthropogenic emissions of carbon dioxide from thermal power plants is to reduce the amount of carbon that is subjected to the oxidation process, i.e. to reduce the consumption of fossil fuels. That's why when talking about steps to reduce carbon dioxide emissions from thermal energy plants, it's mostly about replacing fossil fuels with other energy sources.

1.2 Emission rate of carbon dioxide from different energy sources

Different fossil fuels cause different amounts of carbon dioxide per unit of energy contained in that fuel. The amount of carbon dioxide emitted per unit of energy in the fuel is called the emission coefficient and is expressed in the mass of carbon dioxide per unit of energy, i.e. kgCO2/GJ. Natural gas has the lowest coefficient because a significant part of the energy is generated from hydrogen, which creates water vapor. Coal has the highest emission coefficient because energy is generated mainly by burning carbon. Liquid fuels have a coefficient value between natural gas and coal. If biomass is managed in a sustainable way, energy from biomass is considered carbon neutral because the amount of carbon dioxide emitted during combustion is equal to the amount of carbon dioxide absorbed from the atmosphere during the growth of biomass. Looking at direct emissions, renewable energy sources are considered carbon neutral. Direct emissions are emissions that occur during the operation of a facility, and indirect emissions are those that occur during the production of materials and transportation for a facility.

Tab 1. Direct emission of carbon dioxide [3]

Fuel/energy source	Emission coefficient (kgCO_2/GJ)
natural gas	56
petrol	69
kerosene	72
diesel	74
heavy fuel oil	77
lignite	95
brown coal	96
biomass	0 (in life cycle)
hydro energy	0 (no direct emission)
wind energy	0 (no direct emission)
solar energy	0 (no direct emission)

2. ENERGY TRANSITION TOWARDS CLIMATE NEUTRALITY

In order to achieve climate neutrality, it is necessary to apply technologies and business models that will lead to have buildings are net energy producers, which mean that annually they produce more energy than they consume. In addition, it is necessary to replace energy from fossil fuels with energy from renewable energy sources. Renewable sources such as wind energy and solar energy are not controllable energy sources, which mean that their production depends on natural phenomena regardless on energy demand at the moment. Because of this, there is an additional need for new ways of storing both electrical and thermal energy. The goal is to commercialize energy storage from one season to another. An important element is also smart networks that manage energy needs according to the availability of energy from renewable sources. In order to achieve climate neutrality, a stimulating legal framework, new business models and the development of technologies are needed. Changes that are necessary for climate neutrality are:

- Buildings are net energy producers (at the level of the year that buildings produce more energy than they consume)
- Production of energy from RES (in time to completely suppress energy from fossil fuels)
- New methods of energy storage (seasonal storage in addition to storage that is already commercial - several days)
- Smart networks (electricity and thermal energy).

The conditions for transitioning to a net climate economy are

- Encouraging legal framework
- New business models (prosumers, ESCO, PPP, crowdfunding, etc.)
- Technical innovations

The key elements of the energy transition or the energy shift from fossil fuel energy to renewable energy sources are the transition from a centralized to a distribution energy system, which means many individually smaller energy sources, then the transition from carbon-intensive energy to decarbonized energy. Carbon-intensive energy is energy from fossil fuels.

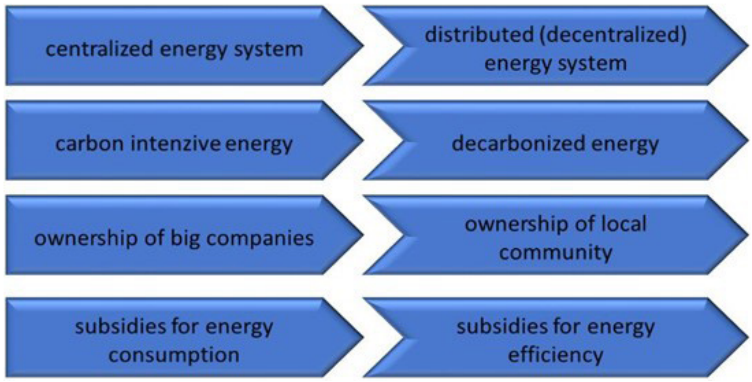

Fig. 2. Elements of energy transition

An important element is the transition of energy sources from the ownership of large companies to the ownership of the local community, which is made possible by decentralization, i.e. the trend of building many relatively small plants. In order for investments in the energy transition to happen, it is necessary to stop subsidizing energy consumption, and direct these funds to subsidizing energy efficiency.

3. EMISSION AND DECARBONIZATION IN BOSNIA AND HERZEGOVINA

BiH has a growing trend of greenhouse gas emissions. BiH has emissions inventories from 1990 to 2018. In 2018, emissions amounted to about 30 million tons. Emissions per inhabitant are at the level of the European Union average. Greenhouse gas sinks in the same year amounted to slightly less than 6 million tons and have a decreasing trend. For climate neutrality, which BiH committed to by signing the Sofia Declaration, it is necessary that emissions and sinks be equalized. Achieving climate neutrality is the goal by 2050, and the goal for 2030 is to reduce emissions by about 40% compared to emissions from 1990, when they amounted to about 34 million tons of CO2eq. In the Integrated Plan for Energy and Climate of BiH, measures to reduce emissions are defined, which focus on encouraging energy efficiency and the use of renewable energy sources in construction, industry and transport, as well as in the production of electricity and thermal energy.

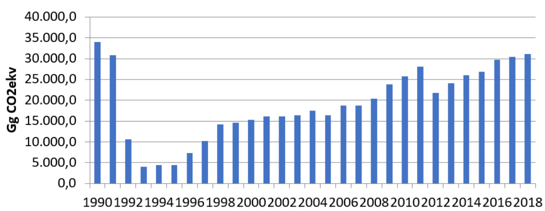

Fig. 3. GHG emission in Bosnia and Herzegovina [4]

BiH has a growing trend of greenhouse gas emissions. BiH has emissions inventories from 1990 to 2018. In 2018, emissions amounted to about 30 million tons. Emissions per inhabitant are at the level of the European Union average. Greenhouse gas sinks in the same year amounted to slightly less than 6 million tons and have a decreasing trend. For climate neutrality, which BiH committed to by signing the Sofia Declaration, it is Per capita, BiH has emissions at the level of the EU average, although the gross domestic product is significantly lower in BiH. This indicates an irrational consumption of energy, and most of that energy comes from fossil fuels.

By signing the declaration on the Green Program for the Western Balkans, on November 10, 2020 in Sofia, the countries of the region undertook to implement measures in the field of climate change mitigation, energy transition, sustainable mobility and circular economy, as well as the protection of biodiversity, sustainable agriculture and food production . The countries of the region have committed to a series of concrete actions, including the introduction of a tax on carbon dioxide emissions and market models to encourage renewable energy sources, as well as the gradual abolition of subsidies for coal.

The green program is foreseen in the European Green Plan, which is a set of measures to make the EU climate neutral by 2050. Following the Sofia Declaration, the Guidelines for the implementation of the Green Program were presented, which propose activities and measures that the EU and the countries of the Western Balkans should jointly adopt. The basic measures are:

- Harmonization with the EU climate law after its adoption, the goal of which is for the EU to be climate neutral by 2050
- Defining energy and climate goals until 2030 in accordance with the legal framework of the Energy Community and the EU acquis, as well as the development and implementation of National Energy and Climate Plans with clear measures to reduce greenhouse gas emissions
- Continuation of alignment with the EU Emissions Trading System (EU ETS), as well as the introduction of other models for taxation of emissions, in order to promote decarbonization in the region
- Analysis and revision of all regulations that support the progressive decarbonization of the energy sector and their full implementation, primarily through the Energy Community
- Cooperation in the preparation of an assessment of the socio-economic impact of decarbonization on each country and at the regional level with the aim of a just transition
- Giving priority to energy efficiency and its improvement in all sectors
- Increasing the share of renewable energy sources and providing the necessary conditions for investment, in accordance with the legal acquis of the EU and the Energy Community
- Reduce and gradually abolish subsidies for coal, strictly respecting the rules of state aid
- Actively participate in the Coal Regions in Transition initiative for the Western Balkans.

In order to achieve the goals contained in the Green Program for the Western Balkans, Bosnia and Herzegovina must further improve its approach to strategic planning, especially in the areas related to decarbonization, i.e. the gradual reduction of the use of fossil fuels with the aim of achieving climate neutrality by 2050. It is clear how big a challenge this is for Bosnia and Herzegovina. The current goals of reducing greenhouse gas emissions are not sufficient to achieve climate neutrality, which is expected in accordance with the commitment expressed by signing the Green Program. Therefore, continuously, in accordance with changes in the relevant areas, it is necessary to constantly work on reviewing the goals for reducing emissions.

BiH has defined the strategic commitments to reduce greenhouse gas emissions through the following documents:

- Initial Determined National Contribution (INDC) for reducing emissions by 2030,
- National Determined Contribution (NDC) for the period 2020-2030 with projections until 2050 (document adopted in March 2021).
- Integrated energy and climate plan (NECP, draft, year 2023)

In the NDC, BiH defined the goal of reducing total GHG emissions by 17.5% by 2030 compared to 2014. The goals stated in the NDC have been assessed as satisfactory by the UNFCCC Secretariat. However, this goal is insufficient when talking about the ambitions of a member state of the Energy Community, and with this level of ambition for emission reduction, no significant international aid for decarbonization can be expected. Additionally, the NDC did not take into account the achievement of climate neutrality by 2050. For this reason, the goal of reducing emissions for 2030 should be significantly more ambitious in order to achieve climate neutrality by 2050. Potentials for reducing greenhouse gas emissions by sector in Bosnia and Herzegovina are:

- Electric power (gradual closure of thermal power plants),
- Growth of RES production,
- Decarbonization and growth of district heating,
- Decarbonization in industry (energy efficiency and prosumers),
- Reducing the use of fossil fuels in buildings (EE and OIE),
- Transport - volume growth with new technologies (synergy with decarbonization of the power industry - electric vehicles and production and use of hydrogen),
- Agriculture – production and use of biogas,
- Waste management – quantity reduction, recycling and use,
- Increasing the GHG sink.
- Two key measures to reduce greenhouse gas emissions in BiH are the introduction of:
- Prosumers
- Greenhouse gas emissions trading system.

Prosumer is a concept according to which all consumers of electricity can also be producers. There are two variants. The first variant is net metering, which ensures that consumers who install generators (typically photovoltaic (PV) systems) receive a one-for-one credit for each electricity their systems generate and feed into the grid during the billing period. In this case, production and consumption are compensated over a longer period (up to one year). At the same time, all produced kWh are valued equally.

The second variant is the net calculation, according to which the consumer receives cash credits one for one for each kWh exported to the network. Each kWh is valued either at a single price or at a price that corresponds to the time of production. Loans are granted for a specific time frame, usually one year. It is equivalent to a net metering scheme, but with monetary compensation instead of energy compensation.

Another key measure is the introduction of the Emissions Trading System (ETS). It is planned to introduce a greenhouse gas emission trading system compatible with the system in the EU, where it has existed since 2005, from 2026.

Plants receive emission “cap” in accordance with the state’s emission reduction goals. The “cap” has been decreasing for years. Companies that reduce their emissions below the allowed “cap” are allowed to trade, i.e. sell emission alloeances to companies that emit more than their “cap” is. Companies that produce electricity in the EU buy emission allowances, while other sectors have a certain part of free emission allowances.

In order to equalize the business conditions and prevent the so-called carbon leakage, the EU introduced the Carbon Border Adjustment Mechanism (CBAM). This means that a fee is being introduced for emissions that occur during the production of certain products outside the EU, and are imported into the EU. The EU has already introduced this mechanism, and the payment of emissions fees will begin in 2026.

In addition to the aforementioned measures to reduce emissions, it is necessary to introduce new business models such as:

- Energy service companies (ESCO) instead of energy supply companies
- Communities of renewable energy (citizen energy – energy cooperatives)
- Public-private partnership.

4. CONCLUSION

On the global scale there is significant potential for reducing greenhouse gas emissions. Deployment of these potentials should be seen first and foremost as the direction of economic development and avoidance of climate change demages, which, in addition to mitigating climate change, will also have positive effects on air quality, competitiveness of the economy, greater number of jobs and better quality of jobs. In addition, relying on domestic resources of renewable energy sources improves the security of energy supply.

The biggest resource in this context in Bosnia and Herzegovina is energy efficiency, which should be at the top of all plans because it is the cheapest and safest “source” of energy. The potentials of renewable energy sources are more than sufficient, but the legal and business framework needs to be improved so that local communities are actively involved in exploiting these potentials in such a way that they become decision makers on how to use these potentials.

The energy transition is often seen as a threat to jobs. However, if the transition is approached in an adequate way, it leads not only to an increase in the number of jobs, but also to a better quality of jobs and an increase in productivity. In this context, it is necessary to improve and direct the education system (regular schooling and retraining).

On this path, the transfer of new technologies such as solar power plants, heat pumps, modern biomass boilers, hydrogen production, storage and use technologies, energy storage technologies (electrical and thermal) etc. is necessary.

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Air Quality in BiH - Causes, Consequences and Recommendations

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Abstract: The air pollution in Bosnia and Herzegovina (BiH) has been a problem for a long time, and this article looks at that history, as well as the sources of emissions now and the damage they do to the ecosystem. The report highlights the serious consequences on public health, noting that Bosnia and Herzegovina ranks fifth in Europe for fatalities caused by pollution. The implementation of organizational and technical measures, the improvement of energy efficiency, and the transfer to renewable energy sources are all suggestions for better air quality. Prioritizing air quality control and promoting sustainable living in BiH requires coordinated efforts across society and government, as stressed in the conclusion.

Keywords: air pollution, energy, emission.

1. INTRODUCTION

The history of atmospheric pollutant emissions can be split into three major phases, each with its own set of characteristics and environmental implications. Understanding these phases allows for a better understanding of present conditions and the development of effective solutions to enhance air quality.

- The initial phase (1870–1970) was characterized by local air pollution resulting from the incomplete burning of fossil fuels. Urban centers and industrial regions of the era experienced elevated levels of soot, carbon monoxide, and various pollutants, resulting in considerable repercussions for human health and the environment.
- The second phase (1950–2000) is marked by regional pollution resulting from the production of acidic gases, including sulfur dioxide (SO_2) and nitrogen oxides (NOx). These pollutants resulted in soil and water acidification, leading to significant repercussions for ecosystems and human health, necessitating comprehensive air quality control efforts.
- The third phase, which begins after 1990, represents anthropogenic climate change caused by greenhouse gas emissions. Emissions, notably carbon dioxide (CO_2), contribute to global warming and the depletion of the ozone layer, influencing global temperatures and weather patterns.

These three stages represent the progression of air quality regulation methodologies. The first wave of approaches centered on pollution management, providing the framework for contemporary control systems. The second generation has improved pollution forecasting methodologies and implemented scientific and technological methods to keep air quality within acceptable standards.

The third generation prioritizes sustainable development by incorporating ecological solutions into social and economic advancement, thereby balancing human needs with environmental conservation. Air pollution manifests in a variety of ways, including localized contamination from incomplete combustion byproducts, acidification, eutrophication (for example, the saturation of aquatic environments with carbon dioxide), air quality degradation, ozone layer depletion, and negative effects on humans and ecosystems. Greenhouse gases, such as CO_2, are not considered pollution, but their impact on global temperature and climate change makes them a crucial issue in current air quality and environmental protection. [1]

2. EMISSIONS OF POLLUTANTS AND CARBON DIOXIDE INTO THE AIR AND THE IMPACT ON THE ENVIRONMENT

Emissions denote the release of compounds from sources into the atmosphere, which can negatively impact humans, plants, animals, and both natural and human-made items at certain amounts. Natural emissions arise from the release of matter by living organisms (respiration) and decomposition, in addition to other natural phenomena (aeolian erosion, wildfires).

Anthropogenic sources of air emissions include:
- energy facilities (thermal power plants and heating),
- industrial operations,
- the residential sector, and
- transportation

Energy facilities include thermal power plants, heating plants, boiler rooms to produce energy for heating and technological needs. Emissions from these facilities are produced through the conventional combustion of fossil fuels (coal, oil, gas). In the combustion products from all sources, the most frequently encountered pollutants in the atmosphere include

- ***Carbon dioxide (CO_2) is formed by the oxidation of carbon atoms [3]:***

$$C + O_2 \rightarrow CO_2 + 406.612 \text{ kJ} \quad (1)$$

Carbon dioxide is not considered a pollutant. The toxic chemical is already beneficial for plants. Carbon dioxide is seen by many as a pollutant due to its contribution to the warming of the Earth's surface through the greenhouse effect, making it the most prominent greenhouse gas and the primary driver of climate change.

- ***Carbon monoxide (CO) is produced by the incomplete combustion of fuel [3]:***

$$C + O_2/2 \rightarrow CO + 66.332 \text{ kJ} \quad (2)$$

Carbon monoxide is an unwanted byproduct of combustion, as its formation produces considerably less heat than the entire oxidation of carbon to carbon dioxide. Moreover, it is hazardous and lacks any scent. At present, it is not a substantial concern, as modern technology, especially computerized oxygen supply regulation, nearly eradicate CO emissions from major facilities. The principal sources of CO emissions are home fireplaces and automobile traffic.

- ***Sulfur dioxide (SO_2) is formed by the oxidation of sulfur in fuel [3]:***

$$S+O_2 \rightarrow SO_2 + 296.844 \text{ kJ} \quad (3)$$

Sulfur dioxide is a colorless, non-flammable, and non-explosive gas characterized by a unique pungent odor, great solubility in water, and significant reactivity at low concentrations. It is generated from the complete combustion of sulfur, accompanied by the release of heat.
Atmospheric natural sources of SO_2 encompass volcanic activity, biological decomposition processes, and the ocean, where wind action generates "sea mist" containing metal sulfate particles. Anthropogenic sources of sulfur dioxide encompass the combustion of fossil fuels in furnaces, vehicular emissions, and the metallurgy of non-ferrous metals (Zn, Pb, Cu), wherein the combustion of sulfide ores produces significant amounts of SO_2 in conjunction with certain metals. Sulfur dioxide adversely affects human health by reacting with moisture in the lungs to form sulfurous acid (H_2SO_3) and sulfuric acid (H2SO4). Even moderate amounts can lead to reduced lung function in patients with asthma. At high doses, they provoke chest tightness and coughing.

- ***Nitro oxides (NOx)***

Nitrogen oxides (NOx) relate primarily to a combination of nitric oxide (NO) and nitrogen dioxide (NO_2), which are regarded as the more consequential pollutants within this broader category. These two nitrogen oxides are produced through the combustion of fossil fuels, particularly at elevated temperatures exceeding 1,000 °C [3]:

$$N_2+O_2 \rightarrow 2NO \quad (4)$$

Nitrogen monoxide (NO) is a faintly colored gas with low solubility in water, and it is significant due to its propensity to react readily with oxygen, subsequently transforming into nitrogen dioxide (NO2) under sunlight:

$$2NO+O_2 \rightarrow 2NO_2 \quad (5)$$

Despite the absence of documented human poisoning cases with nitric oxide (NO), the substance poses a threat to people as it, akin to carbon monoxide (CO), attaches to hemoglobin. At concentrations ranging from 1 to 3 ppm, a discernible odor is detected, causing discomfort to humans at a concentration of 2.5 ppm after one hour of exposure.

NO2 is a gas distinguished by its unique odor and dark red hue, and it is the most dangerous among all nitrogen oxides. It is classified as a phytotoxic chemical, indicating that it produces detrimental effects on flora. Nitrogen dioxide irritates the lungs and diminishes resistance to respiratory diseases, including influenza. Prolonged or frequent exposure to concentrations significantly beyond typical atmospheric levels might lead to a heightened occurrence of acute respiratory illnesses, particularly in youngsters.

- ***Hydrocarbons (VOCs)***

Hydrocarbons (VOCs) are organic molecules composed solely of hydrogen and carbon atoms. Polycyclic aromatic hydrocarbons are significant due to their carcinogenic properties and their role as a component of volatile organic molecules. They undergo chemical reactions with sulfur and nitrogen oxides and radicals.

Ozone is generated through the formation of several secondary pollutants, including sulfuric and sulfonic acids, organic nitrites and nitrates, epoxides, alcohols, and peroxides. Natural sources of hydrocarbon emissions include forest fires, volcanic eruptions, and the incomplete combustion of fossil fuels and organic materials. Anthropogenic emission sources include industrial activities such as coke production, aluminum manufacturing, and oil refining, as well as the incineration of municipal and industrial waste, residential furnaces, and primarily, automobile exhaust gases, which are the principal source of hydrocarbons. Prolonged exposure to elevated levels of hydrocarbons may lead to chronic health consequences such as cancer, central nervous system diseases, hepatic and renal damage, reproductive system abnormalities, and congenital anomalies. [3].

- ***Particulate matter (PM)***

Particulate matter (PM) consists of a complex mixture of tiny solid particles and liquid droplets. The composition of solid particles frequently exhibits significant variability and encompasses several components, including acids (such as nitrates and sulfates), organic compounds, metals, soil, or dust particles. The dimensions of the particles are closely correlated with their capacity to induce health issues. Particles with a diameter of 10 µm or smaller (PM10) can penetrate the nasal and pharyngeal passages, reaching the lungs and potentially resulting in considerable health issues. Consequently, the oversight of particulate matter emissions is confined to the assessment of PM10 emissions and below. Particles ranging from 2.5 to 10 µm in size may be present in proximity to roadways and industrial facilities, where dust emissions might arise. Particulate matter measuring 2.5 µm or less is present in smoke and haze. These particles may be directly discharged from sources like wildfires, or they can be generated when flue gases from industrial processes, thermal power plants, and vehicles interact with specific chemical compounds in the atmosphere. Soot is a byproduct of incomplete combustion, primarily from solid fuels, consisting of a variety of carbonized compounds derived from carbon-containing substances. Soot is classified as a solid particle based on its physical qualities. A portion of PM2.5 particles comprises soot, namely soot generated from the combustion of wood or biomass [3].

3. DISTRIBUTION AND DEPOSITION OF POLLUTANTS [3]

Upon exiting the emission source, pollutants are disseminated, resulting in concentration dilution and subsequent chemical changes. Two fundamental mechanisms for concentration dilution are: (i) convection and (ii) diffusion.

Convection is a pollutant dispersal mechanism characterized by dilution from the influx of fresh air (wind), whereas diffusion refers to the intermingling of polluted and fresh air resulting from atmospheric vortices. It is essential to comprehend the method of broadcasting. In optimally built chimneys, the flue stream is augmented by dynamic (flue gas velocity) and static (flue gas temperature) buoyancy.

Consequently, the chimney's height is artificially augmented, as the effective height surpasses the construction height by the magnitude of the cant (refer to Figure 1). When wind speed exceeds the velocity of the flue gases at the chimney's outlet, the smoke plume alters its initial trajectory and begins to travel parallel to the Earth's surface.

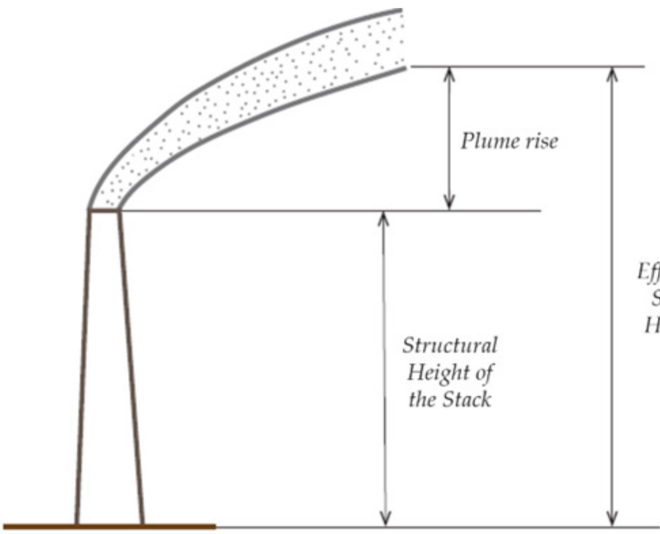

Fig. 1. The impact of the height of the stack

The effects of elevation gain can be reduced if the air temperature increases with altitude (then atmospheric buoyancy acts towards the Earth's surface). This phenomenon is known as temperature inversion. The impact of chimney height can be mitigated if air temperature rises with altitude, as atmospheric buoyancy then acts downward toward the Earth's surface. This occurrence is referred to as temperature inversion. The greater the effective height of the chimney, the longer the dispersion pathway for pollutants before they reach the ground, resulting in reduced ground concentrations. In this instance, pollutants are disseminated over extensive distances; during transit, they undergo chemical transformations, resulting in the formation of new compounds; their concentrations accumulate from various sources; ultimately, they permeate the soil and water, thereby impacting humans, objects, and the biosphere. The utilization of elevated chimneys mitigates the risk of acute short-term pollutant concentrations in confined areas; nevertheless, it also results in long-term effects of pollutants at low concentrations and their accumulation in the soil. The intricate dynamics of transport and inertia can lead to a substantial rise in secondary pollutants in areas distant from the origin.

Fig 2. A view of the city of Sarajevo from the mountain above the inversion layer

A smoke plume is a path delineated by a specific volume of flue gases emitted into the atmosphere at a particular location, extending in the wind's direction. The plume is characterized by turbulent atmospheric diffusion influenced by the temperature profile and expands with greater distance from the discharge location. Plumes can be categorized into distinct shapes:

1. Coning plume occurs in neutral and moderately unstable conditions, most often in cloudy weather or during sunny days after the cessation of radiation inversion, and before the onset of unstable daily conditions

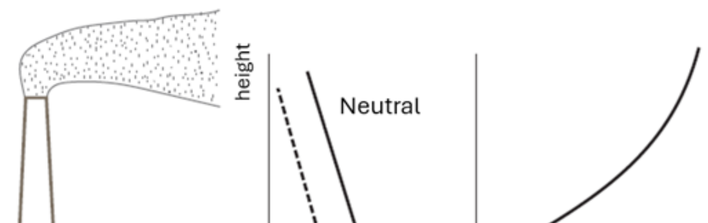

Fig. 3. Coning plume

2. Looping Plume is formed in an unstable atmosphere under strong convective conditions when flue gases are caught in an upward and downward curve due to the vertical movement of air caused by the rise of warm particles in the air and the descent of cold particles in the air; It usually occurs on clear days with strong solar radiation and light winds.

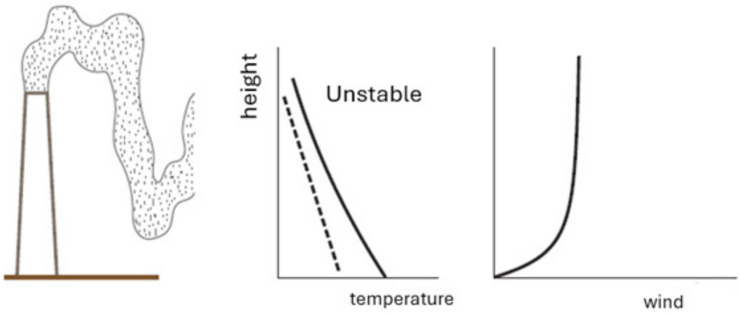

Fig. 4. Looping plume

3. Fanning Plume is present at stable atmospheric conditions, i.e. inversion;

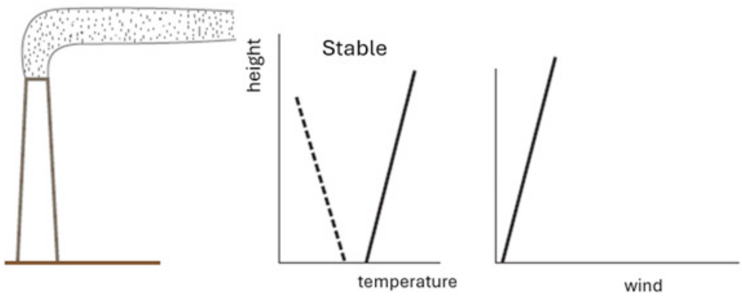

Fig. 5. Fanning plume

4. Lofting Plume occurs when flue gases are released into the atmosphere, the lower part of which is in a stable layer (inversion) and above it there is an unstable layer;

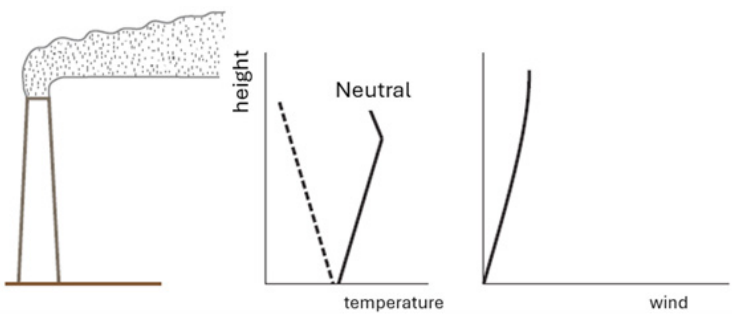

Fig. 6. Lofting plume

5. Fumigating plume occurs when the inversion layer is above the center of the flue gas and the unstable layer is below it

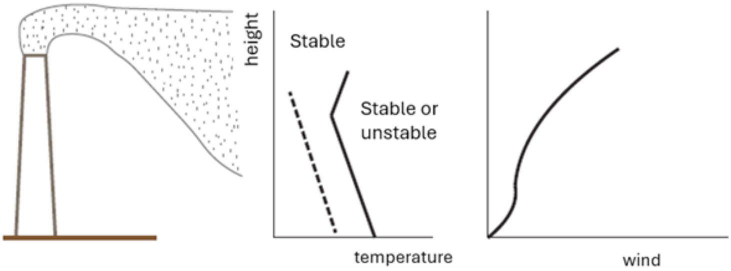

Fig. 7. Fumigating plume

6. Trapped Plume is a similar case to the fumigating plume in which the unstable layer is slightly weaker and downward diffusion is slower.

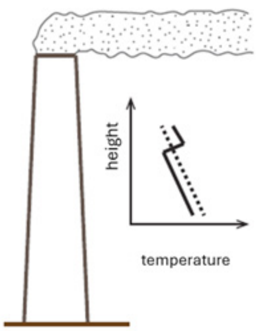

Figure 8. Trapped Plume

4. AIR QUALITY IN BIH

The air quality in Bosnia and Herzegovina is influenced by natural factors (orographic features, climate, local wind patterns, and weather variations), the volume of emissions, and the kind of emission sources (including surface, point, line, volume, chimney height, and flue gas emission rates).

Notwithstanding the limited industrialization and urbanization, air quality in BiH was a notable concern throughout the period from 1970 to 1990. The stoppage of operations at certain plants due to the war, followed by ownership transformation and, in certain instances, technological transfer, diminishes the issue's prominence; yet, it remains highly significant.
The main causes of air pollution in BiH are:

- character of industry (base industry inherited from the former Yugoslavia) - expressed in BH cities such as, Zenica, Maglaj, Lukavac,
- Emissions due to energy transformation, i.e. operation of thermal power plants - expressed in the cities of Kakanj, Tuzla, Gacko and Ugljevik
- high heat losses in the residential sector - expressed in the cities of Sarajevo, Kakanj,

Banja Luka, Banovići, Zenica, Tuzla, etc.

- inadequate constructions of fireboxes (room stoves and low-power boilers are mostly made according to Western European licenses) designed for other types of coal, which does not allow efficient and low-polluting combustion of domestic coals,
- Burning of damp firewood and coal in individual fireplaces
- Vehicles that traffic around cities in BiH are on average over 13 years old, and the number of vehicles is inadequate to the projected traffic in cities, so large traffic jams are created, i.e. large emissions from traffic, especially in the morning and afternoon hours

Air pollution in Bosnia and Herzegovina is well below the quality requirements established by the WHO, the European Union, and national legislation. Regular exceedances transpire during the winter season, mostly attributable to emissions from industrial activities, vehicular traffic, and residential heating utilizing coal and other solid fuels, including firewood. The geographical location of specific regions in Bosnia and Herzegovina significantly impacts air quality, particularly due to the prevalence of surface temperature inversions and inadequate wind circulation during the winter months. A geographical characteristic of Bosnia and Herzegovina is that when temperature inversions, air linkages between specific valleys are absent. Consequently, during periods of heightened concentrations, air quality varies within the Sarajevo basin, including the regions of Kakanj, Tuzla, Zenica, and Travnik, with local emissions during these times contributing to increased concentrations in each respective basin. Under conditions of weak wind or a stable anticyclone, particulate matter and pollutants persist in the lower layers of valleys, resulting in smog; in certain pollution origin models, this phenomenon is frequently misattributed to movement from external regions. The noticeable valley topography is the primary reason for the frequent formation of fog, particularly during the morning and evening hours.

According to the GAHP research[1] published in December 2019, Bosnia and Herzegovina is ranked fifth in Europe for mortality rates per 100,000 inhabitants attributable to air pollution. A 2019 World Bank analysis indicates that over 3,300 residents die annually due to PM2.5 pollution. The WB analysis indicates that the annual expenses of health impairment in BiH vary from 1.8 to 3.3 billion KM.

The effects on air quality can be categorized into many levels. The most basic categorization consists of four tiers: local, regional, state, and global effects. Every level is delineated in terms of time and place. This delineation of air quality impact facilitates clearer observation of the issue and the formulation of solutions. A detailed categorization of the impact facilitates a more accurate identification of the emission sources.

Consequently, the local and regional levels encompass emissions from residential furnaces, industrial activities, and transportation, whereas the national and global levels involve heavy industries and thermal power plants, specifically those characterized by tall chimneys and increased dispersion of deleterious particles.

In Bosnia and Herzegovina, the management of air quality is the duty of the entities and cantons within the Federation of Bosnia and Herzegovina. Pollutant concentration measurements are conducted in accordance with reference or equivalent procedures stipulated by regulatory acts [4] and [5]. The established air quality limit values comply with EU directives and recommendations, as shown in Table 1.

[1] *https://gahp.net/wp-content/uploads/2019/12/PollutionandHealthMetrics-final-12_18_2019.pdf*

Table 1. Limit values for certain pollutants prescribed by applicable regulations in BiH

POLLUTANT	SAMPLING TIME (AVERAGING)	LIMIT VALUES	MINIMUM DATA AVAILABILITY
SO_2	1 hour	350(1) µg/m^3	75 %
	1 day	125(2) µg/m^3	90 %
	Year	50 µg/m^3	90 %
NO_2	1 hour	200(3) µg/m^3	75 %
	1 day	85 µg/m^3	90 %
	Year	40 µg/m^3	90 %
WHAT	8 hours	10 mg/m^3	75 %
	1 day	5 mg/m^3	75 %
	Year	3 mg/m^3	90 %
PM10	1 day	50(4) µg/m^3	75 %
	Year	40 µg/m^3	90 %
PM2.5	Year	25 µg/m^3	90 %

1. The value is prescribed for one-hour average values and must not be exceeded more than 24 times in one calendar year for SO_2
2. The values are prescribed for one-day averages, and must not be exceeded more than 3 times in one calendar year
3. The value is prescribed for one-hour average values and must not be exceeded more than 18 times in one calendar year for NO_2
4. Values prescribed for daily average values, and must not be exceeded more than 35 times during the year for PM10

In numerous cities in Bosnia and Herzegovina where air quality is monitored, the recorded levels greatly exceed the permissible limits, particularly for particulate matter and sulphur dioxide pollutants. Figures 8 to 12 [6] illustrate diagrams depicting air quality in Bosnia and Herzegovina for the year 2023.

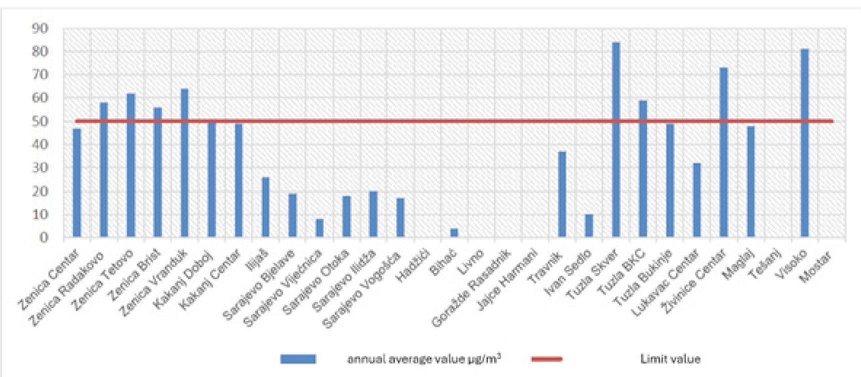

Fig. 9. Annual average concentrations of sulfur dioxide at measuring points in the Federation of BiH in 2023. (stations that have achieved more than 75% of valid measurements). The limit value is 50 ug/m^3

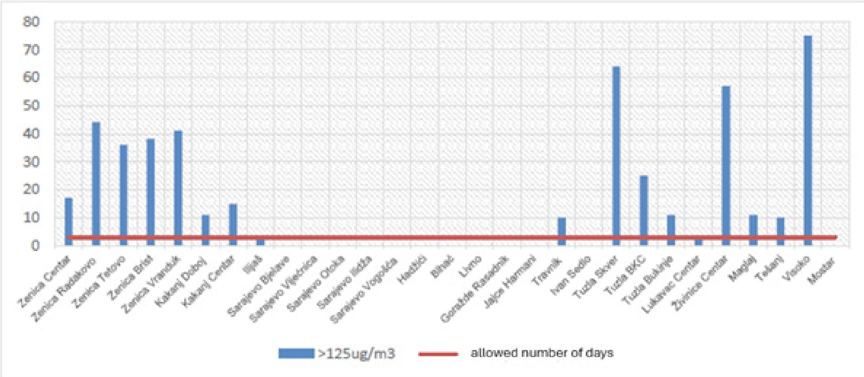

Fig. 10. Number of days with a daily concentration of sulfur dioxide higher than the limit value (>125 ug/ m_3) in 2023 (stations that achieved more than 75% of valid measurements). Three days with exceeding LV are allowed

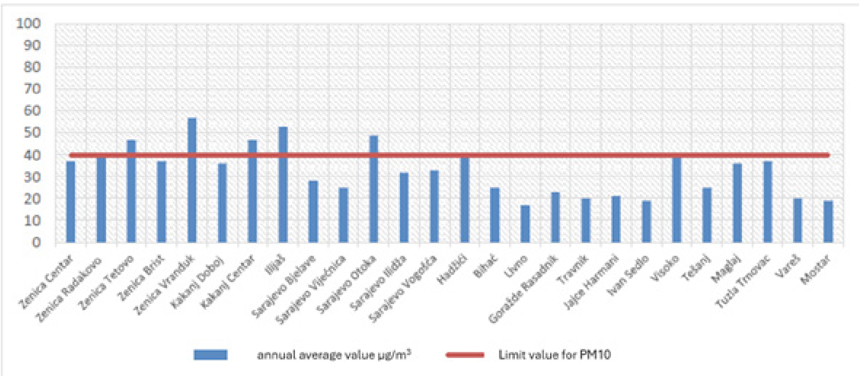

Fig. 11. Annual average concentrations of PM10 particulate matter at air quality monitoring stations in FBH that achieved more than 75% of valid measurements during 2023 (in ug/ m_3)

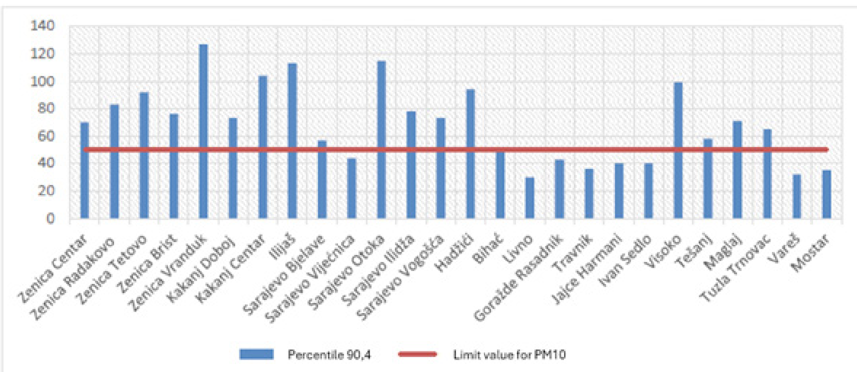

Figure 12. The value of 90.4 percentiles of daily average values of PM10 particulate matter concentrations in 2023 (in ug/m3). Exceeding the value of 50 ug/m3 corresponds to exceeding the number of permitted days in a year with a concentration above the limit value

As can be seen from the diagrams that came before, most of the cities in Federation of Bosnia and Herzegovina, which are the locations where air quality measurements are taken, have an air quality that is extremely polluted. When it comes to cities in Republic of Srpska, the scenario is very similar. Especially noticeable are the high concentrations of pollutants, sulphur dioxide, and particulate matter that are present over the short and medium term respectively.

5. MEASURES TO IMPROVE AIR QUALITY

Improving air quality means, first, reducing emissions of pollutants into the air. There are certain measures for this on the production side and on the consumption side. On the production side, these are technical measures that can be primary and secondary. Primary measures are measures related to emission reduction measures in the furnace itself, while secondary measures are measures to reduce emissions behind the boiler, e.g. on the flue pipe. One such measure is the installation of filters to reduce particulate emissions. Also, increasing the efficiency of boilers is one of the measures to reduce emissions into the air from energy and technological emission sources, because for lower energy consumption, and therefore emissions, you get the same amount of service or production.

In addition to measures from energy and technological plants that emit particulate matter, sulfur dioxide, nitrogen oxides, etc., measures are imposed to reduce emissions of particulate matter on the consumption side, i.e. in traffic and buildings. In traffic, the problem of emitting emissions into the air is expressed throughout the year, while the emission of pollutants caused by the combustion of fuel for the purpose of heating residential space is a phenomenon that occurs only during the heating season. Possible measures to reduce emissions from transport are:

- Construction of bypasses to and from cities
- Acceleration of traffic on existing roads (e.g. reconstruction and widening of roads), as traffic congestion emits most of the emissions
- Stricter technical regulations for car imports and stricter roadworthiness tests for unauthorized removal of catalytic converters
- Improving the city’s public transport services
- Prohibiting and punishing the parking of cars in improper places (this encourages the use of public transport instead of one’s own cars)
- By reducing the need to drive a car,
- Use of alternative means of transport (e.g. bicycles, scooters, electric scooters, hiking, etc.)

In the building industry, measures can be divided into:

- Organizational measures
- Spatial planning measures
- Energy Efficiency Measures

Some of the organizational measures are as follows:

- Increasing awareness through educating citizens about the importance of reducing emissions through educational programs in kindergartens, primary and secondary schools.

- Promotion of alternative fuels instead of solid fuels through public campaigns that inform about the benefits of these options.
- Organization of campaigns to raise awareness of the impact of pollutants on health and the need to reduce them.
- Promotion of energy efficiency projects to reduce energy consumption and emissions.
- Educating construction and design companies on the principles of energy efficiency and the use of renewable energy sources in construction and design.
- Establishment of energy efficiency education centers, where workshops and trainings would be conducted.
- Establishment of a fund for financing energy efficiency projects, which will provide support for the implementation of innovative solutions.
- Furnace and boiler certification
- Control of installation and commissioning of new furnaces and boilers
- Monitoring of emissions from the furnace, etc.

Spatial planning measures can be:

- Planning and conservation of green areas in cities (parks, forests) that absorb pollutants and improve air quality.
- Establishment of zones with stricter rules for the emission of pollutants.
- Incorporating energy efficiency measures into all phases of spatial planning, from construction to use of buildings.
- Planning space for the installation of solar panels, wind turbines and other renewable energy sources to reduce dependence on fossil fuels.
- Expansion of district heating systems in cities to avoid emissions from residential and public buildings, etc.

Energy efficiency measures in buildings can be divided into architectural-construction measures, measures related to thermomechanical systems and electricity reduction. Some of the measures listed are:

- Thermal insulation of the facade involves the installation of thermal insulation material on the external walls. Performing thermal insulation of external walls implies the addition of a new heat-insulating layer on the outside of the wall. The recommended insulation thickness should not be less than 15 cm, which reduces the heat transfer coefficient U to approximately 0,25 W/m^{2}K. (Figure 13)
- Thermal insulation of the ceiling or roof involves the installation of mineral wool inside the roof covering itself or on the ceiling towards an unheated attic. Roofs often cause high heat loss in winter and overheating in summer. If it is not insulated, heat loss through the roof can be up to 30%. The installation of insulation is economically viable with a return on investment of 1 to 5 years. The recommended insulation thickness is at least 20 cm. (Figure 13)
- Replacing openings implies replacing old, worn-out, inefficient windows and doors with new ones that have at least double glazing and a low-e coating. Losses through joinery can account for more than 50% of the total heat loss of a building. The installation of high-quality windows with good sealing and a low heat transfer coefficient U (below 1.4 W/m2K) significantly reduces energy consumption.
- Improvement of the heating system, which may include the replacement of energy

sources, e.g. solid fuels, with more environmentally friendly fuels, e.g. pellets or natural gas
- Installation of a heating system with a high-efficiency heat pump, which eliminates the source of emissions at a local level

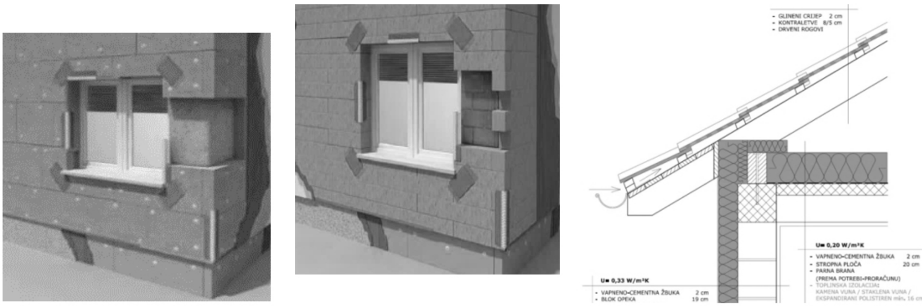

Fig. 13. An illustration of a compact façade with mineral wool panels, slats, and insulation for a pitched roof [7]

These measures are usually integrated, as substituting the energy source without implementing energy efficiency strategies, such as architectural and building modifications, may result in elevated heating expenses. The objective of the measures is to decrease or, at a minimum, maintain expenses at their pre-measure levels. Reducing energy use results in a proportional decrease in emissions. By altering the heating method, emissions can be entirely eradicated from a specific region or structure.

6. CONCLUSION

The issue of air quality is associated with various emission sources, including industrial activities, transportation, and inefficient energy utilization in residences. Despite lower levels of industrialization in BiH relative to other regions, air quality remains substandard according to WHO and EU criteria, attributable to antiquated industrial facilities and the dependence of these economic entities on coal with elevated dust and sulfur content. Elevated levels of particulate matter and sulfur dioxide are particularly evident during the winter months, when weather conditions facilitate the accumulation of pollutants. The topographical features in certain regions of BiH are exacerbated by occurrences such as temperature inversions, which intensify local air quality issues. Due to the elevated mortality rates linked to inadequate air quality, the projected health expenditures and economic repercussions necessitate immediate actions to enhance air quality.

The implementation of technical, organizational, and energy efficiency measures, alongside the substitution of conventional fossil fuels with renewable energy sources, can substantially reduce pollutant emissions. Implementing renewable energy sources and enhancing public transportation can foster a more sustainable environment and promote healthy living for the citizens of Bosnia and Herzegovina. Success hinges on the amalgamation of diverse methodologies and collaboration across various governmental tiers and society to guarantee that air quality remains a prioritized issue.

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Rethinking Cities and Buildings for Better Quality of Life and Indoor Air Quality

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Abstract: Climate change is profoundly affecting our contemporary civilization, influencing the environment in which we live. This necessitates rethinking our construction methods and energy creation processes, requiring greater responsibility for environment and human health. The building sector accounts for over 40% of the total energy consumption and over 43% of the total pollutions in Europe. Energy Efficient EU Directives have evolved from requirements for Low Energy Buildings to official mandates for a full decarbonization in the building sector by 2025.

The Green Building Certification initiative forms a consortium that includes all stakeholders working together to verify the performance of green building projects. This ensures that these projects are environmentally responsible, provide healthier conditions, respect the circular economy, and are energy-efficient and responsibly decarbonized. The measurement of Indoor Air Quality (IAQ) performance is a crucial criterion in Green Building Certification, representing a significant advancement in addressing specialized healthcare needs.

A Pilot Study in Education Institutions in Canton Sarajevo, conducted from October 2020 to March 2021, proved that despite anti-epidemic measures such as frequent ventilation and restricting classroom occupancy, the IAQ parameters recorded during the heating season frequently deviated from WHO- recommended values. Additionally, the study showed that current energy efficiency practices in public building renovations are inconsistent with existing regulations, inadequate, unhealthy, do not support the local economy, and are irresponsible and unsustainable. The absence of adequate monitoring further hinders progress and the achievement of adequate savings.

Future practices for constructing new buildings or renovating existing ones in Bosnia and Herzegovina will need to incorporate Green Certification measures. This approach is essential not only to safeguard the health of citizens but also to achieve the planned decarbonization goals.

Keywords: better quality of life, indoor air quality, energy efficiency, green certification, decarbonization

1. BETTER QUALITY OF LIFE IN CITIES AND BUILDINGS

Today, we are fully aware of the world we live in and that people prefer living in the same cities due to their proximity. This preference leads to migration, causing congestion and overpopulation in urban areas. [1]

Climate change, a growing concern, necessitates rethinking how we live, build, and create energy, emphasizing the importance of environment protection and health. Climate change is transforming our contemporary civilization, making these issues the most important topics of our time.

According to a United Nations report from 2017, the current world population of 7.6 billion is expected to reach 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100. [2] For architects and builders, this means accommodating more than 2 billion additional people by 2050, raising the critical question on how to meet their needs without further harming the planet's resources. This challenge requires mobilizing all professions and raising comprehensive awareness among stakeholders and citizens.

The EU Green Deal highlights clean air as a strategic goal to ensure the quality of life for all EU citizens. To protect Europe's citizens and ecosystems, EU Green Deal outlines a zero-pollution action plan for air, water and soil. [3]

The buildings and construction sector accounted for 36% of final energy use and 39% of energy and process-related carbon dioxide (CO_2) emissions in 2018, 11% of which resulted from manufacturing building materials and products such as steel, cement and glass. [4] That is why the building sector has to provide the optimal, responsible and sustainable solutions as soon as possible. The building sector also polluted the more than 43% compared to other sectors like energy, industry, transport, or agriculture. [5] A large number of reasons have been recognized why building sector plays a significant role in solving the issues of climate change, sustainable development, green policies, the circular economy, and a better, healthier environment and life.

Beside materials, primary energy and pollution, rethinking in the building sector also needs to be focused on responsible urban planning and sustainable landscape architecture projects. [6] Due to the poor urban planning and investment architecture in Bosnia and Herzegovina, a lack of green areas in cities has been noticed, which additionally affects the overheating of the cities by increasing pollution of external and internal air, soil, water and reduction of the quality of life in cities.

Additional rethinking is required for obligatory measures of life cycle assessment, circular economy, responsible use of the renewable energy sources, health, education, and transparency.

This research will reflect on current practices in energy efficiency and Indoor Air Quality (IAQ) in Europe and in Bosnia and Herzegovina (BiH). Special focus will be given to health as well as indoor air quality in the education institutions due to the latest research's proving that IAQ in classrooms significantly affects children's health and academic performance.

2. ENERGY EFFICIENCY PRACTICES IN EUROPE AND BOSNIA AND HERZEGOVINA

Sustainable development is a long-standing philosophy that has become increasingly important in addressing the growing issues of climate change and environment protection. For today's society to be considered sustainable and responsible, we must immediately start practicing efficient and responsible resource use, considering not only present but also future generations. Energy efficiency is a crucial principle in the building sector, focusing on significantly reducing the amount of energy required for the functioning of a building facility without compromising the quality of living conditions. Between 1985 and 2010, the major focus of authorities, scientists and practitioners was on energy savings and building energy performances.

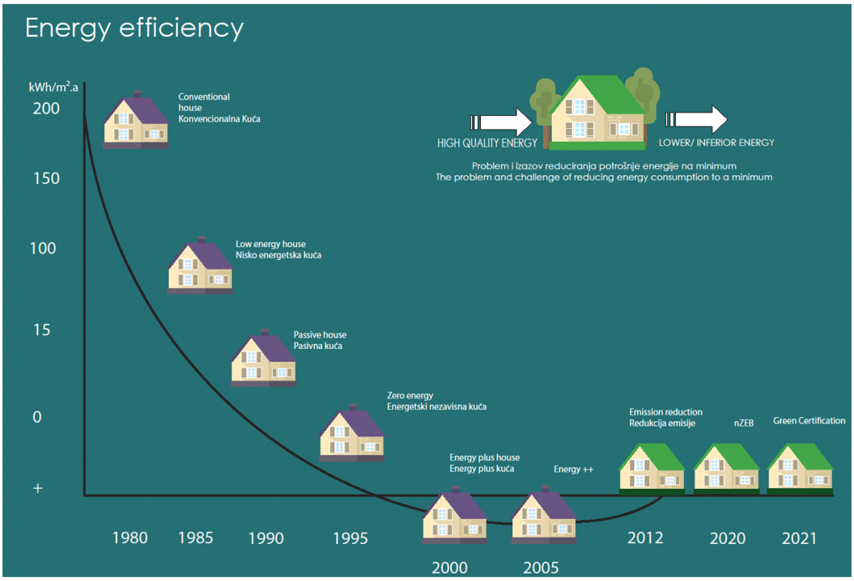

Fig 1. Development of the energy efficient buildings until now, source: author

In 2010, authorities and practitioners began to discuss and reconsider important parameters beyond energy savings that influence the quality of life in buildings. These parameters include indoor air quality, user health, environment protection, sustainable resource use, life cycle assessment, pollution and primary energy. [7] From January 1, 2012, the EU introduced two new categories of certification into the process, both of materials and architectural objects. The first is the total consumption of primary energy required for each material or element incorporated into the object, from extraction from nature, transportation, processing, and installation to the moment of use and recycling. The second is the CO_2 emission during the processing, installation, use and recycling of materials. [8]

This directive made a shift in the design process from a linear to a cyclical approach and required a strong interdisciplinary approach in the building sector. It gathered all stakeholders to focus on location, bioclimate architecture, waste management, sustainable and responsible water management, responsible resources management, primary energy, decarbonization, natural materials, health, IAQ, noise pollution, renewable energy sources and energy efficiency. Furthermore, the EU Energy Efficiency directive evolved to aim at producing more energy than buildings require, as seen in the Energy + building directives, with a focus on nearly

Zero Energy Buildings (nZEB) [9] as a standard from June 2021. From 2025, EU Directives in building sector will require full decarbonization as a main requirement for future responsible and sustainable building practices.

Unfortunately, Bosnia and Herzegovina is still at the very beginning of this implementation. Despite international commitments and legal obligations since 2010, and despite recognizing the important activities of donors and local actors and the significant potential, the current untenable situation in BiH is due to a lack of a coordinated system of energy efficiency across all levels of government and the absence of a comprehensive strategy for sustainable development of the sector. [10]

In a practice, investment in energy efficiency in BiH are mostly focused on public buildings. Recent research [11] , "Study about Indoor Air Quality in the Schools in Canton Sarajevo" shows that with the implementation of energy-efficient projects in BiH, even the minimum required energy characteristics by existing law, have not been achieved, especially in schools and kindergartens. In energy-efficient projects of residential buildings in BiH, current practices also show many illogicalities and deficiencies. Although residents expressed overall satisfaction with the renovations, they were disappointed that the improvements did not result in reduced energy bills. It is important to note that the heating plants did not reduce the amount of energy delivered to buildings after the renovation, even though the energy needed to heat the apartments is much lower than before. The quality of the indoor air should be monitored especially if since the heating energy delivered to the apartments remines the same.

Monitoring of all energy-efficient projects should be mandatory and regulated by laws, which is not the case in practice in Bosnia and Herzegovina. Only through monitoring and reporting can illogicalities and lessons learned be transparently available to all decision makers and other stakeholders which will ensure better practice on place in line with EU in the future.
Decarbonization and EU Green Deal represent huge opportunity for BiH. It is necessary to develop local potentials, especially local clean and sustainable production, through the utilization of local natural, sustainable raw materials such as wood, sheep wool, clay, lime, straw, and other construction waste material that, in addition to thermal effect, have a great impact on environmental protection, CO_2 reduction, rural development, agriculture development, employment and the provision of healthier and quality living conditions. [10]
Additionally, there is potential in renewable energy sources in BiH that need to be optimally utilized in the future.

3. RETHINKING FOR GREEN CERTIFICATION OF BUILDINGS

The Green Building Certification initiative creates a consortium between engineers of architecture, landscape architecture, civil, mechanical, electro and environment, building companies, building industry, a bank, the investor/developer, the users, academy, CSOs and the Certifying organization to verify performance of green building projects that are environmentally responsible and energy efficient. Additionally, the Green Building Certification initiative ensures quality relative to the standard offer, generating financial, social and environmental benefits. Increased energy savings and other financial benefits (such as improved occupant health and less frequent/lower home repair costs) substantially reduce the mortgage default risk, allowing the lender to lower the monthly interest rate while maintaining profit margins. This enables the home buyer to invest in a more energy-efficient and greener home while lowering their total monthly cost of ownership relative to a standard home. [12] The introduction of Green Certification and Green Financing models is very timely in the context of the current and impending European Directives that require progress toward Decarbonized Buildings, maximal construction waste reduction, circular economy, renewable energy as well as a reduction of toxicity of building materials, compulsory for all new and existing residential buildings.

Fig. 2. Responsibilities and Benefits form the Green Certification program, source SMARTER_Finance_for_Families_Toolkit.pdf (green-council.org) [12]

Growing energy security concerns and rising energy costs reward Green Certified projects and Green Financing models that require less costly and scarce natural resources to build and operate. The Green Certification process is very complex and demanding, require full dedication, transparency, and interdisciplinarity from all participants. The Green Certification process starts from the beginning with location selection and analyses, as well as from the earliest moments of initial design, creation, discussion and concept development. In practice, the list of the measures for Green Certification has to be communicated from the start between all participants in the process.

Environmental leadership measures start with strong interdisciplinary teamwork, discussion, and education which lead to capacity building of the teams for all new green practices. Integrated Design, Life Cycle Assessment and Construction Waste Management Planning are required measures that must be implemented according to the required standards. Responsible construction practices must reduce pollution and disruption caused by construction activities and recognize and encourage an environmentally and socially responsible approach to construction site management. [12] Information about new practices, green performances and user behavior requirements is communicated transparently to all participants through official manuals to ensure the sustainable and responsible use and maintenance of buildings over time.

Site and location measures require sustainable and responsible location use, Heat Island Effect Reduction, Light Pollution Reduction, Rainwater Management, easy access to amenities, and the encouragement of the green transports and sustainable mobility.

Water efficiency measures require full support to water efficiency efforts by monitoring and benchmarking water use over time, fully operational greywater system, irrigation and landscaping, green walls and roofs practices, and innovations in sustainable and responsible sewerage systems.

Bio design, materials and resources measures are set up to motivate innovations in use of the local natural resources, recycling and reusing, circular economy principles, and local development. All participants in the Green Certification process are encouraged to use of natural materials that have environmentally and economically preferable life cycle impacts, such as wood, straw, limestone, brick, cob, hemp and sheep wool. Participants are also encouraged to use at least 30% reclaimed material (salvaged, refurbished or reused) in volume from the total materials used on-site and to use local production, with products extracted, processed, or manufactured within a 160 km radius for 50% of the materials used; 30% from a 500 km radius, and 20% from a 1000 km radius. Timber used must be legally forested as evidenced by Chain-of-Custody (CoC) documentation and Forest Stewardship Council (FSC) certification.

All participants must responsibly reduce the health risks to users by using low (up to 10 grams per liter VOC) or no VOC materials, reducing concentrations of chemical contaminants that can damage air quality, human health, productivity, and the environment, and by using fire-resistant insulation materials. Additionally, all participants need to decrease the dependence of non-renewable materials by using at least 30% in volume of renewables and rapidly renewable materials such as bamboo wood, cork, cotton (recycled denim), agrifiber, and natural linoleum from the total volume of materials used on-site.

Human health and wellness measures require reducing the risk of lung cancer, testing indoor air for formaldehyde, total volatile organic compounds (VOC) and particulates (PM2.5) to ensure levels of these pollutants are within healthy limits. Green Certification also requires testing before building occupancy to ensure bacteria, lead, pesticides, nitrate/ nitrite, chlorine, pH, and water hardness are within healthy/acceptable limits. Additionally, it is required to improve indoor comfort and relaxation through sound mitigation solutions to reduce interior and exterior noise, alleviate stress and anxiety, and improve the indoor environment and air quality.

Green Certification motivate investors to invest in better energy characteristics of buildings, with special points for those who invest in nZEB or decarbonized buildings and innovations.
Current Green Certification practices confirm and prove a direct correlation between the energy efficiency and green performance of a building and the quality of life, comfort, design, construction and operation of that building. There are multiple Green certification programs worldwide; in BiH the one accredited by EU SMARTER project is currently operational. [12] All these Green Certification programs focus on a healthier environment for humans and nature. Currently, the Green Building Council in BiH is implementing three Green Certification contracts in BiH. There is a great need to promote this program and to involve more stakeholders to collectively increase the understanding and proof of benefits for all users, developers, investors, nature, resources, the local economy and more.

4. INDOOR AIR QUALITY MEASURES AS AN OBLIGATORY PART OF GREEN CERTIFICATION

It is a generally accepted scientific fact that a high level of air pollution endangers human health in many ways. However, a special danger is air contamination in closed spaces, in which we spend 80 - 90% of our life and where the pollution can be significantly higher than outside. Such pollution, according to increasingly complex research and analysis, leaves not only health problems, but also significant economic consequences, especially in low and medium developed societies. Indoor Air Quality performances of the buildings as measures that must be implemented and proved for optimal characteristic in the Green building certification present an important breakthrough when we talk about special health care, which is becoming an important segment in the construction sector. That is why it is important in all future energy efficiency projects in BiH to include budget line and to plan the investment in planning and installing HVAC infrastructure to ensure IAQ in inner space besides all other measures for energy savings, decarbonization and circular economy. Additionally, the budget needs to plan for monitoring of IAQ in order to ensure the quality and durability of the measure, quality of the work, installations and equipment.

4.1 Strategies and policies for Indoor Air Quality in the EU and Bosnia and Herzegovina

Climate change and environmental degradation are an existential threat to Europe and the world. To overcome these challenges, Europe needs a new growth strategy that transforms the Union into a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases. The main strategic goals of EU Green Deal are: Europe without net greenhouse gas emissions by 2050, economic growth with optimal utilization of resources, and ensuring no person and no place is left out of the strategy. The first thing to notice in the EU Green Deal, for every policy field, is that clean air is one of the important strategic goals that contribute to the main goal of this strategic document, which is aimed at securing quality of life for all EU citizens.

Indoor air quality (IAQ) is a crucial aspect of building environments, significantly impacting the health of occupants and other living organisms within these structures. Exposure to indoor air pollutants can have detrimental effects on health. In response to these concerns, the European Union has implemented comprehensive legislation that sets health standards and targets for various airborne pollutants. These standards and objectives are applied over different time periods to address the varying health impacts associated with different pollutants over different exposure durations.

Nearly-zero energy buildings is a requirement introduced by the Energy Performance of Buildings Directive EU/31/2010 (revised in 2018). [13] It means that all new buildings – as of 2020 - must have a high energy performance and very low-energy needs, covered largely by onsite and nearby renewable energy sources. In June 2021 nearly Zero Energy Building (nZEB) standard become mandatory for all public investment in new or in renovations of the existing building in EU. Currently, it is recommended by European Commission that all EU members introduce the obligation for completely decarbonized buildings by the year 2025.

The European Parliament Resolution on Europe that Protects: Clean Air for All (2018/2792) defines the importance of clean air and the obligations of Member States to provide capacity for interventions.

Directive 2008/50/EC [14] introduced additional targets for PM2.5 aimed at population exposure to fine particles. These targets are set at the national level and are based on the Average Exposure Indicator (AEI). Also, according to this EU Regulation on the concentration of carbon dioxide (CO2) in living rooms, the concentration must not exceed 1500 ppm.

The European Parliament Resolution on a smoke-free environment, 2009, defined the framework for adapting the legislation banning smoking indoors. [15]

Directive (2018/844) of the European Parliament and the Council on the energy properties of buildings and energy efficiency prescribes in a very detailed manner the steps that member states should take in order to improve climate conditions during construction and reconstruction. [16]

One year after the Fifth Ministerial Conference on Environment and Health, the European Parliament and the Council adopted Regulation (305/2011) [17] on establishing and harmonizing the conditions for placing construction products on the market. The decree defines that buildings must be designed and built in such a way that during their life cycle they do not pose a threat to the health and safety of workers, tenants or neighbors, nor have an extremely high impact on the quality of the environment or the climate during their construction, use and demolition. especially as a result of the emission of hazardous substances, volatile organic compounds, or greenhouse gases into indoor or outdoor air.

The European Action Plan for the Environment and Children's Health [18], 2004 recognizes clean air as an obligation. WHO Europe, under the title of Guidelines for Indoor Air Quality 1987, 2000, 2010, defines pollutants and maximum permissible amounts in the air, especially in the indoor spaces. The International Society for Indoor Air Quality and Climate (ISIAQ) was established in 1992.

Accession to the European Union (EU) is a strategic priority for Bosnia and Herzegovina. The Stabilization and Association Agreement with the EU, which has entered into force, has intensified the country's integration process and underscored its full responsibility for this endeavor.

Bosnia and Herzegovina have adopted the Strategy for Harmonization of the Regulations of Bosnia and Herzegovina with the European Union's Acquis in the Field of Environmental Protection (EAS-BiH) (Official Gazette of Bosnia and Herzegovina, number 91/18). [19] By signing the Agreement on the Establishment of the Energy Community, BiH, among other things, undertook to take over parts of the EU acquis, that is, to transpose and implement the relevant EU directives and regulations in the field of energy and air emissions.

The Decision on the Conditions and Method of Implementation of the Montreal Protocol and the Gradual Phase-Out of Substances that Damage the Ozone Layer ("Official Gazette of Bosnia and Herzegovina," Number 36/07 and 67/15) [19] mandates that Bosnia and Herzegovina comply with the provisions of the Montreal Protocol. Bosnia and Herzegovina ratified the Vienna Convention for the Protection of the Ozone Layer based on the assumed succession of international obligations from the former Socialist Federal Republic of Yugoslavia (SFRY) ("Official Gazette of the SFRY MU" No. 16/90 and "Official Gazette of the RBIH" No. 13/94).

At its 32nd regular session on December 20, 2016, the Presidency of Bosnia and Herzegovina adopted the Decision on the Ratification of the Paris Agreement. This treaty commits EU countries to reducing greenhouse gas emissions by at least 40% compared to 1990 levels by 2030. The primary objectives of the Agreement are to limit global warming to "well below" 2°C, ensure food security, enhance countries' capacities to combat climate change impacts, develop new "green" technologies, and assist economically weaker member states in achieving their national emission reduction targets.

Open green spaces hold the potential for purifying both outdoor and indoor air. The Green Cities initiative provides a strategic opportunity to enhance this potential. Currently, the cities of Banja Luka, Zenica, and Sarajevo have adopted Green Action Plans.

The European Commission has published a working document titled "Guide for the Implementation of the EU Green Agenda for the Countries of the Western Balkans," which details activities related to the Green Agenda for the region. This document includes the communication, economic, and investment plan for the Western Balkans, adopted by the European Commission on October 6, 2020. All Western Balkan countries signed this document on November 10, 2020, in Sofia, committing to fulfill the defined measures. The Sofia Declaration provides grant funds in the amount of EUR 9 billion for all countries of the Western Balkans until 2030.

Competence for environmental protection issues in BiH is divided between entities, Brčko District and cantons in the Federation of BiH. It is essential to comprehensively revise all laws and regulations across various sectors in BiH in order to harmonize air quality standards, both indoor and outdoor, with the latest EU standards and directives. The Parliament of Federation of BiH adopted the Resolution on Improving Indoor Air Quality on 12 June 2024. [20] This Resolution obliges the Government of FBiH to, within 12 months, establish interdisciplinary team in charge of preparing and to adopting an Action plan for the Protection of Children and Young People from indoor air pollution, a Draft Law on Indoor Air Quality in the Federation of Bosnia and Herzegovina, Draft Law on Amendments to the Law on Construction in the Federation of Bosnia and Herzegovina, Amendments to the Rulebook on Technical Properties for Chimneys in Buildings, the Rulebook on Technical Properties of Ventilation Systems, Partial Air Conditioning and Air Conditioning in Buildings and the Rulebook on Technical Properties of Heating and Cooling Systems in Buildings; and an Analysis of the Compliance of the Rulebook on Air Quality Limit Values (2005) and the Rulebook on the Manner of Monitoring Air Quality and Defining the Types of Pollutants, Limit Values and Other Air Quality Standards (2012) with the recommendations of the World Health Organization.

4.2 PILOT RESEARCH of Energy Efficiency Practices in Educational Institutions of Sarajevo

Children are especially vulnerable to negative influences and suffer from various diseases due to the air pollution. Current data indicate worrying consequences for both health and academic success in Bosnia and Herzegovina. The World Health Organization (WHO) defines indoor and outdoor air pollution as the contamination of air with chemical, physical or biological contents that threaten the normal characteristics of the atmosphere. [21] Indoor and outdoor air pollution are globally recognized threats to human health, ecosystems, environment, and climate. [22] According to the WHO, a total of 12.6 million deaths worldwide are due to an unhealthy environment, representing 23% of the total global mortality and 26% of the mortality in young children. [23] According to the of the WHO data, 9 out of 10 people breathe polluted air with concentration of pollutants exceeding WHO guidelines. Low and medium-developed countries suffer from the greatest exposure. [24]

School-aged children (usually 4–12 years old) spend more time (about 80%) indoors (e.g. in schools and their homes) than outside. After the home, the school/classroom is the second most important environment for children, where they spend about 25-30% of their life (up to 10 hours a day), mostly indoors. Therefore, adequate air quality in schools is an important determinant of the healthy life and well-being of school children.

It has been repeatedly confirmed that poor indoor air quality is associated with various unfavorable health conditions that have recently been classified into syndromes: Sick Building Syndrome and Building Related Syndrome. [25] Exact data are scarce, but it is assumed that the concentration of indoor air pollutants (IAPs) is directly affected by both internal factors such as classroom orientation, ventilation, heating systems, and insulation materials, as well as by external factors such as outdoor concentrations, proximity to roads, farms, other pollution sources, moisture, or sun exposure. [26]

The only evidence-based data on IAQ in elementary schools in Bosnia and Herzegovina (BiH) originate from "SEARCH project", international research on school environment and respiratory health of children that indicated poor IAQ in BiH schools in 2010. [27] Pilot research of Energy Efficiency Practices in Educational Institutions of Sarajevo was conducted in 2020 and 2021, during Covid period, in Canton Sarajevo, BiH. [11] The aim of this pilot study was to determine IAQ in elementary schools with different in internal and external characteristics. The Covid pandemic additionally set different criteria that the team had to follow.

The pilot study was part of a wider research of energy efficiency practices in educational institutions of Sarajevo Canton (natural vs. artificial construction materials) during the non-heating and heating seasons. The research was designed and conducted by an interdisciplinary team gathered under the association Green Building Council in BiH. Due to limited resources and time the following IAQ parameters were measured from October 2020 to March 2021: temperature (°C), relative humidity (%), PM2,5 mass concentration (μg/m3), and CO_2 concentration (ppm).

The analysis or architectural characteristic of the education institution started with existing documentation as well as new project documentations for energy efficiency interventions and energy building audits. The focus of the architectural research was on external factors such as location, orientations, proximity to roads, rivers, green areas, pollution sources as well as internal factors such as classroom orientation, ventilation and heating systems, interior materials, equipment, insulation materials, and energy efficiency characteristics and details. All photo documentations, site analyses, drawings and energy efficiency calculations helped the architecture team understand relations and influences of different architecture characteristics on IAQ.

Out of all schools in Sarajevo Canton, four schools were selected for inclusion in the study. The primary criterion for school selection was different insulation materials, presenting a basis for four different scenarios for IAQ assessment.

School 1. Osman Nakaš Elementary School (Fig. 3.) is located in the Municipality Novi Grad in a residential area called Čengić vila 1 (urban). The school building is located near major local roads, a petrol station and the Miljacka river. The elementary school was built in 1967. The building has undergone basic renovations and remains in that condition. The school will be a part of the program for energy efficiency renovation of public building in Canton Sarajevo. The envelope remains very basic with old windows and the façade without thermal insulation. The school's heating system is part of the district heating on natural gas.

The analyzed classroom orientation in this school is to the south, directly facing the local road, and positioned on the first floor. The classrooms have wooden flooring, painted walls, wooden furniture, and wooden windows. Sun exposure in the classroom is high, ventilation is natural, and the duration of windows opening in this classroom was every third class. The classroom is indirectly oriented toward the river.

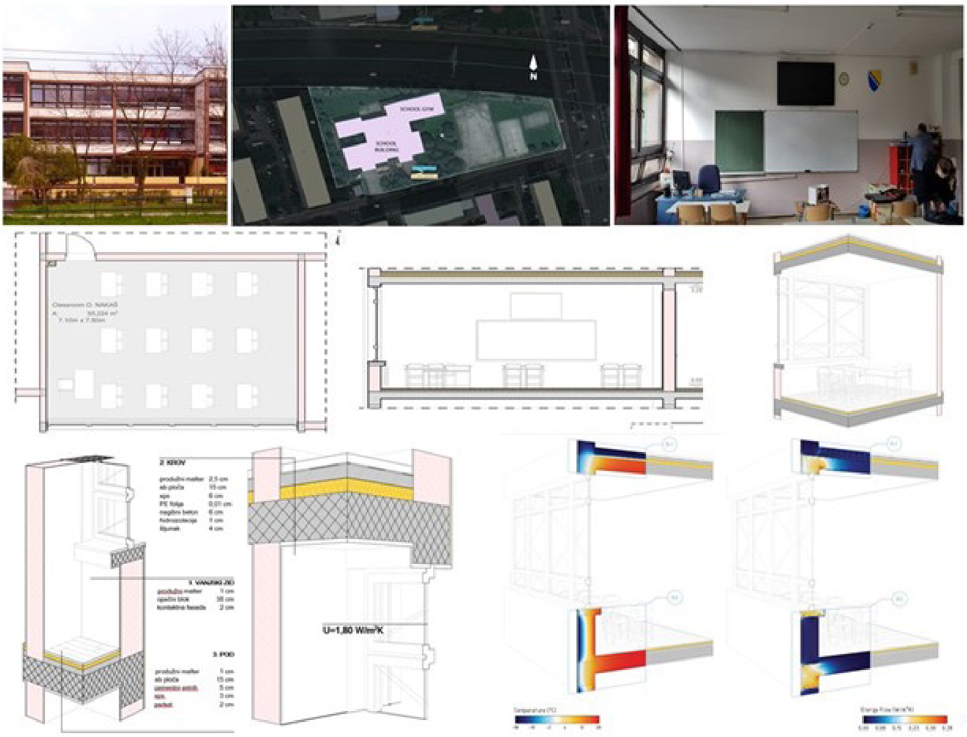

Fig. 3. School 1. - Elementary School Osman Nakaš - architectural analyzes by authors [11]

School 2. Porodice Efendije Ramić Elementary School (Fig. 4.) is located in the Municipality of Vogošća in a small residential area called Semizovac (rural). The school building is situated near a major road, a petrol station, and Ljubina river. The elementary school was built in two phases: one part in 1914 (Old School) and the other in 1957 (main building), connected by a corridor. The building was renovated in 1998 and again 2011 as a part of the program for energy efficiency renovation of public buildings in Canton Sarajevo. The renovation measures included installing thermal insulation on the facade (styrofoam) and plastic windows. In 2014 a sport hall was built as an additional building connected by the corridor to the rest of the school. The school has its own gas boiler for heating.

The analyzed classroom orientation in this school is south, indirectly orientated toward the major road, and positioned on the first floor. The classroom had vinyl flooring, painted walls, and is equipped with wooden furniture and plastic windows. Sun exposure in the classroom is high, ventilation is natural and duration of window opening in this classroom was every second and third class. The classroom is indirectly oriented toward the river.

Fig. 4. School 2. - Elementary School Porodice Efendije Ramić, Semizovac: Architectural Analysis by Authors [11]

School 3. Mula Mustafe Bašeskije Elementary School (Fig. 5.) is located in the Municipality of Stari Grad, in a residential area (urban). The school building is located near local roads and mostly residential buildings. The school was built in two phases: one part was built in 1928 (building A) and the other in 1962 (building B), connected by a corridor. The building was renovated in 2019 as a part of the program for energy efficiency renovation of public building in Canton Sarajevo. The renovation measures included installing thermal insulation on the facade (mineral wool) and plastic windows. The school has its own gas boiler for a heating.

The analyzed classroom orientation in this school is south, indirectly orientated toward the local road, and positioned on the first floor. The classroom has artificial laminated flooring, painted walls, and is equipped with wooden furniture and plastic windows. Sun exposure in the classroom is high, ventilation is a natural and duration of the windows opening in this classroom was every second class.

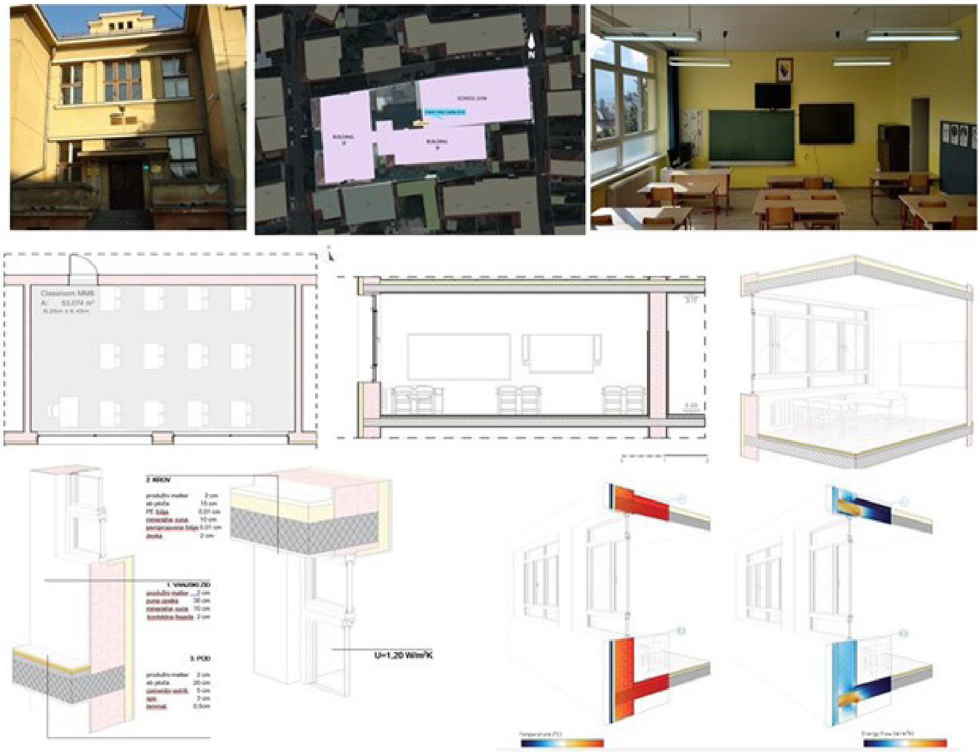

Fig. 5. School 3. - Elementary School Mula Mustafe Bašeskije: Architectural Analysis by Authors [11]

School 4. Porodice Efendije Ramić District Elementary School in Gora (Fig. 6.) is located in Municipality of Vogošća, in a residential area called Gora (rural). The school building is situated near a major road, a river, a local farm and green areas. The school was built in 1960. The building was renovated in 2004 and again in 2019 as a part of the program for energy efficiency renovation of public buildings in Canton Sarajevo. The renovation measures included installing locally produced natural thermal insulation on the facade (sheep wool and wood) and wooden windows. The school has its own eco oil boiler for a heating.

The analyzed classroom orientation in this school is south, indirectly orientated toward the major road and the farm, and positioned on the ground floor. The classroom has vinyl flooring, painted walls, and is equipped with wooden furniture and wooden windows. Sun exposure in the classroom is indirect and medium, ventilation is natural, and duration of window opening in this classroom was never.

Fig. 6. School 4. - Elementary School Gora: Architectural Analysis by Authors [11]

All schools have classrooms oriented to the south with natural ventilation. All analyzed school/ classroom characteristics during the Pilot study 2020-2021 are summarized in the Table 1.
Table 1. School/classroom characteristics analyzed during Pilot study 2020-2021 [26]

Characteristics	School 1	School 2	School 3	School 4
Nr of students in classroom	8	8	9	8
Grade of children	V	III	IV	II, III
Classroom level	first floor	first floor	first floor	ground floor
Classroom volume (m^3)	172,2	181,7	180,8	171,3
m^3/person	19,7	20,2	18,1	19,0
Flooring	wooden	vinyl floor	laminate floor	vinyl floor
Wall covering	painted	painted	painted	painted
Type of windows	wooden	plastic	plastic	wooden
Duration of windows/opening	third class	second, third class	all three classes	never
Type of ventilation	natural	natural	natural	natural
Classroom orientation	south	south	south	south
School location	urban	rural	urban	rural
Vicinity of the road	yes	yes	yes	yes
Classroom orientation to the road	direct	indirect	indirect	indirect
Vicinity of the farm	no	no	no	yes
Vicinity of water	yes	yes	no	yes
Sun exposure	direct, high	direct, high	direct, high	indirect, medium
Type of heating	public/natural gas	own/natural gas	own/natural gas	own/fuel oil
Type of insulation materials	none	styrofoam	mineral wool	sheep wool and wood
Energy efficiency class*	D	A	A	C

*Regulation on the implementation of Energy Audit and issuance of Energy Certificate; Official gazzet FBiH No 87/18 file:///Users/Aida/Downloads/EPBD%20implementation%20Report_BiH%20(1).pdf

Additionally, the analyzed energy efficiency characteristic of the building show that the heat transfer coefficients for external walls, roofs, floors, and ceilings, as specified by the Rulebook on Minimum Requirements for the Energy Characteristics of Buildings in the Federation of Bosnia and Herzegovina (FBiH) for the North climate region, were not met in any of the analyzed schools renovated under the Program Support for Investing in Energy Efficiency of Sarajevo Canton facilities. Additionally, these elements fail to meet the prescribed conditions concerning surface humidity. Simulations of thermal bridges related to energy flow and temperature indicate that the buildings lose significant amounts of energy through all parts of their envelopes.

The results of our pilot study Indoor Air Quality analyzes indicated that despite anti-epidemic measures such as frequent ventilation and limiting the number of students in classrooms, indoor air quality (IAQ) remained low, particularly during the heating season. The highest PM2.5 concentrations were recorded in Schools 1 and 4, and the highest CO_2 levels in School 4, where natural ventilation was never utilized during classes. However, School 4 also exhibited the most optimal temperature and relative humidity, creating the most pleasant microenvironment for students. Conversely, urban schools displayed the greatest deviations in temperature, typically above the recommended range, and in relative humidity, usually below the recommended range.

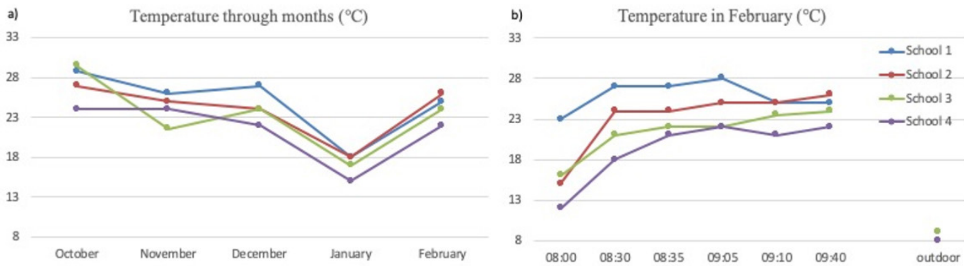

Fig. 7. Inter-school comparisons of temperature: a) At the end of the third class through the non-heating, heating season and holiday period in January, b) At the beginning and at the end of each class and outdoors in February, within-day comparison. Note the difference in the length presented on x-axis: class vs break (30 vs 5 min) [26]

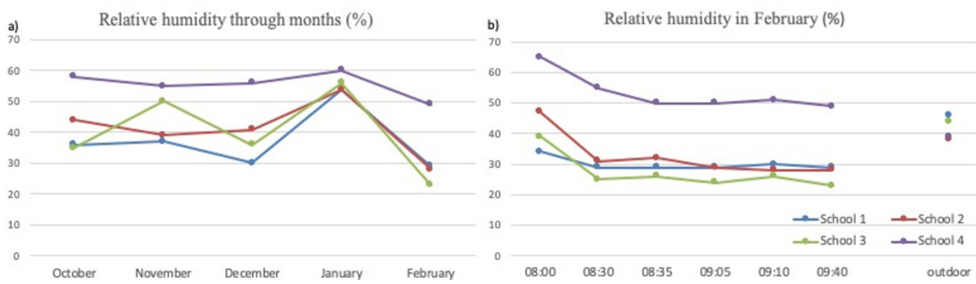

Fig. 8. Inter-school comparisons of relative humidity: a) At the end of the third class through non-heating, heating season and holiday period in January. b) At the beginning and end of each class and outdoors in February, within-day comparison. Note the difference in the length presented on x axis: class vs break (30 vs 5 min) [26]

Indoor PM2.5 concentrations in schools primarily consist of a mixture of organic matter (such as skin flakes, cloth fibers, and possible condensation of volatile organic compounds) and particles from chalk and building deterioration. These particles can also originate from outdoor sources, such as road traffic emissions, especially if windows and doors face busy roads or industrial areas, and typically enter indoors through natural ventilation. The highest PM2.5 concentrations in Schools 1 and 4 were influenced by several shared characteristics. Our intra-school comparison of PM2.5 concentrations with windows either closed or open for short durations indicated that the lack of ventilation in School 4 and its brief duration in School 1 were significant factors in the elevated PM2.5 levels in these schools. Notably, PM2.5 concentrations in School 4 were higher indoors than outdoors. Since windows in School 4 were kept closed at all times, its direct exposure to the road and high outdoor PM2.5 concentrations did not contribute to the high indoor levels of PM2.5.

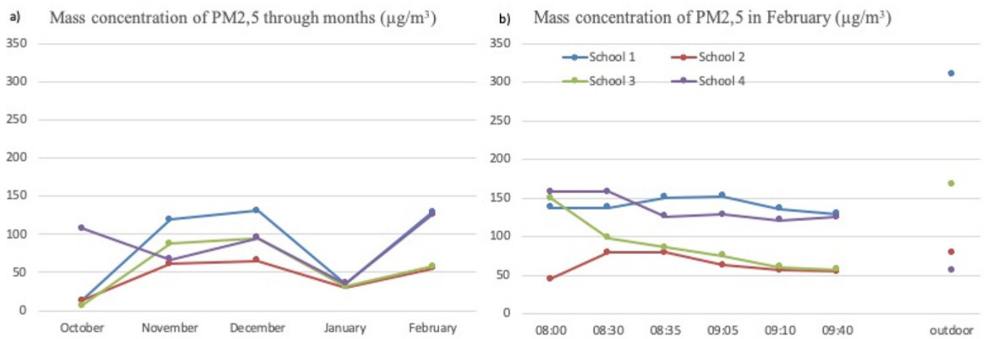

Fig. 9. Inter-school comparisons of PM2,5 mass concentration: a) At the end of the third class through the non-heating, heating season and holiday period in January. b) At the beginning and end of each class and outdoor in February, within-day comparison. Note the difference in the length presented on x-axis: class vs break (30 vs 5 min) [26]

Additionally, an increase in CO_2 concentration despite ventilation was observed in Schools 2 and 3. High outdoor CO_2 concentrations and/or inadequate classroom ventilation during the heating season generally exacerbate indoor CO_2 levels. Similar to the PM2.5 concentrations in our study, one would expect high CO_2 values in both Schools 1 and 4 under the same conditions. However, unexpectedly, only School 4 exhibited high CO_2 levels, while School 1 had high PM2.5 concentrations but the lowest CO_2 levels. This disparity suggests the influence of other factors beyond the lack of ventilation. Differences in classroom level, flooring, school location, proximity to roads or farms, type of heating and fuel, insulation materials, and various indoor activities may explain the unexpected dynamics in PM2.5 and CO_2 concentrations.

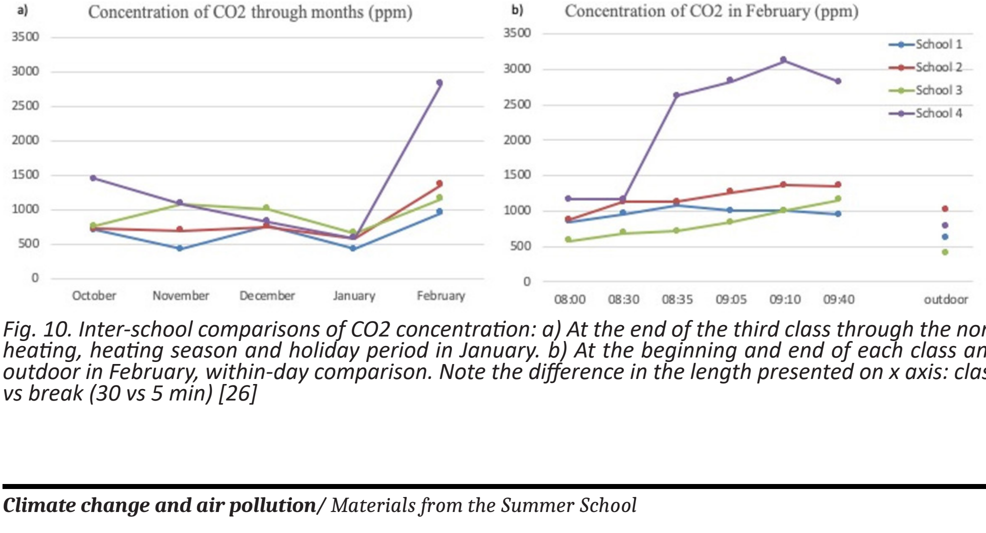

Fig. 10. Inter-school comparisons of CO2 concentration: a) At the end of the third class through the non-heating, heating season and holiday period in January. b) At the beginning and end of each class and outdoor in February, within-day comparison. Note the difference in the length presented on x axis: class vs break (30 vs 5 min) [26]

Despite anti-epidemic measures such as frequent ventilation and limiting the number of students in the classroom, the IAQ parameters measured during the heating season mostly fell outside the recommended values. Since students and their activities can also be sources of PM2.5 and CO_2, the IAQ would likely deteriorate further if all students were present. Therefore, to ensure a healthy school environment during the heating season, optimizing both indoor and outdoor conditions is necessary, whether in pandemic or non-pandemic situations.

4.3 Rethinking Building Materials

The advancements in technological development have provided humans with unprecedented grace and comfort, fostering a sense of superiority over nature. However, this justified feeling of supremacy has led to a loss of the intrinsic connection between humans and the natural world. This estrangement has jeopardized human survival on the planet, resulting in significant climate changes, pollution, and the extinction of various plant and animal species. Conversely, nature is perfect, offering answers to numerous questions, doubts, problems, and worries. Yet, modern humans often fail to recognize or utilize the benefits of cooperating with nature. Historically, our ancestors lived in harmony with the natural world, and their heritage and traditions hold many answers that could benefit modern humans. Reconnecting with these practices could help address contemporary environmental challenges. [7]

Analyses of the lifecycle of materials used in building construction reveal that they have a significant impact on energy consumption and CO_2 emissions. From processing, transport, and installation to the operational phase of the building, these materials can greatly influence energy demand and pollution levels. Therefore, using the natural, local materials can contribute to total decarbonization, aligning with the goals of the EU Green Deal.

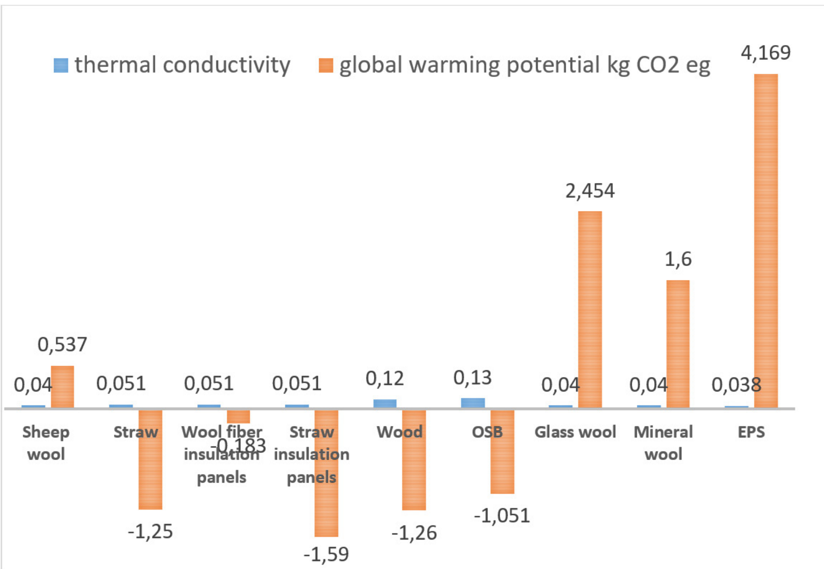

Fig. 11. Ratio between thermal conductivity and global warming potential values for characteristic insulation materials [10]

Natural materials, which are continuously available and renewable, necessitate planned and sustainable management. These materials also have excellent thermal properties, making them ideal for use as insulation in energy efficiency projects. Materials such as wood, sheep's wool, straw, hemp, clay, and lime have a long tradition and are embedded in our cultural heritage, offering sustainable solutions for modern construction. There must be a balance between the use of the raw materials and the energy, as well as between waste management and control of greenhouse gas emissions, because environmental impact of every material or product is monitored through its entire life cycle.

A large number of conducted research clearly indicates the connection between exposure to toxic or polluting substances from the exterior and interior materials in the building environment and the development of acute and chronic diseases in humans. Data from the World Health Organization (WHO) indicate that nine out of ten people breathe air in which concentrations of pollutants exceed the limits given in WHO guidelines. This is why we must carefully rethink which materials to use in the future in order to avoid harmful materials in building construction. Pollutants can remain in the air of closed spaces for a long period of time and thus affect people through various exposure methods, namely inhalation, ingestion or through the skin.

Toxic compounds (e.g. formaldehyde, benzene, trichloroethane, toluene, ethyl-benzene and xylene and many others), CO, CO_2 and other chemical and biological compounds originate from inside the building. Most often they are released:

- from materials used in the construction or renovation process, for example polyvinyl chloride (PVC) floor coverings, parquets, linoleums, rubber carpets, glues, varnishes, paints, silicones, chipboards, etc.
- when using electronic devices such as computers, photocopiers, printers and other devices and furniture that emit ozone (O_3) and volatile compounds
- during internal activities, e.g. emissions from cleaning products during cleaning activities, emissions from cooking, emissions from care products, etc.
- From burning in home fireplaces and smoking cigarettes
- humans also create favorable conditions for the development of millions of molds, fungi, pollen, mites, bacteria, viruses and insects. [28]

According to some studies, indoor air quality in the classroom is more affected by indoor than outdoor pollutants. In the future, it is necessary to continue with targeted research, which would pay special attention to the materials we use in the civil engineering industry, to ensure completely healthy and high-quality facilities that provide full safety for users. [28]

5. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

Climate change is a reality that profoundly affects both our lives and the natural environment on Earth. It is crucial to rethink our strategies and implement significant, tectonic changes to ensure responsible and sustainable development for the future. The building sector is responsible for over 40% of total energy consumption and more than 43% of total pollution in Europe. Since 2002, the EU has adopted Energy Efficiency Directives that have progressively shifted the requirements from low-energy buildings, Passive buildings, + Energy Buildings towards more responsible, healthier and sustainable solutions such as nearly Zero-Energy Buildings to full decarbonization targets set to be achieved by 2025.

Green certification should be mandated for all public facilities, including educational, health, and social institutions. This approach is essential to ensure optimal and healthier conditions, particularly for the recovery and well-being of vulnerable segments of society.

Poor air quality in classrooms poses significant threats to children's health, academic progress, and overall well-being. The absence of green spaces in urban areas exacerbates both outdoor and indoor air pollution. Current data from Bosnia and Herzegovina reveal alarmingly high levels of indoor air pollutants and a troubling prevalence of asthma symptoms among students.

There is an urgent need to adopt practical strategies and action plans to improve classroom environments, thereby reducing the risks associated with polluted indoor air and ensuring a safe educational setting for children. Such measures are essential for supporting their psychosocial development and educational success. Also, the urgent need for better temperature and humidity monitoring in schools must be recognized and demanded as soon as possible.

Green certification should be mandated for all public facilities, including educational, health, and social institutions. This approach is essential to ensure optimal and healthier conditions, particularly for the recovery and well-being of vulnerable segments of society.
Poor urban planning and investment practices in Bosnia and Herzegovina have led to a noticeable lack of green spaces in cities, exacerbating both outdoor and indoor air pollution. Additionally, the inadequate placement of schools results in the infiltration of polluted outdoor air into indoor environments.

Energy efficiency projects, which focus primarily on renovating building envelopes and upgrading energy sources, often exacerbate indoor air quality issues. These projects typically seal buildings more tightly and discourage natural ventilation. Notably, none of the public buildings renovated for energy efficiency have installed ventilation or recuperation systems. Research shows that even with these energy-efficient renovations, buildings often fail to meet the minimum required energy standards. Meanwhile, EU standards, which mandate that all new buildings must be nearly zero-energy buildings (nZEB) as of June 2020, are not adhered to locally. This gap highlights a significant shortfall in meeting both local regulations and broader legal requirements.

Additionally, the choice of materials for construction, renovation, energy efficiency, and interior decoration is crucial, as many studies have demonstrated that poorly selected materials can significantly degrade air quality. Natural materials are recommended for insulation, windows, and interior decoration due to their positive impact on air quality.

The principles of circular economy and green certification further enhance this approach by supporting local production, boosting the local economy, and reducing transportation costs. Green public procurement is a key mechanism for promoting the best and healthiest practices. Assessing the socio-economic costs of indoor air pollution in schools can help guide the creation and implementation of effective public policies to address these issues.

The Green Building Certification program must create a strong consortium involving all stakeholders to collaboratively verify the performance of green building projects. This will ensure that projects are environmentally responsible, provide healthier living conditions, respect the principles of the circular economy, are energy-efficient, and support responsible local economy and decarbonization. The measurement of Indoor Air Quality (IAQ) performance presents a critical criterion in Green Building Certification, representing a significant advancement in addressing specialized health care needs. Bosnia and Herzegovina, must involve not only IAQ but all other Green Certification measures in future energy-efficient programs of investments.

RECOMMENDATION:

Harmonize and Update Regulations: It is essential to align and amend existing laws or create new ones that are harmonized with current EU standards and regulations in environmental protection, construction, urban planning, and green building certification.

Adopt EU Best Practices: Embrace best practices from the EU and actively participate in implementing the EU Green Deal and the action plan for the Western Balkans.

Allocate Funding for Green Building Certification: Ensure the allocation of funds to finance energy efficiency measures in line with Green Certification. Special emphasis should be placed on measures that improve indoor air quality, noise levels, lighting, and overall comfort within the premises.

Mandatory Monitoring of Energy-Efficient Projects: Monitoring of all energy-efficient projects should be made mandatory and regulated by law, as is currently lacking in Bosnia and Herzegovina. Transparent monitoring and reporting of inconsistencies and lessons learned are crucial for providing decision-makers and stakeholders with clear insights, thereby promoting improved practices that align with EU standards in the future.

Responsible Approach to Sustainable Planning of Cities and Buildings: Capacity building should embrace the best practices of using natural local materials and recycled materials in construction to ensure better quality and healthier living conditions.

Engage Stakeholders: In the future, it is crucial to involve all relevant parties in developing and managing solutions for indoor air pollution issues, ensuring a collaborative approach.

Conduct Targeted Research: Special research should be carried out to address new requirements and standards in construction that arise from pandemics or large-scale epidemics.

Promote and Develop Green Spaces: Focus on raising awareness about the importance of open green areas in urban environments and buildings. Additionally, build capacity for the planning and development of these green spaces to enhance overall urban health and sustainability.

Develop and Adopt IAQ Standards: It is essential to prepare and implement a comprehensive manual detailing standards and norms for indoor air quality across all public, educational, health, residential, and work environments throughout Bosnia and Herzegovina.

Strategic Location for New Schools: New schools should be strategically located away from major roads, heavy traffic, industrial zones, ongoing construction sites, agricultural farms, domestic fireplaces, and other potential sources of pollution.

Capacity Building and Awareness: Establish programs to build human capacity and raise awareness about promoting a healthy school environment.

Maintain Healthy School Environments: Implement a program for the maintenance of classrooms and other school facilities using natural cleaning products with minimal release of harmful substances.

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Environmental Violenece in Bosnia and Herzegovina: Challening the Logic of The Wasteocene

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Keywords: environmental violence, waste colonialism,Wasteocene, mental health and environmental violence, environmental humanities.

1. INTRODUCTION

Aldin Bejhanović, a scrap metal picker, recounts his harrowing experience working at the remains of the Chlor-alkali Power Plant, known as HAK, near Tuzla. After suffering a pulmonary embolism when picking scrap metal in HAK, he reflects: “We took off gunmetal valves from the pipes below the manhole covers. There was work. But after some time, the barrels appeared. It was stinking…It stank so strongly that it hurt my eyes. I could not take it…I stopped for a while, but later I, my father and a neighbour arrived to cut out pipes. And we found it there. We did not know that it was a poison. The place was not even marked.” His description of the poisoning that followed is vivid: “I was feeling out of breath when I bent down to pick up something, and I had put up with this for around 14 days. I thought it was cigarettes. When it grabbed me and threw me down and when blackness fell over my eyes, I could not reach my car” (CIN 2018). Bejhanović’s uncle was not as fortunate—his lungs were irreversibly damaged by the same toxic fumes.

The decaying HAK factory, emblematic of Bosnia and Herzegovina’s post-industrial landscape, still holds more than 47 tons of toxic propylene oxide and unknown quantities of chlorine within its rusting pipes. Nearby, 120 corroding barrels filled with mercury, and cadmium and arsenic, have been leaking their deadly contents into the ground for over 25 years. The land in and around HAK is contaminated with hidden waste sites, mainly filled with carcinogenic toluene diisocyanate (TDI) waste, their precise locations undocumented, leaving only impoverished former workers, like Bejhanović, to sift through the toxic remnants of the factory’s infrastructure for scraps of metal to sell. The slow violence of abandon industrial toxic waste claims lives in drawn-out, insidious ways, with former workers experiencing higher rates of chronic illness and untimely deaths.

Bejhanović’s story illustrates the polyvalence of violence—ranging from overt wartime atrocities to the quieter, less visible effects of toxic waste on human bodies. Stacy Alaimo captures this connection, observing that “bodies and selves are constructed from the very stuff of the toxic places they have inhabited. As various toxins take up residence within the body, the supposedly inert ‘background’ of place becomes the active substance of self” (Alaimo 2010, 102). The poisoned bodies of workers like Bejhanović are both victims of a privatization process that stripped assets and abandoned toxic waste, and witnesses to an ongoing form of structural violence.

The unregulated disposal of industrial waste at HAK is not a mere afterthought of privatization but an ongoing, deliberate act of neglect. As the legacy of socialist Yugoslavia’s industrial strength was dismantled, factories were sold to international private owners who then stripped the factories of assets and left the hazardous byproducts behind. Toxic landscape now harms local communities. This environmental degradation is not accidental. It is part of a broader strategy of violence executed by the ethno-capitalist elites, whose power has been built on both the spoils of war and the systematic exploitation of natural and human resources.

On March 9, 2019, a fire broke out in the privatized “Energetika” building of the former Incel pulp and paper mill in Banja Luka, Bosnia and Herzegovina, unleashing a torrent of carcinogenic polychlorinated biphenyls (PCBs) into the environment. Established in 1954, Incel once employed over 6,100 workers but became a shadow of its former self following the tumultuous privatization after the 1992-1995 war. Hazardous materials lingered untreated, posing grave risks to both the ecosystem and public health. Following the incident, authorities analyzed soil contamination, yet they failed to disclose the severity of the pollution. Reports emerged that PCB levels exceeded permissible limits by an alarming 33,000 times, casting doubt on the safety of surrounding areas, including the Vrbas River. Despite growing public concern and a 2023 criminal complaint filed by the Center for the Environment regarding illegal soil dumping, the government's inaction persisted. Residents from nearby communities reported hazardous soil waste dumped illegally, linked to the Incel site (Momić 2023). These events illustrate a broader narrative of environmental violence, where the remnants of industrial negligence intersect with a failure of governance, leaving communities vulnerable to the long-term effects of toxic contamination.

The cases of Aldin Bejhanović and the Incel industrial complex reveal two distinct, yet interconnected manifestations of toxic violence in post-industrial Bosnia and Herzegovina. Both illustrate the long-term consequences of industrial destruction and neglect caused by privatization, where toxic waste and contamination directly affect the health and lives of local communities. Bejhanović's experience is more personal and immediate, involving direct exposure to toxic waste while scavenging scrap metal at the abandoned HAK factory. His story highlights the acute and physical toll of exposure, leading to serious health conditions like his pulmonary embolism, as well as the death of his uncle. The Incel incident in Banja Luka reflects a broader, more systemic form of environmental violence. The release of carcinogenic PCBs after a fire at the former industrial site, compounded by the government's failure to address the contamination, represents a large-scale ecological disaster that affects entire communities, though its impact is slower and less immediately visible. While Bejhanović's poisoning is a symptom of how poverty and neglect are produced and maintained in Bosnia and Herzegovina, the Incel disaster exposes the wider, structural failures of governance and accountability in managing post-industrial toxic legacies. Both cases, however, underscore the shared reality of slow violence and environmental injustice, where human bodies and environments are left vulnerable and prey to the toxicity of industrial and political neglect.

Contextual Debates

To fully grasp ecological disasters and incidents in the post-Yugoslav states, it is essential to recognize that these events are not mere "accidents" but manifestations of a deliberate strategy of protracted violence led by ethnic authoritarian elites. This violence ranges from the appropriation of vast land tracts through the calculated placement of landmines to the exploitation of natural resources as spoils of war. A striking example is the decision by "the Croat Republic Herceg-Bosna," a wartime ethno-capitalist fiefdom, to lease Buško Jezero to Croatia for the Orlovac hydroelectric plant (Obrenović and Smajlović 2018). Another disturbing example is the unsafe disposal of toxic industrial waste from privatized and dismantled factories, which is hidden and buried in unknown locations or simply left in the skeletons of former factories. These actions reveal a continuation of wartime logic, extending long after the war is over.

The UN Environment Programme (UNEP) ranks Bosnia and Herzegovina as the second deadliest country in the world in terms of air pollution-related deaths per capita (UNEP 2018). The cities of Tuzla and Zenica, both heavily polluted by coal-fired power plants, report alarming rates of cancer. In Zenica, sulfur dioxide ($SO2$) emissions were recorded as exceeding legal limits by 166 times in 2015 (Geoghegan and Ahmetasevic 2017). Tuzla's Thermal Power Plant is among the ten largest polluters in Europe (Unmask My City n.d.). The economic toll is also severe, with air pollution costing Bosnia and Herzegovina 21.5% of its GDP annually (UNEP 2018). The European Environment Agency (EEA) presents even more sobering data: its 2020 air quality report estimates that a staggering 60,500 years of life are lost annually in Bosnia and Herzegovina due to air pollution (EEA 2020, 109).

Environmental violence, in its various forms, involves both immediate and long-term damage to ecosystems and human and more-than-human lives. While some forms of violence, such as the exploitation of natural resources or large-scale pollution, are visibly destructive and immediate, others unfold slowly and out of sight. The concept of environmental violence includes what is referred to as "waste colonialism," a practice whereby affluent nations externalize their toxic waste to impoverished countries. Initially recognized by the United Nations Environment Programme's Basel Convention (Porter, Brown, & Chasek, 2000, p. 105), waste colonialism highlights the global inequalities that perpetuate environmental exploitation.

However, this narrow understanding of waste colonialism requires expansion, particularly when applied to contemporary deindustrialized contexts like Bosnia and Herzegovina. Here, the aftermath of deindustrialization and neoliberal capitalist exploitation has left communities grappling with both environmental and economic degradation. Factories are stripped of assets, capital is removed, and toxic legacies—both material and symbolic—are left behind. The logic of neoliberal capitalism, with its reliance on "ambiguity, illusion, evasiveness, trickery, collusion, and guile" (Hoggett, 2013, pp. 60, 68), not only accelerates environmental violence but also conceals it, making the victims of such a system appear complicit in their own suffering. In the context of Bosnia and Herzegovina, this only amplifies social trauma that is lived in our society (Arsenijević 2021).

Environmental Violence

The concept of slow violence, introduced by Rob Nixon (2011, p. 2), is crucial to understanding environmental violence that is less perceptible yet deeply destructive. Nixon describes slow violence as "a violence of delayed destruction that is dispersed across time and space," often unrecognized as violence at all. This slow, cumulative violence is evident in Bosnia and Herzegovina, where the remnants of war—including landmines, hidden mass graves, and toxic waste from the privatization of factories—continue to inflict harm on the population long after the war has officially ended.

Environmental violence is a core component of the ethnic authoritarian strategy, lingering long after active military conflict has ended. It is deliberately maintained as a persistent threat to large parts of the population, weaponizing nature and creating an enduring sense of dread about looming, uncontrollable disasters. When major ecological crises arise, they are often blamed on "nature," "chemicals," or "toxic waste." This is depoliticization at its most obvious, as causes of such violence are obscured. Meanwhile, the slow, insidious effects of abandoned and unsafely managed or scattered industrial waste transform contaminated sites into chilling symbols of fear, masking the true sources of harm.

This type of environmental violence benefits ethnic authoritarian elites by exploiting nature to reinforce their power, presenting a grim spectacle of ongoing human sacrifice to fate. Its impacts are visible in the disposability of populations: in communities where childhood cancer rates spike, scrap metal pickers breathe in toxic chlorine at abandoned industrial sites, impoverished farmers irrigate crops with polluted water, and civilians unknowingly wander into areas still littered with landmines.

In post-war Bosnia, the logic of disposability that governs neoliberal capitalism has permeated the social fabric, leaving behind a population deemed expendable. This form of environmental violence sediments over time, manifesting through invisible injuries and deaths that remain unrecorded and unacknowledged. At this level of normalized human disposability, one might ask: how can politicians remain indifferent, and why do not people resist? To start answering this, we should view it as an organized disavowal at the societal level. This disavowal reflects a cynical stance, encapsulated in the formula: “I know very well this is happening, but…”, which aligns seamlessly with the perverse logic of neoliberal capitalism. Unlike simple denial, disavowal represents a structured and systematic way of avoiding the anxiety associated with confronting loss.

As Weintrobe (2013, p. 7) argues, the disavowal of such realities enables societal complicity, where “the more reality is systematically avoided...the greater is the need to defend with further disavowal.” Thus, environmental violence persists, not through immediate destruction but through the slow, corrosive effects of neglect, disempowerment, and systemic inequality. Thus, the entire country has become a shrine to daily sacrificial rituals. Deaths—whether swift or slow—resulting from environmental violence have become a normalized post-war reality. People unwittingly offer up their lives, while ethnic elites, playing the role of high priests, continue to demand further sacrifice. These elites maintain control over time and space, deciding when enough lives have been taken. This tragic narrative operates in the realms of myth and destiny, where individual subjectivity has no room to exist.

Waste Colonialism and the Wasteocene

Waste colonialism functions both globally and locally, redistributing environmental harms to marginalized communities while profiting affluent nations and elites. In Bosnia and Herzegovina, the toxic legacies left behind by neoliberal economic policies and the ethno-capitalist elites align with this broader framework of waste colonialism. Factories, once the lifeblood of communities, are privatized, stripped of value, and left as sites of environmental ruin. These processes mirror the historical dynamics of waste colonialism, where the burden of environmental degradation is shifted onto the most vulnerable.

This dynamic can be understood through the concept of the “Wasteocene,” a term introduced by Marco Armiero to describe the socio-ecological relations that produce “wasted people and wasted places” (Armiero, 2021, p. 24). In this framework, waste is not merely a material byproduct but a socio-political phenomenon, whereby certain populations are systematically rendered disposable. The Wasteocene, as Armiero and De Angelis (2017, p. 348) argue, involves “the making of collective identities out of struggles, building on the embodied experience of capitalist violence.” In Bosnia and Herzegovina, this capitalist violence is evident in both the environmental degradation of post-industrial spaces and the dehumanizing narratives that frame people as expendable.

Within the expansive array of “-cenes” as heuristic frameworks prevalent in academia and activism, such as the Anthropocene and Capitalocene, the Wasteocene serves as a dual function: a characterization of the contemporary state of life under capitalism and a heuristic tool employed for its analysis. In contrast to approaches that lament the omnipresence of waste or nostalgically yearn for an idealized environmental purity, the Wasteocene functions as the analytical frame that facilitate the examination of how capitalist ecologies enforce abstract forms of domination.

The concept of the Wasteocene offers a powerful framework for understanding the socio-political and ecological violence embedded in waste regimes. According to Armiero (2021, p. 24), the Wasteocene is not merely about waste as a material entity; rather, it is about the processes of sorting, classifying, and displacing value, determining which lives and landscapes are deemed disposable. As Armiero explains, the Wasteocene thrives on the creation of "toxic narratives," where environmental harms are concealed, naturalized, and the victims are blamed for their own suffering.

Armiero's analysis provides a compelling critique of the mechanisms that uphold the Wasteocene. First, he argues, there is the need to conceal the true extent of environmental violence, making disasters and slow degradation disappear from collective memory. This is followed by the normalization of injustice, where harm is depoliticized, and sorrow is encouraged over outrage. In this way, narratives that challenge the status quo are dismissed, and those who resist are marginalized. Finally, the victims of the Wasteocene are blamed for their plight, reinforcing the idea that waste is an ontological reality rather than the product of unequal socio-ecological relations.

The Wasteocene brings back contingency into this seeming necessity and speaks of the formation of a revolutionary project that "encompasses the making of collective identities out of struggles, building on the embodied experience of capitalist violence" and the constitution of a revolutionary subject in "the making and experience of the Wasteocene, in an antagonistic relationship with the forces that create it" (Armiero & De Angelis, 2017, p. 348). As Armiero argues:

> *To brew the perfect toxic narrative, the first ingredient is concealing; the overspilling of the Wasteocene logic – whether it is a dam disaster or the slow violence of industrial production – has to disappear from the collective memory. The second ingredient is naturalizing/normalizing injustice: if something bad occurs, it is nobody's fault. Sorrow, not outrage, is the right sentiment. Thirdly, it is vital to dismiss any kind of knowledge and experience, which may prove that other points of view existed; this is what always happens to those who try to denounce toxicity while resisting the wasting relationships that render them disposable. Finally, the ultimate result of a toxic narrative is to blame the victims; if one is on the wrong side of the Wasteocene line, it must be their fault. Waste is an ontological quality and not the product of unjust socio-ecological relationships – this is the main message of any toxic narrative. And it is against it that any counter-narrative must rise up. (Armiero, 2021, p. 24)*

The argument for constructing counter-narratives forms the basis for a genuine political response to the wasting perpetuated by the authoritarian ethnic elites in Bosnia and Herzegovina. Attending to the concealed timescale of slow violence requires acknowledging the existence of untold testimonies of its effects. Recognizing these testimonies is the first step in creating spaces where people, their families, and their stories can finally be heard. This approach is essential to challenging the ongoing, often overlooked maintenance of toxic narratives. Such toxic narratives are evident in the case of Bosnia and Herzegovina, where the remnants of war and privatization—landmines, hidden toxic waste, and ruined factories—are seen not as the products of capitalist exploitation but as unfortunate byproducts of progress. The victims of this environmental violence are left without a voice, their stories concealed by a system that thrives on their disposability.

However, the Wasteocene also offers a site of resistance. Armiero (2021, p.12) emphasizes that “the bodily experience of the Wasteocene has also produced resisting subjects.” These subjects challenge the social relationships that enforce their disposability, transforming their disposable bodies into political bodies. In Bosnia, this means reclaiming the narratives of slow violence, bringing to light the hidden injuries and deaths caused by environmental harm. As Nixon (2011, p. 6) argues, “chemical and radiological violence, for example, is driven inward, somatized into cellular dramas of mutation that—particularly in the bodies of the poor—remain largely unobserved, undiagnosed, and untreated. From a narrative perspective, such invisible, mutagenic theater is slow paced and open ended, eluding the tidy closure, the containment, imposed by the visual orthodoxies of victory and defeat.” Yet it is through the recognition of these invisible harms that new political possibilities can emerge.

The Wasteocene framework challenges the notion of time as linear and progressive. In Bosnia and Herzegovina, time is perceived as frozen, with the population suspended between a war that has not fully ended and a future that has yet to begin. This “meantime,” as Jansen (2014, p. 90) describes it, is characterized by an endless loop of depoliticization, where the transition to capitalism appears perpetual and unachievable.

In such a context, the struggle for political time becomes paramount. Armiero (2021, p. 12) argues that by entering the bodies and ecologies of human and more-than-human lives, “wasting politicizes bodies and ecologies,” transforming the struggle for survival into a form of insurrection against the social relationships that define the boundaries of the Wasteocene. By reclaiming the narratives of slow violence, the people of Bosnia and Herzegovina can challenge the depoliticization that renders their suffering invisible, bringing their stories and experiences into the public sphere. Thus, the struggle for political time is first and foremost the struggle for air time, the chance to articulate and resist the forces that seek to silence them.

The Wasteocene, therefore, is not just an analytical framework for understanding environmental harm but also a call to action, a reminder that the political struggle for survival is deeply intertwined with the fight against the socio-ecological relations that perpetuate disposability. By exposing and resisting these forces, marginalized communities can reclaim their place as political subjects, challenging the very foundations of the Wasteocene.

Environmental Humanities in Bosnia and Herzegovina: challenging environmental violence

Zemlja-Voda-Zrak is a digital platform I launched in 2019 to establish and promote environmental humanities in Bosnia and Herzegovina. It focuses on the fundamentals: earth, water, and air—our limited resources. This approach challenges the ethnic authoritarian imperatives of limitless extraction of human labor and natural resources. The platform confronts the logic of wasting by fostering collective community practices and counter-toxic narratives that emphasize the lived experience of environmental violence. Its goal is to expose and expand the fault lines within power structures that sustain the Wasteocene logic. Environmental crises are framed as the outcome of social and economic inequalities perpetuated by ethnic authoritarian elites who prioritize profit by extracting natural resources at the expense of human and ecological life.

Zemlja-Voda-Zrak merges arts, activism, and academia, fostering creative collaborations between activist organizations, scientific research, and artistic practices for the protection, conservation, and enhancement of the environment (zemljavodazrak.com). The platform draws lessons from the 2014 Protests and Plenums in Bosnia and Herzegovina, uniting artists, activists, and academics (Arsenijević 2014).

The reconstruction of communities is deeply interwoven with artistic and activist interventions, essential for repoliticizing the situation. Zemlja-Voda-Zrak focuses on what has been neglected, destroyed, or weakened by authoritarian ethnic elites, including our collective capacity to envision and demand inclusive justice and societal transformation. Through community rebuilding, we highlight overlooked forms of life, emerging subjectivities, and those actively resisting the violence of the Wasteocene. By valuing, protecting, and cultivating these elements through artistic and activist interventions, we aim to empower our communities to break free from the logic of wasting and the anti-social will to power.

At the core of resisting environmental violence is the concept of survivance (Hodžić 2023), which transcends the victimization of Bosnian citizens since the war's onset in 1992. This survivance is embodied by the women of Kruščica, a village near Vitez, Bosnia and Herzegovina, who successfully opposed the construction of two mini-hydropower plants threatening the river Kruščica and its ecosystem. Their statement, "our rivers connect us," reflects a deep awareness of interconnection through shared natural habitats and emphasizes a solidarity that transcends the identity politics upon which ethnic authoritarian elites rely. This form of interconnection, promoting solidarity beyond ethnic divides, faced violent resistance from police forces in Kruščica. What emerged was not mere anger but a politically productive and emancipatory form of resistance advocating for social well-being and care for all.

This struggle challenges neocolonial initiatives, from international transitional justice efforts to local projects backed by ethnic authoritarian elites (Arsenijević, 2023). In such neocolonial scenarios, the women of Kruščica would be reduced to sacrificial figures, the river destroyed, and the village left with a monument and a day of commemoration. This reflects the broader situation in Bosnia and Herzegovina, where individual lives are acknowledged through commemorative events, with victims allowed to speak but confined to this role. Violently, lives are either sacrificed, or natural resources are extracted, leaving surviving community members entangled in long legal battles. Eventually, the community might receive a commemorative plaque and a substantial legal bill. This represents contemporary justice in its liberal democratic form.

In contrast, survivance illuminates the critical need to resist, both violently and non-violently, the extractivist enclosures of natural resources and the disposability of marginalized populations, while actively caring for human and more-than-human life.

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Part II
Interactive Learning: Workshops on Climate Change and Air Pollution

Stakeholder Impact Analysis in Nature Conservation and Climate Change: Using the Interest-Power Grid

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Abstract: Protected areas are highly significant instruments for nature conservation and biodiversity preservation. They play a crucial role not only in maintaining biodiversity but also in providing essential ecosystem services. These areas secure sources of drinking water, contribute to climate regulation, and help reduce the risks of floods and landslides, as well as absorb CO_2, which actively supports climate change mitigation and adaptation. However, the process of establishing protected areas is often lengthy and requires the support of various stakeholders. In the context of Bosnia and Herzegovina, the process of advocating for and designating a protected area can take over 10 years. One of the primary reasons for this delay is the complex administrative and geographical jurisdiction of most proposed protected areas. In this proces collaborative multi-stakeholder approach is essential, but frequently fail when there isn't enough effort put into identifying and involving stakeholders with the appropriate profiles for the issue in question. For that matter, stakeholder analysis is increasingly utilized. Engaging stakeholders at the very beginning of the process can help expedite and facilitate the overall process. There are various techniques and analyses for determining the impact of stakeholders on nature conservacy and climate change projects, and this paper examines the stakeholder impact analysis technique using the power-interest grid.

Keywords: Protected areas, climate change, stakeholder analysis

1. INTRODUCTION

According to the International Union for Conservation of Nature (IUCN), nature conservation encompasses all appropriate activities and measures aimed at preventing harmful activities, damage, or pollution of nature, reducing or eliminating existing damage, and restoring nature to its original state (IUCN, 2008). A protected area is a clearly defined geographical space with an established purpose (goal) that is protected and managed by legal or other effective means, with the aim of long-term conservation of nature and associated ecosystem services as well as cultural values (IUCN, 2008).

Globally, there are approximately 270,361 protected areas covering an area of 19.8 million km², which represents 15.73% of the Earth's surface. These areas play a key role in preserving biodiversity, providing ecosystem services, and maintaining cultural values.

Protected Areas in Bosnia and Herzegovina

Bosnia and Herzegovina (BiH) spans approximately 51,209 km² and contains various protected areas, including national parks, protected landscapes, and natural monuments. However, only about 3.13% of the country's territory is protected, which is far below the AICHI Target 11, which called for the protection of 17% of terrestrial and 10% of marine areas by 2020. The new target being pursued is the protection of 30% by 2030, in line with the Green Agenda for the Western Balkans.

Despite the low coverage, protected areas in BiH are rich in biodiversity and natural beauty. According to the IUCN classification, BiH has 48 protected areas: 14 in the Federation of Bosnia and Herzegovina and 34 in the Republika Srpska. In 2024, new protected areas were declared in BiH: the "Starača" Protected Landscape, covering 424.4 hectares, and the "Tišina" Protected Landscape, covering 471.91 hectares.

The legal process of protecting natural areas in BiH involves a series of steps that ensure the establishment, management, and conservation of these areas. BiH has a complex and fragmented institutional structure, with multiple levels of government (state, entity, cantonal, and municipal) responsible for environmental protection. Protected areas in BiH are defined by entity laws, with precisely defined geographical locations, legally recognized, and intended for the long-term conservation of natural and cultural values. This structure complicates the establishment of protected areas, reducing the efficiency and potential for achieving legal protection and long-term conservation of significant areas. The main laws governing nature protection and protected areas in BiH include the Nature Protection Law of the Federation of BiH (Sl. novine FBiH, br. 66/13)), the Nature Protection Law of the Republic of Srpska (Sl. glasnik RS, br. 20/14), and the Nature Protection Law of the Brčko District (Sl. glasnik Brčko Distrikta BiH, broj 24/04). The establishment of protected areas in FBiH and RS depends on the administrative level of the territory where the area is located. In FBiH, areas within a single canton are declared protected by the cantonal assembly, while areas spanning multiple cantons are designated by the Federation Parliament with the agreement of the relevant cantonal legislatures. In RS, national parks are proclaimed by the National Assembly, whereas the RS Government can declare other forms of protected areas such as nature reserves, protected habitats, protected landscapes and etc., based upon the proposal of the authoritative environmental ministry (Ministry of Spatial Planning, Construction, and Ecology) and prior consultation with other relevant ministries. At the local level, a municipality's council/assembly can declare a protected natural monument or a sustainable use area with the approval of the Ministry of Spatial Planning, Construction, and Ecology.

Each declaration requires a Expert Study/Justification, which includes assessing natural values, management methods, and funding sources for protective measures. Declarations are published in official gazettes, and the areas are registered as protected natural values. The complexity of administrative procedures, including the need for municipal council approvals, often presents significant obstacles to establishing new protected areas in BiH, prolonging the process and reducing the effectiveness of natural resource protection (Zečić et al., 2021). Protected areas in BiH play a vital role in preserving the country's natural heritage, promoting sustainable tourism, and supporting scientific research. These areas provide essential ecosystem services, including climate regulation, water resource protection, soil conservation, and erosion prevention, and they serve as important habitats for many plant and animal species. With increased efforts to expand the network of protected areas and improve the management of these areas, BiH can significantly contribute to global nature conservation and sustainable development goals.

The role of protected areas in climate change mitigation and air quality

Protected areas provide enormous benefits to people through ecosystem services. These services can be categorized into four types: provisioning services, regulating services, cultural services, and supporting services. Essentially, these include services such as pollination, food production, air purification, recreational activities, mental health benefits, and more (Mestanza-Ramón, et al. 2023; Terraube, et al. 2017). Unlike protected areas, urban environments tend to have poorer air quality, higher temperatures in areas lacking sufficient greenery, and pollution from light and noise, all of which contribute to environmental stress. There are also assumptions that the lack of biodiversity in urban areas contributes to the global increase in allergies and chronic inflammatory diseases in humans. The ecosystem services derived from preserved biodiversity can serve as a buffer against environmental stress, particularly in the context of climate change. The diversity of habitats and biodiversity in urban areas directly contributes to improving air quality, as well as regulating climate, specifically by reducing the urban heat island effect (Cook, et al. 2019). In the context of international policies, the UN Sustainable Development Goals (SDGs), decisions under the United Nations Framework Convention on Climate Change (UNFCCC), and the Convention on Biological Diversity (CBD) emphasize the contribution of habitat protection in the processes of climate change mitigation (Terraube, et al. 2017). Protected areas, especially forests, reduce greenhouse gas emissions through carbon storage and sequestration. Estimates suggest that protected areas store 238 Pg C, or about 12% of land carbon stocks. Of this total, 92 Pg C is in vegetation and 146 Pg C is in soil (Melillo et al. 2016). Given that protected areas are still subject to the impacts of air pollution and climate change, recent studies have questioned their effectiveness and the possibility of maintaining their values in a climate-driven shifting environments. One study has shown that, although protected areas are also facing biodiversity decline and loss, with adequate management and governance, they can slow down species loss caused by climate change and maintain significant biodiversity despite these challenges. The behavior of species in response to ecosystem changes within protected areas indicates that they remain vital for maintaining biodiversity, and expantion of the network of protected areas can help mitigating climate change (Gillingham et al., 2024; Thomas & Gillingham, 2015, Duncanson, et al. 2023).

Stakeholder analysis and power-interest grid

Stakeholders are individuals and organizations involved in or affected by a particular action or policy, with varying interests and influence on decision-making. In the context of environmental protection, their inclusion is crucial due to the diverse perspectives they bring, ranging from government agencies to local communities. This diversity often creates complexity in environmental protection processes (Vogler, et al. 2017)(Fig. 1).

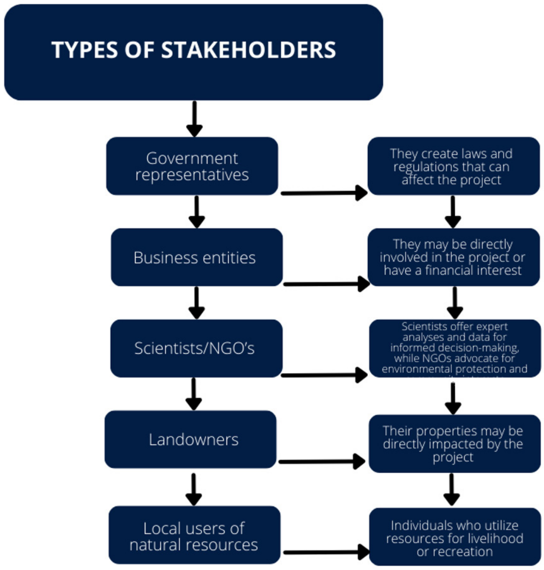

Figure 1: Diversity of stakeholders in environmental protection

Stakeholder analysis is a set of various techniques and tools used to gain insight into the relevance of stakeholders, their characteristics, interconnections, and their impact on a particular issue. Stakeholder analysis first appeared in business management in the 1980s, but it is now a popular tool used in other fields, with its importance recognized in advocacy processes, nature conservation, and the sustainable use of ecosystem services. Since it is used in different disciplines, this has required the development of various approaches and methods for stakeholder analysis. Even within the same discipline, combinations of different techniques are used to contribute to the specific situation, project, or advocacy process. The selection of techniques used in stakeholder analysis mostly depends on two factors: the complexity of the challenge being discussed and the reasons for involving stakeholders. For the analysis to be successful, it is necessary to determine these two factors in the early stages of project development, advocacy processes, etc (Weperen, 2013; Vogler, et al. 2017).

In the processes of advocating for the establishment of protected areas, biodiversity conservation, or climate change mitigation and adaptation projects, using a power-interest grid proves to be a useful tool. To prepare an effective grid, it is helpful to conduct a *stakeholder power analysis* beforehand (Mayers, 2005). A simple and effective three-step process can be followed for this purpose.

The first step is to **identify and understand stakeholders**. Clarifying the purpose and procedures of the analysis ensures a solid grasp of the system or project in question. This involves identifying and investigating all key stakeholders who have a vested interest or influence in the system, their interests, characteristics, and circumstances, which helps to understand their perspectives, goals, and potential impact on the system.

The next step is to **analyze stakeholder interactions and influence**. This involves examining the patterns, contexts, and dynamics of their interactions that shape their influence on the system. Assess each stakeholder's power, influence, and potential roles within the system, considering factors such as their resources, expertise, and level of engagement, which helps in mapping out the power dynamics and understanding potential collaborations or conflicts.

The final step is to **synthesize findings and strategize engagement**. With a clear understanding of stakeholders and their influence, the findings can be used to assess possible options and strategies for stakeholder engagement. During this step, action plans can be developed that leverage stakeholders' power and roles to advance the system's goals, mitigate risks, and foster collaboration, ensuring that the insights from the analysis are translated into practical strategies that drive progress and achieve desired outcomes.

To visualize and simplify this data, a **stakeholder grid power-influence** can be used. It consists of a simple representation of relative influence on one axis and the level of interest (positive/negative) on the other, where identified stakeholders are placed (as seen in Figure 2). This approach makes it easier to see which stakeholders, perhaps unexpectedly, share common interests and positions, allowing them to collaborate in advocating for a shared stance (Mayers, 2005; Vogler, et al. 2017).

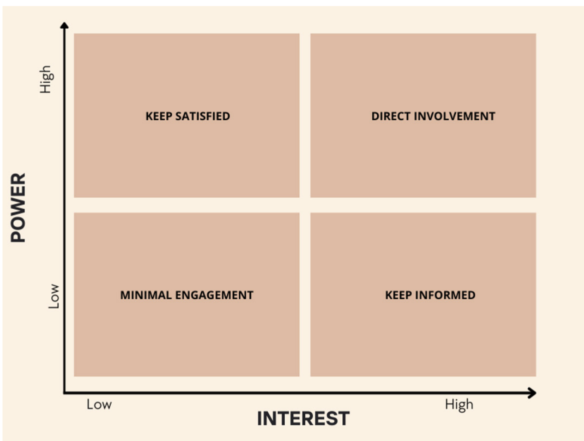

Figure 2: Example of power-interest grid

Benefits of stakeholder analysis and engagement

Stakeholder analyses conducted early in nature conservancy projects and initiatives can facilitate and accelerate the entire process, achieving more lasting sustainability for the project. This is particularly important when there is a complicated governing structure within the country and there are numerous stakeholders with significant power who can slow down or halt the process. In the context of BiH, most initiatives for establishing protections, addressing climate change, and sustainable resource use require active engagement and support from various stakeholders, ranging from local communities and municipal/cantonal councils to entity and state authorities. Therefore, it is crucial to employ stakeholder analysis techniques and ensure timely, active, and evenly distributed stakeholder involvement and success of the initiatives.

In a broader context, stakeholder analysis provides several key benefits that are crucial for the success and sustainability of projects and initiatives. Firstly, it enhances decision-making by incorporating diverse perspectives, ensuring that decisions are well-rounded and they consider the needs and concerns of all relevant parties. This inclusive approach reduces the likelihood of conflicts, as stakeholders involved from the beggining are more likely to support and comply with decisions, having had the opportunity to contribute to the process. This also implies that involved stakeholders foster a sense of ownership. When stakeholders engage in the planning and decision-making process, they are more likely to feel responsible for the outcomes, leading to greater commitment and adherence to agreed-upon actions. This ownership is vital for the long-term sustainability of initiatives, as stakeholders invested in the process are more likely to ensure its success over time.

An important aspect of stakeholder analysis and engagement is that it promotes equity in decision-making. By ensuring that all voices are heard, it helps to balance power dynamics and provides a platform for marginalized groups to influence decisions that affect their lives. This inclusive approach not only fosters fairness but also aids in identifying and resolving potential conflicts, making the implementation of decisions more effective and just. In the long run, it is a more cost-effective way to ensure a project's long-term success. While stakeholder engagement may take longer than traditional top-down approaches, it often proves to be more cost-effective in the long run. The continuous process of engaging stakeholders allows for the testing and adjustment of ideas before they are adopted, leading to more sustainable and resilient solutions (Conde & Lonsdale, 2005).

CONCLUSION

Stakeholder analysis and the use of the power-interest grid can significantly facilitate and accelerate the process of developing new policies for climate change mitigation and adaptation, the establishment of protected areas, and initiatives for improving air quality. While there are numerous techniques for effective stakeholder analysis, the power-interest grid visually and simply illustrates the potential impact of each stakeholder on the process. This grid can aid in the development of engagement strategies, showing which stakeholders need to be kept directly involved, satisfied, informed, and minimally engaged. In the context of Bosnia and Herzegovina, this approach can contribute to more efficient resource management and environmental conservation.

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Workshop as a tool to raise awareness of the need for a Multidisciplinary Approach to Climate Change Issues

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Abstract: This paper explores the effectiveness of workshops as tools for raising awareness about the need for a multidisciplinary approach to address climate change. The focus is on three key sectors in Bosnia and Herzegovina —energy, transport, and forestry—each of which plays a crucial role in climate dynamics. The energy sector, heavily reliant on coal, remains a significant contributor to both local pollution and global greenhouse gas emissions. The transport sector faces challenges related to outdated infrastructure and vehicle emissions, while the forestry sector struggles to adapt to climate extremes exacerbated by global warming. Through participatory engagement, workshop attendees, primarily young people preparing for their entry into the labor market, explored sector-specific solutions and policies to mitigate and adapt to climate challenges. The findings emphasize the importance of cross-disciplinary collaboration among experts from environmental science, engineering, economics and policy making to achieve long-term sustainable outcomes. The role of young professionals in this process is highlighted as essential for driving future initiatives in combating climate change.

Keywords: Multidisciplinary Approach, Climate Change, Sustainability, Energy Efficiency, Youth Engagement.

1. BACKGROUND OF THE THREE SECTORS IN BOSNIA AND HERZEGOVINA

Three main sectors that are in the focus of this raising awareness workshop concept are the energy sector, transport sector and the forestry sector. The energy sector in Bosnia and Herzegovina (BiH) relies on several key energy sources that have a significant impact on climate change, including coal-fired power plants, hydropower plants and renewable energy sources. Those coal-fired power plants which are currently operating have usually outdated technologies that emit large quantities of pollutants and greenhouse gases, contributing to local air pollution and global warming, respectively. Hydropower plants are also an important source of electricity generation in BiH, but their construction can have a significant environmental impact, including changes in river water levels and ecosystems. There is potential for the development of renewable energy sources such as wind power, solar energy, and biomass. However, their share in total energy generation mix is still relatively small. The energy sector in BiH has a significant negative impact on climate change due to the high share of fossil fuels in the energy mix, particularly coal.[1] However, as a developing country, BiH lacks the capacity and organizational ability to address complex issues like climate change. [2] Given the multifaceted nature of these challenges ranging from outdated infrastructure and environmental degradation to elconomic and social implications, it has become evident that a multidisciplinary approach is essential. This approach must involve the collaboration of various stakeholders, including governmental bodies, private sector entities, environmental organizations, and scientific experts with diverse backgrounds, in order to develop sustainable solutions. By integrating expertise from areas such as environmental science, energy policy, economics, and technology, BiH can better tackle the complexities of climate change and implement effective strategies for a low-carbon future.

The road network in BiH is among the less developed in Europe, which is clearly evident from the road network density data of 45 km/100 km², or 5.7 km/1000 inhabitants, which is 2.5–4 times smaller than in Western European countries. Currently, there are no significant programs or projects in BiH focusing on reducing emissions in the transport sector. However, state and entity-level legislation in BiH in the field of transport (e.g., the Law on Basic Traffic Safety on Roads in BiH and other laws) and environmental protection (laws on air protection and accompanying secondary legislation) define frameworks for the import, purchase, and registration of motor vehicles, homologation, fuel quality, mandatory annual inspections of motor vehicles, and impose obligations on relevant authorities to prevent vehicle owners from registering vehicles that exceed certain emission limits. Additionally, in the Federation of BiH (FBiH), motor vehicle owners are required to pay a special fee during vehicle registration or technical inspection, depending on the type of engine, fuel type, engine displacement, and the age of the vehicle. The same mechanism is expected to be introduced in the Republic of Srpska (RS) at the beginning of 2016. These activities directly and indirectly contribute to reducing CO_2 emissions in the transport sector. It is anticipated that the further and somewhat intensified application of EU directives related to emission reductions, more efficient motor vehicles, and fuel quality in the transportation sector in BiH will contribute to emission reductions. The activities of regular maintenance and the construction of new transportation infrastructure are carried out by the relevant institutions.[3]

As a consequence of global warming, climate extremes are expected to occur more frequently, threatening the functioning of forest ecosystems. The high genetic diversity of certain species, and therefore the potential for varying levels of tolerance to climate change, highlights specific species that are prioritized in terms of adaptive capacity. However, it is necessary to assess the response of different species and their provenances to climate extremes and to identify appropriate populations or ecotypes that are better adapted to projected climate changes. The state of the forestry sector in BiH shows that climate change is recognized in strategic documents, but concrete measures and adaptations in practice are still lacking. The Forestry Development Strategy of the Republic of Srpska (RS) for the period 2012-2020 and the Forest Genetic Resources Conservation Program 2013-2025 emphasize the importance of climate change and the need for biodiversity conservation. However, no significant changes have occurred in the forestry sector, and measures such as increased afforestation and protection from fires, diseases, and pests are still insufficiently implemented. The 2011 study "Forests and Climate Change" as well as national reports point to the need to strengthen capacities and adopt additional strategic documents to ensure that forests in BiH are adequately recognized as a key factor in mitigating the effects of climate change. Currently, the sectoral strategy in this area is moving very slowly and does not assign sufficient importance to forests in the context of climate change.[3]

2. METHODOLOGY

Awareness-raising workshops, in which participants deeply engage with topics related to critical social issues, have successfully demonstrated their capacity to motivate and change the participants' attitudes. [4] The target group of the workshop consisted of around 20 young people which are mostly enrolled in the final year of their studies, who will soon be ready for the labor market. The challenge was to bring them closer what their potential role in influencing climate change issues can be and the how the capacity they possess can be the source of new initiatives. With this goal in mind, the workshop participants were divided into three sectors. One group represented the energy sector, another the transport sector, while the third group belonged to the forestry sector. Within each sector, the members were required to assign the following expertises, including technical experts (engineers), financial experts and decision makers. Once each sector designated its group of experts, they were tasked with the following:

- Analyze, assess and review the current state of their sector in BiH in terms of its impact on climate change, the environment, human health and biodiversity.
- Propose adaptation and mitigation measures for climate change that can be implemented in their sector based on the expertise their team possesses.

Technical experts have the knowledge and competencies to analyze the current technological development of their sector. Using cartographic representations of BiH, the energy sector group can identify areas where they can take action by proposing technological innovations and solutions to mitigate the effects of climate change, such as droughts, heatwaves, floods, and similar events. The technical experts should explain why they propose the implementation of a particular energy source for specific regions and how its implementation contributes to the goals of sustainability, energy efficiency, and environmental protection. This should not be seen as a limitation but rather as a guideline, so an innovative approach from each area of expertise is encouraged.

The task of financial experts is to create a financial plan that will support the further development of the sector within the borders of BiH. Financial experts need to create various investment plans, analyze different ways of financing projects, and develop a plan for the allocation of funds. They need to identify key projects and initiatives that will be important for improving the sector in which they operate, including the construction of new facilities, modernization of existing infrastructures, research and development of new technologies, as well as programs to improve efficiency. They have to analyze different ways of financing projects and create a fund allocation plan that will ensure the efficient use of available resources and optimize return on investment. The following financing methods were introduced so that they can be used while creating financial proposals. Among them are self-financing, loans, public financing (which includes funding through public funds, subsidies, or grants provided by governments at various levels (local, regional, national) or by international organizations), private financing (which may include investments from private investors, corporations, or private equity funds and crowdfunding model which involves raising financial resources from a large number of people through online platforms, donations in exchange for certain types of rewards, vouchers, etc).

Decision makers are responsible for creating key policies and the legislative framework that will shape a sector within the state of BiH in the coming years. Additionally, decision makers need to develop a strategy for the long-term development of the sector they are operating at, setting clear goals for the next 20 years. For example, decision makers can review all laws that regulate the functioning, assess which are adequate, suggest which should be amended and propose new ones to adopt. In the policy proposals, the focus should be on the laws, regulations, and decisions that can be enact, as well as measures that will promote sustainability, efficiency, and diversification of energy sources in BiH. Also, your long-term development strategy should include clear goals and guidelines for the development of the sector where the financial plan is taking place over the next 20 years. For example, in the energy sector, this might include setting targets for the share of various energy sources in total consumption, emission reduction goals, improving energy efficiency and similar initiatives.[5]

3. RESULTS

The workshop took place in a positive atmosphere, with an interactive approach and highly motivated participants. Each group brought its own unique touch, opinions and perspectives, further shaped by their participation in the summer school program. Participants in the energy sector proposed a transition from coal to renewable energy sources, focusing on wind, solar, and biomass, while emphasizing the need for technological innovation and financial investment. They highlighted that natural gas in BiH is an efficient transition fuel, and that renewable energy sources should be geographically distributed to ensure the highest level of energy security, as one of the key priorities of a just energy transition. The group demonstrated an innovative approach by addressing the high risk of energy poverty in BiH, proposing serious measures to mitigate this threat. The transport sector group identified key infrastructure challenges and advocated for the adoption of European Union emission standards to significantly reduce CO_2 emissions. One proposed measure in this sector was to offer subsidies for people carpooling in a single vehicle. For example, a vehicle used by four passengers could be exempt from toll fees, thereby incentivizing citizens to reduce single-occupancy trips. The forestry group, on the other hand, placed a strong emphasis on reforestation as a key tool for mitigating climate change. They proposed large-scale reforestation projects aimed at restoring degraded areas, increasing forest cover, and enhancing carbon sequestration. The group also recommended protecting biodiversity by prioritizing native species and implementing adaptive management techniques to respond to climate-related threats such as wildfires, pests and diseases. They stressed that these measures not only combat climate change but also preserve the ecological balance and promote long-term sustainability of forest ecosystems. Throughout the workshop, participants were encouraged to engage in constructive dialogue, leading to the conclusion that experts in their respective fields cannot bring about significant change in isolation; collaboration among various stakeholders and experts is essential to successfully tackle challenges of this magnitude. Young people are the drivers of change, bringing fresh energy to open new perspectives. The positive outcomes of this workshop underscore its potential as a replicable model for similar efforts in other regions facing climate change challenges.

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Impressions from the Summer School „Climate Change and Air Pollution "

*The Summer School **"Climate Change and Air Pollution"** brought an extraordinary opportunity for education, connection and exchange of knowledge among young experts, scientists and activists dealing with climate change and air pollution. As organizers and participants, we have witnessed the importance of creating platforms that enable an in-depth understanding of these complex topics, through theoretical foundations and practical skills.*

*The school provided a solid foundation for further action, not only through the acquisition of knowledge but also through raising awareness of the urgency of climate action. Participants had the opportunity to look at global challenges through a local prism, which allowed them to identify specific problems and potential solutions within their own communities. Given the different perspectives brought by participants from different countries and disciplines, the school demonstrated the power of **multidisciplinary and transdisciplinary approaches** in addressing climate change.*

Reflecting on what has been achieved, we are convinced that this school has contributed to the creation of new leaders in the field of environmental protection and climate action. Their commitment, engagement and ability to cope with challenges are of utmost importance for the future of the fight against climate change and air pollution.
In the future, we plan to expand this project through the organization of new schools and workshops, with an emphasis on the application of sustainable technologies and practical solutions. A special focus will be placed on empowering local communities, supporting innovation and encouraging joint action at the regional and global level. Also, we will work on building networks and programs that will enable the knowledge gained at this school to continue to grow and act through projects and initiatives that students will develop.
In the end, the Summer School "Climate Change and Air Pollution" showed that education and cooperation are the key to a future based on sustainability and respect for nature. With each new generation of young leaders, we believe that we will be closer to the goal of a sustainable and equitable future for all of us.

Authors

Group photo of participants of the Summer School "Climate Change and Air Pollution", July 2024

„Participating in the Summer School Climate Change and Air Pollution, organized by the University of Sarajevo - Centre for Interdisciplinary studies „Prof. Dr. Zdravko Grebo", provided a unique opportunity to deepen knowledge and exchange experiences on topics related to the environment and climate change. This summer school offered the possibility of connecting various university professors, students, and pupils who share a common goal – reducing pollution and adapting to climate change. Through comprehensive presentations of specific topics and their impact on human life, the summer school helped broaden the understanding of the challenges posed by air pollution and climate change. The summer school not only inspired new ideas but also provided an opportunity to explore potential solutions through multidisciplinary cooperation and discussions, which can contribute to a better future. I believe that the knowledge gained through lectures, workshops, and available online materials will be of great importance in raising awareness, not only among participants but also within the wider society, about environmental pollution and climate change".

Prof. dr. Ermin Muharemović

"At a time when BiH and its cities are at the top of the list of the most polluted countries/cities in the world, the initiative to launch the Summer School project dealing with the issue of climate change and air pollution is of great importance. The interdisciplinary structure of the Summer School is particularly interesting, in which participants (high school students and students from all over Bosnia and Herzegovina) go through well-designed thematic units in which experts from various scientific and professional fields share their knowledge and experience. It was an honor for me to share my knowledge and potential perspectives as a full-time professor of pharmacology and toxicology, with experience in conducting research in the field of indoor air quality in primary schools. The synthesis of the curiosity of the participants and the experience of the lecturer can in this way result in new initiatives in this field as well as solutions to problems. In the future, this project should be expanded to a regional and wider level".

Prof.dr Aida Ćesić-Kulo

"Participation in the Summer School "Climate Change and Air Pollution" was an extremely inspiring experience. I had the opportunity to share my knowledge through a lecture on stakeholder analysis in nature conservation and climate change, using the Interest-Power Grid. It was amazing to see the motivation and enthusiasm of the young participants, who showed an excellent understanding of the complex environmental issues we face today. Their willingness to take an active role in preserving the environment and solving climate challenges gives me hope for the future. This program not only provides valuable knowledge, but builds a network of young leaders who will drive change for years to come."

Belma Nahić, Independent Expert

"The complexity of climate change and its impact on air pollution can only be viewed in an interdisciplinary way. The greatest value of the Summer School lies in this approach, where different aspects are presented by experts from various fields. The Summer School allowed me to broaden my understanding and rethink existing attitudes, looking at climate change from a different perspective. Global problems require broad approaches, and this school has taught us how to turn them into concrete actions."

Mirza Selimović, student

„The summer school on climate change and air pollution, held at the Centre for Interdisciplinary Studies, gave us students insight into the current situation of global problems and provided the opportunity to understand how we, as young people, could contribute to the health and future of our planet. During five days of intensive work, we listened to 12 experts who spoke about climate change from different aspects. Thus, we saw the importance of an interdisciplinary approach to the problem. In addition to the acquired knowledge, we also saw the imminent danger posed by climate change, and therefore, we strive to act and spread knowledge among the young population in the near future. "

Tina Tadić, student

„Attending the Summer School was a truly transformative experience. As a young person already deeply engaged in climate action, particularly through my involvement in the Local Conference of Youth (LCOY) for Climate Action in Bosnia and Herzegovina and my advocacy efforts at COP28 in Dubai as the Youth Representative of Bosnia and Herzegovina, this Summer School offered a unique opportunity to both deepen my understanding and broaden my perspective on the challenges we face. The focus of the program on climate change and air pollution felt especially relevant, given the pressing environmental issues in Bosnia and Herzegovina. The combination of theory and practice in the lectures and workshops helped me grasp the complexity of these issues on both a local and global scale. From the scientific explanations of climate processes to discussions on public health implications, particularly related to air pollution, I gained valuable insights into the multifaceted nature of climate change, which further fuelled my passion for climate advocacy. One of the most significant takeaways for me was understanding the specific impacts of air pollution on vulnerable populations in our country—especially on children and pregnant women, which aligns closely with my prior research on maternal health and climate change in Bosnia and Herzegovina. What made this summer school truly stand out was the hands-on approach. Not only were we discussing the science behind climate change, but we also engaged in practical exercises, such as assessing air quality monitoring data and discussing real-world policy solutions that could mitigate the effects of pollution in our communities. It was incredibly empowering

to apply what I had learned from my previous engagements to these discussions and feel that my contributions were valued. Overall, this experience was not only enriching on an academic level but also on a personal one. It reinforced my commitment to working toward a sustainable and just transition for Bosnia and Herzegovina, where young voices, like mine, are crucial in shaping the future. The Summer School reaffirmed that through knowledge-sharing, collaboration, and action, we can make significant strides toward addressing the climate crisis—both locally and globally.“

Layla Jusko, student

For more information about the summer school

“Climate Change and Air Pollution”