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POLLUTION AND AIR QUALITY 1

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Environmental protection

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TERMINOLOGY

- Pollutant: substances of anthropogenic origin that can cause air pollution. There are primary (as emitted, CO, CO2, SO2, NOx) and secondary (created by chemical reactions in the atmosphere PAN, HC, O3) pollutants. Note: we cannot talk about harmful substances, because these are natural substances that cannot be harmful, elevated concentrations of these substances are harmful.
- Pollution, emission (eng. emission, release): release of polluting substances from the source.
- Pollution, air quality: Ground concentrations of pollutants. Note: in the profession, although it can often be found, the term "pollution" is not used.
- Dispersion of air pollutants: After leaving the source of the emission, there is a dispersion of pollutants, which results in a dilution of concentrations.
- Deposition of air pollutants: Deposition of primary and secondary pollutants from the atmosphere onto soil or water. It can be dry (eg sulfates) or wet (rain washing of gaseous compounds from the cloud or deposition of gaseous compounds from the cloud itself).

- **Emission limit values:** are adopted based on techno-economic criteria; technology monitoring is required at reasonable costs. Emission limit values and air quality limit values are the basic levers in air quality management.
- **Characteristics of ambient air quality:** (i) annual distribution of values and (ii) occurrence of episodes of increased air pollution.
- **Annual distribution of air quality values:** The distribution is usually a normal logarithmic distribution defined by the arithmetic mean (long-term impact indicator) and a high percentile (high concentration impact indicator). Statistical evaluation of air quality enables comparison of values from one or more measuring stations over several years or comparison of several locations with each other.
- **Episodes of poor air quality:** periods when, due to a very stable atmosphere (temperature inversion), air quality limit values are significantly exceeded. Episodes lasting longer than five days are particularly significant from a health impact perspective.
- **Exposure:** exposure of population, ecosystems and materials to polluted air.
- **Emission sources:** (i) individual (when the emission from a single source exceeds a given value (e.g. 1 or 2%) of the emission of a given area), (ii) surface (emission from small technological and energy sources, households and traffic in the network) and (iii) line (emission from traffic on frequent roads).
- **Combustion air pollutants:** (i) products of incomplete combustion (soot, carbon monoxide, hydrocarbons), (ii) products dependent on the fuel-combustion combination (sulfur and nitrogen oxides, etc.) and (iii) solid particles (fly ash and fly coke carried out from high-power combustion plants, or solid particles from industrial processes). Note: carbon dioxide is not a pollutant but a greenhouse gas (greenhouse effect gas).

- **Emission registry:** a list of legal entities, plant operators, that have emissions above a certain value; in addition to data on the legal entity, it also contains data on emission sources.
- **Emission balance:** annual emission volume of given pollutants in a given area.
- **Emission inventory:** presentation of emission volumes of a given area given in a grid of quadrants (in cities of size 500x500 or 1,000x1,000 m).
- **Dispersion (atmospheric) model:** simulation of the dispersion of pollutants for given emission volumes and emission conditions using mathematical or physical models. The model is applied to meteorological data for a series of years.
- **Air quality monitoring:** a system for monitoring air quality in a given environment. Data can be generated by calculation, measurement, or a combination thereof. Calculation is performed on the basis of an emission inventory using a dispersion model. Measurement is performed using measuring stations where air sampling is performed. Sample processing can be in a laboratory or automatic in the measuring station itself. The combined system involves calculating the dispersion and calibrating the model based on measured data. The following are distinguished: (i) real-time monitoring (for the purpose of monitoring episodes and responses) and (ii) integrated-time monitoring (for the purpose of an annual series of statistical air quality data). Monitoring is used to forecast air quality in case measures are taken to reduce emissions or to plan development. It also serves to assess the effects of measures taken to reduce pollution. Air quality assessment can also be obtained by using bioindicators, most often the presence of lichens.

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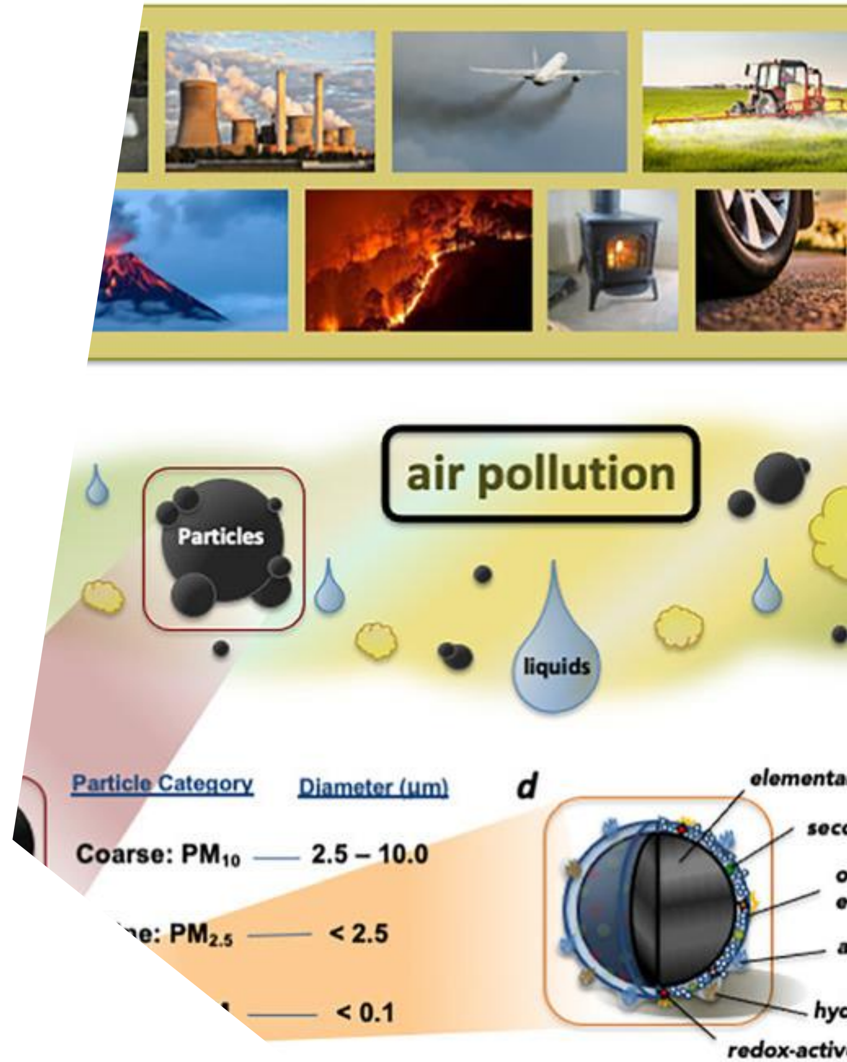
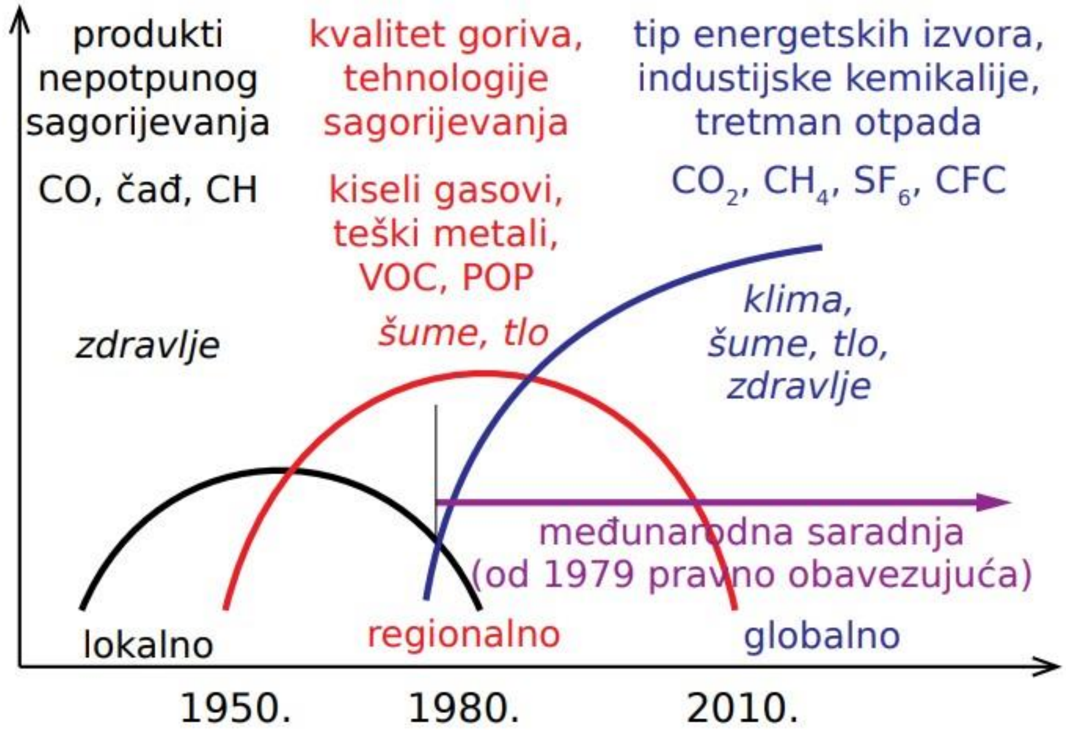
Parameters and Main Pollutants

- Air quality is determined by ambient conditions such as thermal comfort, air humidity, lighting and noise, and pollutants such as particles (PM – particle matter), gases such as carbon dioxide CO2, carbon monoxide CO, sulfur dioxide SO2, nitrogen oxides NOx, CFCs, volatile compounds – VOCs, formaldehyde HCHO, etc.
- Poor air quality in indoor spaces has numerous negative effects on health in general, and especially on the respiratory system, cognitive abilities, especially in children due to the presence of specific air pollutants from various sources, etc.



PROBLEMS



Three generations of problems – Knežević 2005. (Air Quality, book by Husika et al.)

Carbon monoxide CO

- Gas without color, odor, and taste.
- Product of incomplete combustion of carbonaceous fuels, where CO is obtained instead of CO_2.
- 70% of all CO comes from the transport sector, e.g., vehicles.
- Negatively affects human health, replacing oxygen in the bloodstream.

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Nitrogen oxides (NOx)

Gaseous nitrogen oxides: NO (nitric oxide), NO_2 (nitrogen dioxide)

- NOx are formed during the combustion of fossil fuels (oil, coal, wood, gas).
- Most NOx emissions are in the form of NO, which quickly oxidizes to NO_2 in the presence of O_2 or O_3 ($2NO + O_2 \rightarrow 2NO_2$; $NO + O_3 \rightarrow NO_2 + O_2$).
- NO_2 is heavier than air and soluble in water, and it can:
    - Dissociate into NO or further oxidize into HNO_3 or HNO_2.
    - React with organic compounds (VOCs) and produce PAN.
    - React with HC in the presence of sunlight and create smog.

- $NO_2 \rightarrow$ respiratory problems.
- NO, $NO_2 \rightarrow$ smog $\rightarrow$ lung, bronchial diseases.
- PAN $\rightarrow$ eye irritation.
- $O_3 \rightarrow$ respiratory effects, inhibiting crop yields.
- NO_2 is related to mobile (40-70%) and stationary sources.

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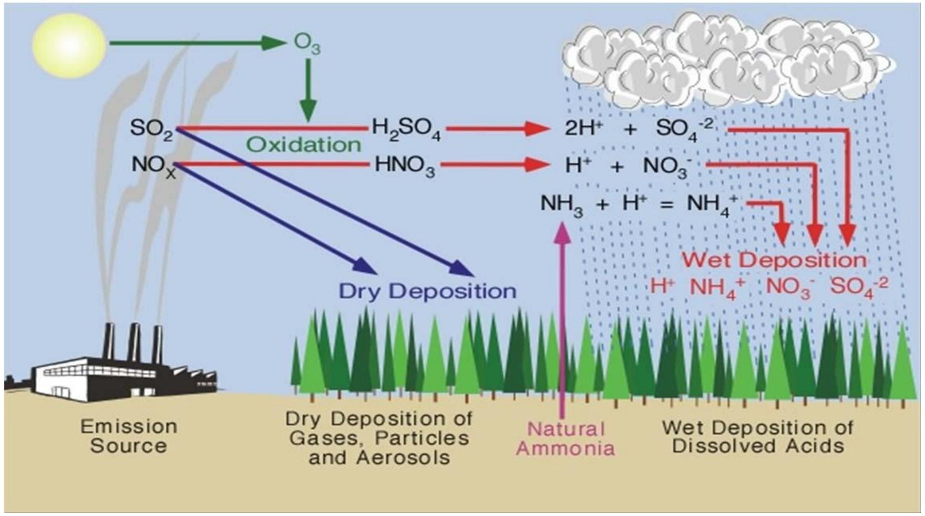
Sulfur dioxide (SO_2)

- SO_2 a product of burning fossil fuels (usually oil and coal)
- dominant gaseous emission: SO_2
- sulfate particles SO_2- are found in the form of wet or dry deposition
- wet drops of acid rain (H_2SO_4), PH < 5.5
- SO_2 negative impact on people and plants
- the functioning of the bronchi, forest growth is inhibited

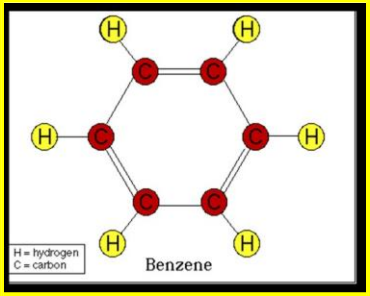
- Emissions of sulfur oxides (SO2), nitrogen oxides (NOx) and HC from industry, transport, households, energy production, are converted in the atmosphere into sulfate or nitrate particles

- In combination with sunlight and water vapor, chemical reactions occur, i.e. sulfuric or nitric acid. These acids return to the earth as dew, rain, fog, sleet, snow or rain

- Normal "clean" rainwater has a PH ≈ 5.7



Volatile Organic Compounds (VOCs)



- Organic air pollutants include HC and other substances
- many are reactive (excluding methane CH4) in the air environment and have significant environmental and health implications
- the most abundant HC is methane (concentrations in the environment: 1-6 ppm)
- less abundant, but more reactive VOCs:
- – benzene (C6H6), CFCs (chlorofluorocarbons), etc.
- they irritate the eyes, throat, lungs; inhibit plant growth
- 27% of road traffic

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Calculation of air emissions

- The calculation of pollutant emissions into the air can be done using the following methodologies:
- calculation of annual emissions based on continuous monitoring;
- calculation of annual emissions of sulfur dioxide based on the material balance of the process of sulfur content in the fuel;
- calculation of annual emissions based on individual annual measurements;
- calculation of emissions based on the emission factor.

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- **Calculation of annual emissions based on continuous monitoring**

a) For an installed automatic system:

$$E = \frac{n \cdot \dot{m}}{1.000} \left[\frac{kg}{a}\right]$$

where is:

- E [kg/a] – the annual emission of the pollutant for which the calculation is made;
- n [h] – total number of hours of plant operation during the accounting year;
- $\dot{m}$ =Vi· ci [g/h] - the mean value of the measured hourly or half-hourly mass flow values during the period for which there are valid data;
- vi [mn 3/h] – mean flow of dry flue gases measured in the i-th hour;
- ci (mg/mn 3) - average concentration of pollutants in flue gases, measured in the i-th hour.

- b) If an automatic system for continuous monitoring of flue gas flow is not installed at the plant, or if there is no valid data, then the annual air emission can be calculated based on the equation:

$$E = \frac{Q \cdot c}{1.000.000} \left[\frac{kg}{a}\right]$$

where is:

- E [kg/a] – annual pollutant emission;
- Q [mn3/a] – the total amount of flue gases emitted during the accounting year, calculated for normal conditions (P=101.3 kPa and T=273.15 K) and reference oxygen;
- c [mg/mn 3] – average concentration of pollutant in dry flue gases, recalculated to normal conditions and reference oxygen, measured over a period of one year, or in case of breakdowns, maintenance, other work interruptions, average concentration of pollutant in dry flue gases for the complete period for which there are valid data.

- The total amount of flue gases emitted, calculated for normal conditions and for reference oxygen, is calculated according to the following formula:

$$Q = B \cdot V_{RS} \left[\frac{m_n^3}{a}\right]$$

where is:

- B [(kg/a) for solid and liquid and (m3/a) for gaseous fuels] – total amount of fuel consumed during the accounting year
- VRS [(mn 3/kg) for solid and liquid and (mn 3/m3) for gaseous fuels] – the unit amount of dry flue gases, converted to normal conditions and reference oxygen, which results from the combustion of one kilogram of solid or liquid fuel, or one cubic meter of gaseous fuel.

- The unit amount of dry flue gases VRS depends on the lower heat capacity of the fuel Hd (MJ/kg) and the flue gas factor S [m3/MJ]:

$$V_{RS}=H_d \cdot S \left[\frac{m_n^3}{kg} \text{ ili } \frac{m_n^3}{m^3}\right]$$

- The flue gas factor S shows how much dry flue gas is produced per unit of heat power of the fuel. The table shows the flue gas factor S, for different fuels and for different values of the reference percentage of oxygen in dry flue gases

	Faktor dimnih gasova S (m³/MJ)								
Referentni kisik (%)	0	3	6	7	10	11	13	15	17
Čvrsto gorivo	0,256	0,299	0,359	0,385	0,491	0,540	0,677	0,907	1,372
Tečno gorivo	0,244	0,285	0,342	0,367	0,468	0,515	0,646	0,864	1,308
Gasovito gorivo	0,240	0,280	0,337	0,361	0,460	0,507	0,635	0,850	1,286

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Calculation of annual sulfur dioxide emissions based on the sulfur content of the fuel (material balance)

- Calculation of annual emissions using the substance balance method can only be done for the polluting substance sulfur dioxide. Calculation of sulfur dioxide emissions using this method is calculated accord

$$E = 2 \cdot B \cdot \overline{w}(s) \cdot (1 - \eta_{od}) \left[\frac{kg_{SO_2}}{a}\right]$$

- where is:
- 2 – stoichiometric ratio of SO2/S molecular masses (64/32=2);
- B [kg/a] – total amount of fuel consumed during the accounting year;
- w(s)- average weighted mass fraction of sulfur in the fuel;
- ηod - degree of operation of flue gas desulfurization plant from 0 to 1 (if no desulfurization plant is installed ηod=0);

- The average weighted mass fraction of sulfur in the fuel w(s) is calculated based on the equation:

$$\overline{w}(S)=\frac{w_1(S)\cdot B_1+w_2(S)\cdot B_2+...+w_n(S)\cdot B_n}{B_1+B_2+...B_n}$$

- where: B1, B2,...Bn - amount of fuel used in one shipment (batch) of fuel (kg) w1(S), w2(S), wn(S) - mass fraction of total sulfur in fuel in one shipment (batch) of fuel.
- To use this method, you need to have the following information:
- Total energy consumption for the period for which emissions are calculated, for each emission source, if there are more;
- The amount of fuel and the chemical analysis of fuel from each shipment of fuel (batch), during the observed year, from which the share of total sulfur in the fuel (not in dry matter) is visible;
- Individual fuel consumption from each shipment for each emission source.

Calculation of air emissions based on emission coefficients

- Based on this method, air emissions are calculated based on the equation:

$$E=\frac{B\cdot Hd\cdot EF}{1.000.000}\left[\frac{kg}{a}\right]$$

- where is:
- B (kg/a for solid and liquid and m3/a for gaseous fuels) – total amount of fuel consumed during the year;
- Hd (MJ/kg for solid and liquid or MJ/m3 for gaseous fuels) – lower heating value of the fuel;
- EF - (g/GJ) – emission factor of NOx or solid particles which depends on the type of fuel and plant and may be at limit values.

- An example of emission coefficient values based on limit values for nitrogen oxides and particulate matter (PM) are given in the table

Postrojenje	Snaga (MWth)	gorivo	Faktor emisije	
			NOx (g/GJ)	ČČ (g/GJ)
mala postrojenja	≤ 1	Čvrsta goriva	143,60	53,85
		Ekstra lako lož ulje		8,55
	≤ 5	Lako lož ulje	128,25	14,25
		Srednje i teško lož ulje		17,10
	≤ 10	Gasovita goriva	35,00	0,00
srednja postrojenja	od 1 do 50	Čvrsta goriva	143,60	17,95
		Ekstra lako lož ulje		8,55
	od 5 do 50	Lako lož ulje	99,80	14,25
		Srednje i teško lož ulje		17,10
	od 10 do 50	Gasovita goriva	28,00	0,00

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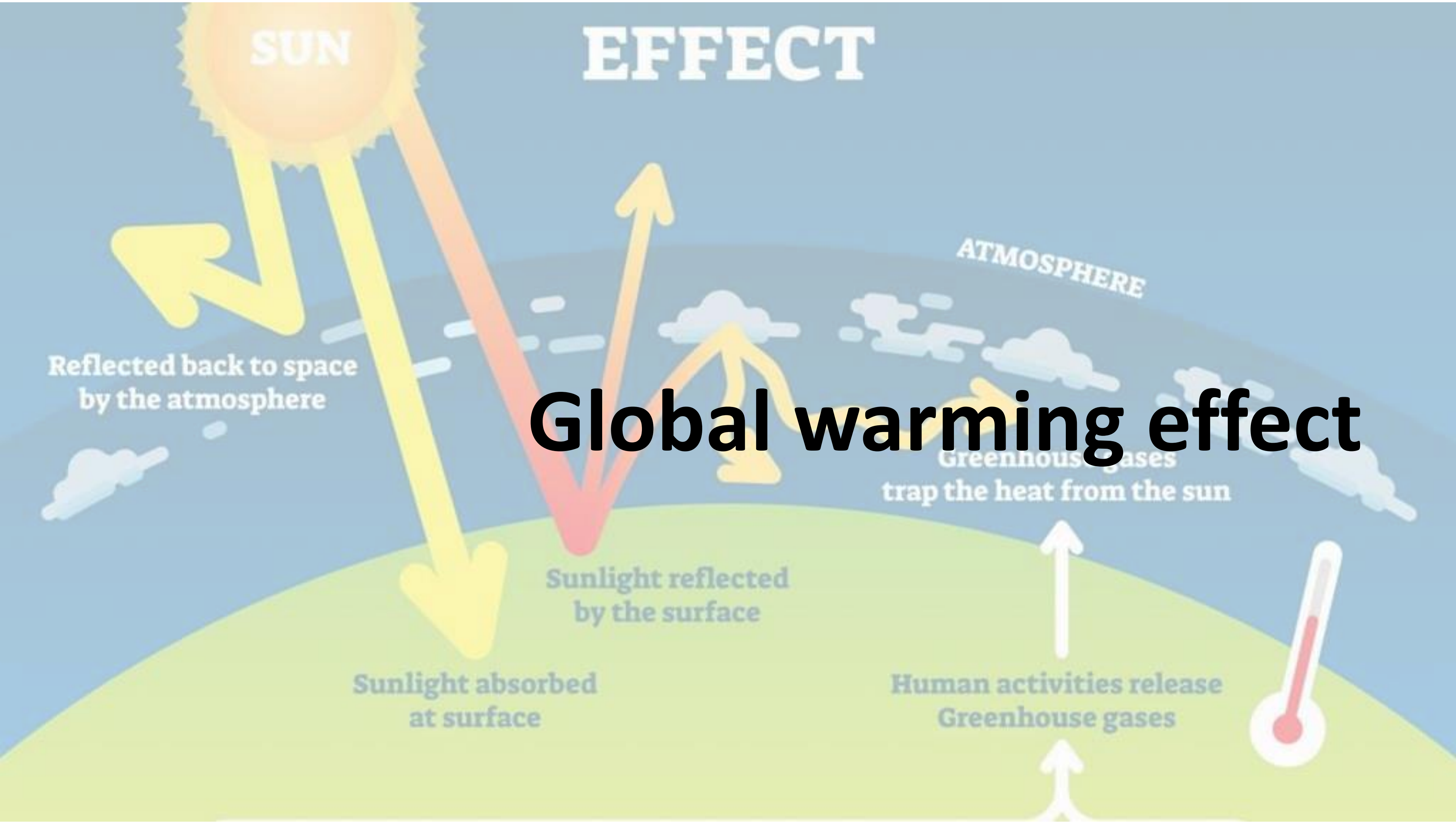
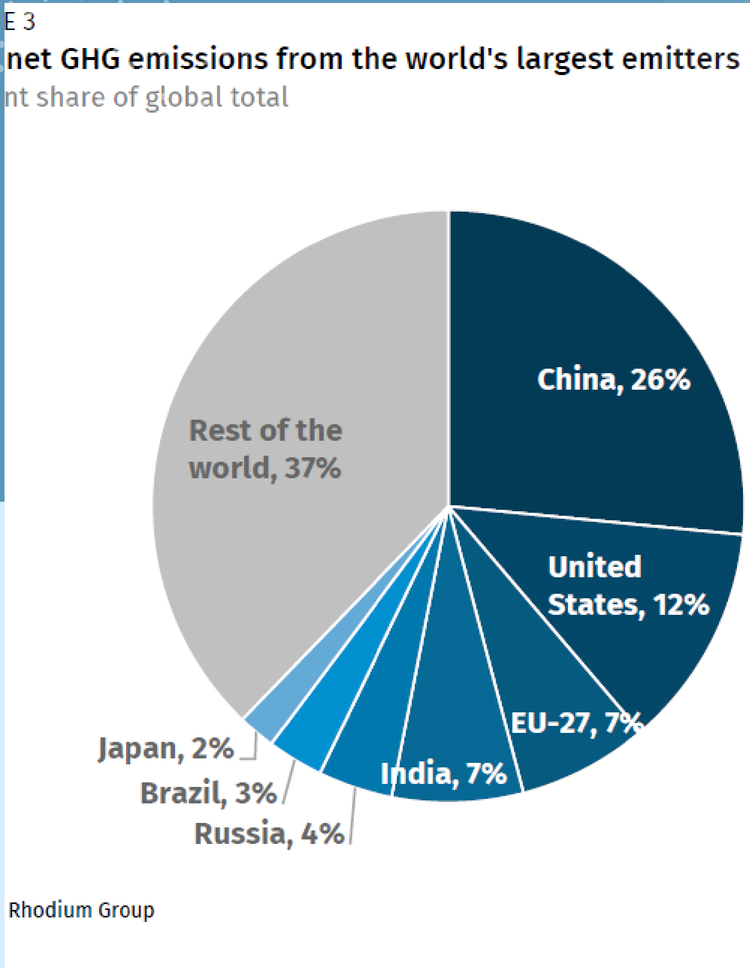
Global warming effect



GHG Emissions and carbon footprint

GAS	GWP
CO_2	1
CH_4	21
N_2O	310
HFC-23	12000
HFC-32	2100
SF_6	22300



Specific emissions of carbon dioxide

Carbon dioxide (CO2) emissions can be divided into direct and indirect. When calculating direct CO2 gas emissions, it is possible to use either the consumed annual mass of the energy source or the useful energy obtained, which is multiplied by the emission factor defined for each energy source. The formula for calculating direct emissions is as follows:

$E_{D.} = k \cdot M$

where is:

ED – total direct emissions of carbon dioxide [kg CO2/year],

k – fuel emission factor [kg CO2/kWh],

M – input energy in the fuel [kWh/year].

	kg CO_2 / GJ
natural gas	56
petrol	69
kerosene	72
diesel	74
heavy fuel oil	77
lignite	95
coal	96
biomass	0 (in LC)
hydro	0
wind	0

- When calculating indirect CO2 emissions, which are used to calculate emissions related to electricity consumption, the formula is used:
- $E_{ID.} = \grave{k} \cdot N$
- where is:
- $\grave{k}$ – electricity grid coefficient for CO2 gas [k=0.726 kg CO2/kWh for BiH],
- N – electricity consumption [kWh/year].

	Emission coefficients CO_2	
Energy Source	Per Energy Unit of Fuel [kg CO2/kWh]	Per Unit of Usable Heat [kg CO2/kWh]
Extra Light Heating Oil	0.26	0.32
Heating Oil	0.27	0.33
Liquefied Gas	0.20	0.26
Hard Coal	0.33	0.44
Brown Coal	0.33	0.44
Lignite	0.35	0.47
Natural Gas	0.20	0.24
Extra light and light oil are grouped into Extra Light Heating Oil, while medium and heavy oil are grouped into Heating Oil.		

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