Understanding global warming – Greenhouse gases (answer sheet)

The greenhouse effect involves many naturally occurring gases whose concentrations have been and are still being increased by humans. The gases absorb the thermal radiation from the Earth's surface and intensify atmospheric counter-radiation, which is bounced back to Earth.
Since the Industrial Revolution, emissions of certain greenhouse gases have greatly increased and are intensifying the greenhouse effect, which leads to continual global warming. Greenhouse gas emissions are responsible for man-made (anthropogenic) climate change.

Assignment 1: Various greenhouse gases

a) Research the properties of the four major greenhouse gases and write down your results as key points. All results will be combined into one list as a class afterwards.
You will find potentially useful research links in the link list.
Your research should include the following properties:

- **Formation and use**: What processes result in the formation of greenhouse gases and in which products are the gases used?
- **Global warming potential**: How great is the "global warming potential" of the various gases? (If you are unfamiliar with the term, research it and write down the meaning.)
- **Lifetime**: How long do the greenhouse gases remain after entering the atmosphere?

  In addition, the following values can be researched: (Tip: You can find related data on the U.S. Environmental Protection Agency website.)
- **Global concentration and contribution to the greenhouse effect in % in 2020**

b) Compare the global warming potential of methane, laughing gas, and chlorofluorocarbons with the global warming potential of CO_2. What do you conclude?

Answer assignment 1

a) Naturally occurring gases such as water vapor (H_2O), carbon dioxide (CO_2), and methane (CH_4) absorb the heat radiated by the Earth's surface and intensify the counter-radiation that is bounced back to Earth. In contrast, oxygen (O_2) and nitrogen (N_2), which form approx. 99 percent of the atmosphere, have a very low emission and absorption capacity in the longwave radiation range; they are therefore not responsible for the greenhouse effect. The major long-lived greenhouse gases are listed below.

CO_2 (carbon dioxide)

- Released when fossil fuels are burned, but also when forests are slashed and burned to clear land for agriculture
- Lifetime up to 100 years, removed only by regrowing corresponding amounts of plants
- Global warming potential is 1 (CO_2 is the benchmark for the other gases)
- Global carbon dioxide concentration in 2020: 412.5 ppm (parts per million) = 412.5 CO_2 molecules per 1 million air molecules
- Contribution to the greenhouse effect in 2020: 66%

CH_4 (methane)

- Formed during agriculture through livestock farming (ruminants, like cattle) and rice cultivation (anaerobic bacteria in the water), but also released by the thawing of permafrost soils and from tropical wetlands
- Global warming potential*: 28, i.e., 28 times more potent than CO_2 over 100 years
- Lifetime approximately 12 years
- Global methane concentration in 2020: approx. 1,879.3 ppb (parts per billion) = 1,879.3 CH_4 molecules per 1 billion air molecules
- Contribution to the greenhouse effect in 2020: 16%

N_2O (nitrous oxide/laughing gas)

- Used in the medical field (anesthesia), indirectly released in intensive agriculture through livestock farming (slurry) and through nitrogen fertilization, since nitrogen fertilizers are converted to nitrous oxide under certain conditions. Measures to reduce nitrogen emissions during combustion, for example, in vehicles with catalytic converters, also lead to a rise in emissions of nitrous oxide.
- Global warming potential*: 265 ➔ 265 times more potent than CO_2 over 100 years
- Lifetime approximately 120 years
- Global nitrous oxide concentration in 2020: over 333 ppb
- Contribution to the greenhouse effect in 2020: 6%

CFCs (chlorofluorocarbons)

- Occur in solvents, propellants (aerosol cans), refrigerants (air conditioners, refrigerators, etc.)
- Global warming potential*: 4,660 to 12,400 ➔ up to 12,400 times more potent than CO_2 over 100 years
- Lifetime up to 50,000 years
- Contribution to the greenhouse effect in 2020: approx. 7%

SF_6 (sulfur hexafluoride)

- Used as an arc-quenching agent in high-voltage switches
- Global warming potential: 23,500 ➔ 23,500 times more potent than CO_2 over 100 years
- Lifetime approximately 3,200 years

* Global warming potential according to IPCC AR5 (Fifth world climate report of the Intergovernmental Panel on Climate Change, IPCC, published in 2014/2015)

b) Methane, nitrous oxide, and chlorofluorocarbons have a higher global warming potential than CO_2, In some cases 1,000 to 10,000 times higher.
Although they occur at lower concentrations in the atmosphere, they contribute many times more to intensification of the greenhouse effect than CO_2.
Reducing CO_2 is the highest priority. However, measures to reduce greenhouse gases should not fail to include methane, nitrous oxide, and chlorofluorocarbons.

Assignment 2: Lifetime

Answer the question "Why will global warming remain constant for centuries and millennia even if no more greenhouse gases are emitted?" based on the gases' respective lifetimes.

Answer assignment 2

Depending on their lifetimes, greenhouse gases remain in the atmosphere for decades to millennia and contribute to global warming. Global warming therefore could not be immediately stopped or reversed, even if not a single greenhouse gas were to enter the atmosphere again. Global warming would thus persist until the greenhouse gases have largely been degraded. Since the degradation process will continue for millennia, it makes sense to stop greenhouse gas emissions as quickly as possible.

Assignment 3: Chlorofluorocarbons and the ozone layer

Explain what chlorofluorocarbons (CFCs) have to do with the hole in the ozone layer and with global warming.

Answer assignment 3

The ozone layer in the stratosphere protects Earth from UV-B radiation from the sun. The stratosphere is a stable atmospheric layer; very little air is exchanged with the layers above and below. Normally, equilibrium prevails between the formation and breakdown of ozone.
Low molecular weight CFCs rise into the stratosphere and are exposed to shortwave UV radiation there. Chlorine-carbon bonds are split as a result. Released chlorine radicals break down ozone molecules. In chain reactions, additional ozone molecules may be broken down. The aforementioned equilibrium is disturbed.
A hole in the ozone layer has formed above the Antarctic since the 1980s and appears every year during the Antarctic spring (September/October). Starting from November, in the Antarctic summer, the hole in the ozone layer shrinks again. New ozone is produced when the level of solar radiation is higher. In addition, the air layers then circulate better and ozone-richer air masses travel to the Antarctic.
However, scientists have determined that this recovery of the ozone layer no longer functions as well due to advancing global warming. Atmospheric circulation is altered by climate change. Warm air is transported faster and lower toward the south pole. However, less ozone is produced in lower air layers.

