Option E: Environmental chemistry (15/22 hours)

Human activities involve intensive use of limited resources found in air, water and soil. Many of these activities produce waste products that build up in the environment to produce pollution with increasingly local and global effects. An understanding of this impact is essential within and beyond the study of chemistry. This option has many opportunities for discussing aim 8 issues and the international dimension.

Core material: E1–E8 are core material for SL and HL (15 hours).

Extension material: E9–E12 are extension material for HL only (7 hours).

E1 Air pollution

2 hours

	Assessment statement	Obj	Teacher's notes
E.1.1	Describe the main sources of carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulfur (SO_x), particulates and volatile organic compounds (VOCs) in the atmosphere.	2	Include both natural and anthropogenic sources. Equations should be used as appropriate.
E.1.2	Evaluate current methods for the reduction of air pollution.	3	Examples include: • CO—catalytic converters • NO_x—catalytic converters, control of fuel/air ratio • SO_x—alkaline scrubbing, limestone-based fluidized beds • particulates—electrostatic precipitation • VOCs—catalytic converters.

E2 Acid deposition

1.5 hours

	Assessment statement	Obj	Teacher's notes
E.2.1	State what is meant by the term acid deposition and outline its origins.	1	Acid deposition refers to the process by which acidic particles, gases and precipitation leave the atmosphere. Both wet deposition (acid rain, fog and snow) and dry deposition (acidic gases and particles) will be assessed. Rain is naturally acidic because of dissolved CO_2 but acid rain has a pH of less than 5.6. It is caused by oxides of sulfur and oxides of nitrogen. The equations for the burning of sulfur and nitrogen, and for the formation of H_2SO_3, H_2SO_4, HNO_2 and HNO_3, will be assessed.
E.2.2	Discuss the environmental effects of acid deposition and possible methods to counteract them.	3	

E3 Greenhouse effect

1.5 hours

	Assessment statement	Obj	Teacher's notes
E.3.1	Describe the greenhouse effect.	2	Greenhouse gases allow the passage of incoming solar short-wavelength radiation but absorb the longer-wavelength radiation from the Earth. Some of the absorbed radiation is re-radiated back to Earth. **TOK:** Some people question the reality of climate change and question the motives of scientists who have "exaggerated" the problem. How do we assess the evidence collected and the models used to predict the impact of human activities?
E.3.2	List the main greenhouse gases and their sources, and discuss their relative effects.	3	The greenhouse gases to be considered are CH_4, H_2O, CO_2, N_2O and chlorofluorocarbons (CFCs). Their effects depend on their abundance and their ability to absorb heat radiation.
E.3.3	Discuss the influence of increasing amounts of greenhouse gases on the atmosphere.	3	Examples include: thermal expansion of the oceans, melting of the polar ice-caps, floods, droughts, changes in precipitation and temperature, changes in the yield and distribution of commercial crops, and changes in the distribution of pests and disease-carrying organisms.

E4 Ozone depletion

1.5 hours

	Assessment statement	Obj	Teacher's notes
E.4.1	Describe the formation and depletion of ozone in the stratosphere by natural processes.	2	Formation: $O_2 \xrightarrow{\text{UV light}} 2O\bullet$ $O_2 + O\bullet \longrightarrow O_3$ Depletion: $O_3 \xrightarrow{\text{UV light}} O_2 + O\bullet$ $O_3 + O\bullet \longrightarrow 2O_2$
E.4.2	List the ozone-depleting pollutants and their sources.	1	Examples include chlorofluorocarbons (CFCs) and oxides of nitrogen (NO_x).
E.4.3	Discuss the alternatives to CFCs in terms of their properties.	3	Alternatives include hydrocarbons, fluorocarbons and hydrofluorocarbons (HFCs). Include toxicity, flammability, the relative weakness of the C–Cl bond and the ability to absorb infrared radiation.

E5 Dissolved oxygen in water

1.5 hours

	Assessment statement	Obj	Teacher's notes
E.5.1	Outline biochemical oxygen demand (BOD) as a measure of oxygen-demanding wastes in water.	2	
E.5.2	Distinguish between *aerobic* and *anaerobic* decomposition of organic material in water.	2	Use redox equations as appropriate.
E.5.3	Describe the process of eutrophication and its effects.	2	
E.5.4	Describe the source and effects of thermal pollution in water.	2	

E6 Water treatment

2.5 hours

	Assessment statement	Obj	Teacher's notes
E.6.1	List the primary pollutants found in waste water and identify their sources.	2	Examples include heavy metals, pesticides, dioxins, polychlorinated biphenyls (PCBs), organic matter, nitrates and phosphates. **Aim 7:** Data banks and spreadsheets can be used.
E.6.2	Outline the primary, secondary and tertiary stages of waste water treatment, and state the substance that is removed during each stage.	2	For primary treatment, filtration and sedimentation should be covered. For secondary treatment, mention the use of oxygen and bacteria (for example, the activated sludge process). Include the removal of heavy metals, phosphates and nitrates by chemical or biological processes.

	Assessment statement	Obj	Teacher's notes
E.6.3	Evaluate the process to obtain fresh water from sea water using multi-stage distillation and reverse osmosis.	3	

E7 Soil

2.5 hours

	Assessment statement	Obj	Teacher's notes
E.7.1	Discuss salinization, nutrient depletion and soil pollution as causes of soil degradation.	3	Salinization: This is the result of continually irrigating soils. Irrigation waters contain dissolved salts, which are left behind after water evaporates. In poorly drained soils, the salts are not washed away and begin to accumulate in the topsoil. Plants cannot grow in soil that is too salty. Nutrient depletion: Agriculture disrupts the normal cycling of nutrients through the soil food web when crops are harvested. This removes all the nutrients and minerals that they absorbed from the soil while growing. Practices leading to amelioration of nutrient depletion may further contribute to environmental pollution. Soil pollution: This is the consequence of the use of chemicals such as pesticides and fertilizers. These chemicals can disrupt the soil food web, reduce the soil's biodiversity and ultimately ruin the soil. The chemicals also run off the soil into surface waters and move through the soil, polluting groundwater.
E.7.2	Describe the relevance of the soil organic matter (SOM) in preventing soil degradation, and outline its physical and biological functions.	2	The term soil organic matter (SOM) is generally used to represent the organic constituents in the soil, including undecayed plant and animal tissues, their partial decomposition products and the soil biomass. It includes: • identifiable, high-molecular-mass organic materials (for example, polysaccharides and proteins) • simpler substances (for example, sugars, amino acids and other small molecules) • humic substances. The functions of SOM can be broadly classified into two groups. • Biological: provides source of nutrients (P, N, S) and so contributes to the resilience of the soil/plant system. • Physical: improves structural stability, influences water-retention properties and alters the soil thermal properties.

	Assessment statement	Obj	Teacher's notes
E.7.3	List common organic soil pollutants and their sources.	1	Examples should include petroleum hydrocarbons, agrichemicals, volatile organic compounds (VOCs), solvents, polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organotin compounds and semi-volatile organic compounds (SVOCs). **Aim 7:** Data banks and spreadsheets can be used here.

E8 Waste

2 hours

	Assessment statement	Obj	Teacher's notes
E.8.1	Outline and compare the various methods for waste disposal.	3	Examples include landfills and incineration.
E.8.2	Describe the recycling of metal, glass, plastic and paper products, and outline its benefits.	2	
E.8.3	Describe the characteristics and sources of different types of radioactive waste.	2	Include both low-level and high-level radioactive waste.
E.8.4	Compare the storage and disposal methods for different types of radioactive waste.	3	

HL E9 Ozone depletion

1 hour

	Assessment statement	Obj	Teacher's notes
E.9.1	Explain the dependence of O_2 and O_3 dissociation on the wavelength of light.	3	$\lambda = 242$ nm $O_2 \longrightarrow 2O\bullet$ $\lambda = 330$ nm $O_3 \longrightarrow O_2 + O\bullet$ The energy needed should be related to the bonding in O_2 and O_3.
E.9.2	Describe the mechanism in the catalysis of O_3 depletion by CFCs and NO_x.	2	For example: $CCl_2F_2 \longrightarrow CClF_2 + Cl\bullet$ $Cl\bullet + O_3 \longrightarrow ClO\bullet + O_2$ $ClO\bullet + O\bullet \longrightarrow O_2 + Cl\bullet$ and $NO + O_3 \longrightarrow NO_2 + O_2$ $NO_2 + O\bullet \longrightarrow NO + O_2$ The net effect is: $O_3 + O\bullet \longrightarrow 2O_2$
E.9.3	Outline the reasons for greater ozone depletion in polar regions.	2	Consider the seasonal variation in temperature in the upper atmosphere. Refer to surface catalysis on ice particles.

HL E10 Smog

2 hours

	Assessment statement	Obj	Teacher's notes
E.10.1	State the source of primary pollutants and the conditions necessary for the formation of photochemical smog.	1	VOCs and NO_x, temperature inversion, windlessness and bowl-shaped cities should be discussed.
E.10.2	Outline the formation of secondary pollutants in photochemical smog.	2	Examples include NO_2, O_3, aldehydes and peroxyacylnitrates (PANs). The role of free radicals and sunlight should be emphasized. **Aim 7:** Three-dimensional and four-dimensional GIS techniques and data banks can be used.

HL E11 Acid deposition

1 hour

	Assessment statement	Obj	Teacher's notes
E.11.1	Describe the mechanism of acid deposition caused by the oxides of nitrogen and oxides of sulfur.	2	Formation of hydroxyl radicals: $H_2O + O_3 \longrightarrow 2HO\bullet + O_2$ or $H_2O + O\bullet \longrightarrow 2HO\bullet$ $HO\bullet + NO_2 \longrightarrow HNO_3$ $HO\bullet + NO \longrightarrow HNO_2$ $HO\bullet + SO_2 \longrightarrow HOSO_2\bullet$ $HOSO_2\bullet + O_2 \longrightarrow HO_2\bullet + SO_3$ $(SO_3 + H_2O \longrightarrow H_2SO_4)$
E.11.2	Explain the role of ammonia in acid deposition.	3	In the atmosphere, ammonia neutralizes the acids formed to a large extent, to form ammonium salts. Slightly acidic ammonium salts, $(NH_4)_2SO_4$ and NH_4NO_3, formed in the atmosphere sink to the ground or are washed out of the atmosphere with rain. As NH_4^+ is deposited and enters the soil, nitrification and acidification can occur. $NH_4^+ + 2O_2 \longrightarrow 2H^+ + NO_3^- + H_2O$

HL E12 Water and soil

3 hours

	Assessment statement	Obj	Teacher's notes
E.12.1	Solve problems relating to the removal of heavy-metal ions, phosphates and nitrates from water by chemical precipitation.	3	Given the equilibrium formed by a metal M and a non-metal X: $MX(s) \rightleftharpoons M^+(aq) + X^-(aq)$ The K_{eq} for this system is given by $K_{sp} = [M^+][X^-]$, and is called the solubility product constant. Students should be able to solve problems associated with this type of equilibrium, including the common ion effect.

	Assessment statement	Obj	Teacher's notes
E.12.2	State what is meant by the term cation-exchange capacity (CEC) and outline its importance.	2	The amount of exchangeable cations in a clay is called cation-exchange capacity. Include equations as appropriate.
E.12.3	Discuss the effects of soil pH on cation-exchange capacity and availability of nutrients.	3	Examples of nutrients include Ca, Mg, Fe, Al, P, N, S, Cu and Zn. Use equations as appropriate.
E.12.4	Describe the chemical functions of soil organic matter (SOM).	2	Include the following. • Contributes to cation-exchange capacity • Enhances the ability of soil to buffer changes in pH • Binds to organic and inorganic compounds in soil • Reduces the negative environmental effects of pesticides, heavy metals and other pollutants by binding contaminants • Forms stable complexes with cations