TASK by Sulitest 1.1.1 — Climate Change

Subject Knowledge Navigational Chart

TASK Framework: Earth Systems → **Domain**: Core Planetary Boundaries → **Subject**: 1.1.1 – Climate Change

Definition: Climate change refers to a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use. (IPCC, 2022)

1. Principles of Earth climate

- Climate vs. weather
- Global mean surface temperature (GMST)
- Causes of natural climate variation
  - Climate carbon cycle variation
  - Solar radiation variation
  - Earth orbit variation
  - Volcanic activity variation
- Causes of Anthropogenic climate variation
  - Disruption of carbon cycle balance
- Plant absorption of CO_2 via photosynthesis
- Role of El Niño and La Niña
- Role of ocean currents (AMOC)

2. Greenhouse effect

- Science established in 19th century (e.g., E. N. Foote, J. Tyndall, S. Arrhenius, N. G. Ekholm)
- Natural greenhouse / heat-trapping gases (GHG)
- Greenhouse gases: CO_2, N_2O, CH_4, CFC, H_2O (water vapor and clouds)
- Solar radiation reflection / absorption
- Earth energy budget / balance (absorbed vs radiated energy)
- CO_2 and CO_2 equivalent (CO_2-eq) emissions

3. Anthropogenic climate change

- Anthropocene epoch (meaning / debate)
- The "Great Acceleration" and globalization
- Anthropogenic GHG emissions
- Atmospheric CO_2 concentration (Parts per million—ppm)
  - Ice age CO_2 : ≈ 200 ppm
  - Interglacial (Holocene epoch) CO_2 : ≈ 280 ppm
  - Current Anthropocene epoch CO_2: ≈ 425 ppm and global warming (GMST) of +1.47°C

4. Carbon imbalance—causes & trends

- Major causes—GHG emissions and land system change (esp. deforestation)
- Major CO_2 sectors: fossil energy, agriculture (deforestation), livestock, transport, food loss / waste, cement
- Efforts in GHG emissions reductions
- Pollution and aerosols loading
- The Albedo effect and feedback loops

5. Impact on air and water

- Atmosphere
  - Temperature rise—global warming, heat waves, forest fires, Arctic warming fastest
  - Extreme weather (rain, storm, etc.)
- Hydrosphere
  - Ocean warming (marine heat wave)
  - Ocean acidification
  - Sea-level rise (via both thermal expansion and terrestrial ice melt)
  - Ocean current change (AMOC)
  - Weakening of ocean as a carbon sink
  - Altered precipitation and evapotranspiration
  - Water scarcity / abundance—drought, wildfire, desertification, flood
  - Altered aquifers and groundwater

6. Impact on land, ice, and life

- Lithosphere
  - Flooding / erosion
  - Heat / wildfire / desertification
  - Soil moisture decline
- Cryosphere
  - Global ice loss—glacial, sea, polar, snowpack, etc.
  - Melting permafrost (release of methane - CH_4)
- Biosphere
  - Biodiversity loss
  - Species stress / migration / loss / extinction
  - Marine habitat loss and destruction (e.g., coral bleaching from higher water temperatures, acidification)
  - Decline of freshwater amphibians
  - Decline of food chains (e.g., fish stocks, phytoplankton, etc.)

7. Impact on human welfare

- Migration (due to extreme climate, conflict, coastal inundation, access to resources, etc.)
- Climate refugees (extreme weather, heat, flooding, soil exhaustion, etc.)
- Pandemic / infectious disease / pests / novel microbes (e.g., melting permafrost)
- Human health (heat exhaustion, dehydration, etc.)
- Food security (terrestrial and marine)
- Crop failure and loss of cropland and grazing land
- Water scarcity / freshwater contamination
- Energy security
- Coastal and river flooding
- Extreme weather events

8. Science of global warming

- Climate sensitivity (temp change vis-à-vis CO_2)
- Climate equilibrium vis-à-vis net zero GHG
- Radiative /climate forcing (change in energy balance due to external factors)
- Climate feedbacks / feedback loops
- Climate threshold / tipping points
- Climate modeling (e.g., "hockey stick" graph, sea ice melt, fluid circulation, energy balance, etc.)
- Evidentiary weight of climate science
- Scientific consensus on climate change

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TASK Framework: Earth Systems → **Domain**: Regulating Planetary Boundaries → **Subject**: 1.1.2 – Biosphere Integrity

Definition: "Biosphere Integrity refers to the capacity of ecosystems across the planet to support life and maintain the overall health and stability of the Earth system, [which] depends on the health, diversity, and interactions of the organisms that make up these ecosystems." (*Potsdam Institute for Climate Impact Research,* 2025) Biosphere integrity includes the "diversity, extent, and health of living organisms and ecosystems [affecting] the state of the planet [which] co-regulates the energy balance and chemical cycles on Earth. Disrupting biodiversity threatens this co-regulation and dynamic stability." (*Stockholm Resilience Center*, 2025)

1. Principles of biosphere integrity

- Biodiversity : genetic and functional diversity, biodiversity hotspots
- Ecosystem functioning: energy, matter and nutrient, water cycles, primary production, photosynthesis
- Ecological resilience to disturbance (i.e., from indigenous to modern)
- Biomes, ecosystems, habitats, species
- Species interdependence, food webs, trophic levels
- Indicator species, keystone species
- Marine ecosystems (coral reefs, mangroves, estuaries, kelp forests, open ocean, polar, etc.)
- Freshwater ecosystems (wetlands, lakes, ponds, streams, rivers, etc.)
- Terrestrial ecosystems (forests, deserts, grasslands, tundra, mountains, etc.)

2. The 6th extinction

- Biodiversity loss—genetic or functional, temporary or permanent (i.e., extinction, collapse)
- Mass extinction events—past and present
- Extinction rate—measured by extinctions occurring per million species per year or E/MSY—currently 100-1000 times higher than normal background rate
- Biodiversity Intactness Index (BII)
- Red List Index IUCN : Extinct (EX), Extinct in Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC).
- Decline of terrestrial invertebrates (e.g., insects, pollinators, spiders, earthworms, etc.)
- Threat to freshwater species (esp. amphibians)
- Effects on migration speed, patterns, transboundary protected areas

3. Indirect drivers of biodiversity loss

- Demography: population dynamics, urbanization, land artificialization
- Technology: modern intensified agriculture (monoculture, pesticides), biomass energy cultivation
- Economics: extractive industries, concentrated production, trade, financial flows
- Governance: market, local communities, states, and policies
- Behavior: unsustainable patterns of production, consumption, resource use, trade, waste generation, etc.
- Ecological illiteracy and modern-day disconnection from nature and natural ecosystem services

4. Direct drivers of biodiversity loss

- Land and sea use change: agriculture, grazing, forestry, mining, infrastructure, urbanization, etc.
- Direct exploitation of organisms: e.g., hunting, overfishing, logging, wildlife trade, exotic pet trade, harvesting, etc.
- Climate change: GHG emissions, temperature patterns, ocean acidification
- Pollution: nutrient runoff, plastics, chemical contaminants, novel entities, air emissions, noise and light, etc.
- Invasive alien species (IAS): animals, plants, fungi and microorganisms introduced accidentally or deliberately by humans, etc.

5. Ethics, animal welfare, and ecosystem rights

- Wild mammals: 4% of all mammals; livestock: 62%; humans: 34%
- Industrial and medical use of animals: livestock, meat and dairy production, aquaculture, medical testing, etc.
- Speciesism
- Nature-culture divide: i.e., perspectives of humans as separate from nature
- Counter-movements: anti-speciesism, animal rights movement, veganism,
- Ecocide as an emerging international crime; recognition of Rights of Nature

6. Climate change impact on biodiversity

- Impact of climate change on natural environments: temperature rise, sea-level rise, glacial melt, ocean acidification, coral bleaching, etc.
- Impact of climate change on living beings: shift in species distribution and migration, impacts on phenology, increased risk of disease, pandemic, and zoonoses
- Ecosystem roles: natural systems act as carbon sinks and buffers, supporting both mitigation and adaptation to climate change

7. Ecosystem services: Nature's Contribution to People (NCP)

- Natural capital: stock of ecosystems that provide benefits to people
- Regulating services: habitat creation, pollination, regulation of air quality, soil fertility, freshwater quantity and quality
- Provisioning services: supply of energy, food, materials, medicinal and genetic resources
- Cultural services: opportunities for learning and inspiration, recreation, identity, spirituality, psychological well-being
- Supporting services: underlying ecological processes that sustain others, (e.g., nutrient cycling and primary production)

8. Indigenous culture & biosphere integrity

- Indigenous lands comprise 22% of Earth's surface and are home to 80% of remaining biodiversity
- Indigenous traditional ecological knowledge systems, belief systems, worldviews
- Principles: generational guardianship, stewardship, kinship, respectful coexistence; love, care, awe, fear, reverence; nature as life-giving, nurturing, and protective, interdependence
- Practices: Indigenous land and territorial governance, tenure, biocultural practices

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TASK Framework: Earth Systems → **Domain**: Regulating Planetary Boundaries → **Subject**: 1.2.1 – Freshwater Use

Definition: Freshwater use denotes the withdrawal or extraction of water from natural sources like rivers, lakes, and aquifers for various human activities. It encompasses all human withdrawals and consumption of Earth's finite, low-salinity water, essential for life and profoundly linked to planetary health. (*Sustainability Directory*, 2025) "Humans are now the dominant driving force altering global scale river flow [...]. Global manipulations of the freshwater cycle affect biodiversity, food, and health security and ecological functioning, such as provision of habitats for fish recruitment, carbon sequestration, and climate regulation, undermining the resilience of terrestrial and aquatic ecosystems." (Rockström, J., W. Steffen, 2009, p.46-47)

1. Natural cycle and processes
- Global water cycle
- Hydrological cycle and the role of fresh water
- Carbon and nutrient cycles in freshwater systems
- Evapotranspiration and precipitation
- Water scarcity: Causes (drought, overuse); Impacts (shortages, restrictions, rationing)
- Water abundance: Causes (heavy rainfall, rapid snowmelt); Impacts (flooding, soil erosion)
- Proportion of fresh water to salt water
- Proportion of accessible fresh water to freshwater stock

2. Blue water – Stocks and Flows
- Blue water
- Global scale vs basin scale; regional hydrological cycles
- Surface water: lakes, rivers, reservoirs; their ecological and economic importance
- Ground water: Aquifers, wells; importance for agriculture and drinking water supply
- Interaction between surface and groundwater: recharge and discharge zone, impacts on water availability
- Global freshwater distribution
- Freshwater resources and supply

3. Green water – Stocks and Flows
- The role of green water in Agro-ecosystems: Crop growth, maintenance of soil moisture
- Anthropogenic causes of disruption of
  - Precipitation: land-use change, GHG and aerosol emissions, etc.
  - Evaporation: agriculture and pasture expansions, CO_2 emissions, etc.
  - Soil moisture: agricultural intensification/expansion, urbanization, precipitation, and evaporation alterations
- Differentiated impact of activities (e.g., deforestation) on blue and green water

4. Use and misuse of fresh water
- Population growth, urbanization as drivers of steep increase in water use (mostly groundwater)
- Water footprint
- Agricultural use: Irrigation and livestock
- Industrial use: Manufacturing, waste disposal
- Domestic use: drinking, sanitation, recreation
- Aquaculture: fish and shellfish
- Energy: hydropower, water for cooling power plants and data centers
- Desalinization, recycling, harvesting, farming, reuse technologies

5. Water pollution
- Water pollution: types, sources, and quantities
- Eutrophication: causes, consequences, and scale
- Nitrogen pollution (fertilizers)
- Phosphorus pollution (phosphate detergents)
- Pesticide and herbicide contamination: effects on aquatic life, bioaccumulation
- Microplastic pollution
- Heavy metal pollution
- Pharmaceutical residues
- Impacts on human health: chronic/waterborne diseases

6. Threats to freshwater resources
- Over-extraction and unsustainable usage: aquifer depletion, groundwater, lake, reservoir degradation
- Impacts of climate change: changes in precipitation patterns, increased evaporation, sea-level rise causing saltwater intrusion, desertification, etc.
- Habitat destruction: dam construction, river diversion, wetland drainage, urbanization, soil artificialization
- Land conversion: loss of biodiversity, increased carbon emissions, loss of natural flood defenses
- Deforestation impacts: increased runoff, reduced infiltration, siltation of water bodies
- Water storage: mega-basins
- Threats to coastal ecosystems

7. Freshwater ecosystems and biodiversity
- Freshwater ecosystems: wetlands, lakes, rivers, and their varieties and characteristics
- Importance of freshwater biodiversity: indicator species, ecosystem services, genetic resources
- Freshwater food webs: trophic levels, keystone species, impact of species loss

8. Impact of water scarcity and overabundance
- Health impacts: Waterborne diseases, malnutrition due to crop failure
- Social impacts: poverty, environmental refugees, etc.
- Water conflict, water war (*Tigris and Euphrates Rivers, Egypt and Ethiopia, Colorado, etc.*)
- Water and education: impact of water-related chores on school attendance, especially for girls
- Excessive water withdrawals and imbalance impacts on soil: soil health, compaction, land subsistence

<table>
<tr><th>Selected Bibliography</th><th>Key International Regulatory Initiatives</th></tr>
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• United Nations Water Conference — 1977
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• Convention on the Protection and Use of Transboundary Watercourses and International Lakes — 1996
• UN Watercourses Convention — 1997
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TASK Framework: Earth Systems → **Domain**: Regulating Planetary Boundaries → **Subject**: 1.2.2 – Land-System Change			
Definition: Land systems "*encompass all processes and activities related to the human use of land*" (Verburg et al, 2015). Changes in land systems have both local and global effects on the environment and human wellbeing. Forests (by their presence or absence) have a larger effect on the global climate than other changes in land systems. Modern agriculture is a significant driver of land-use change worldwide.			
1. Land use and ecosystem services • Human land use: food production, housing, transport, natural resources, energy, industry, etc • Ecosystem services: food production, pollination, resources, etc. • Climate regulation, water provision, carbon sinks, etc. • Cultural, religious, ritualistic services	**2. Forest as land use** • De-, re-, afforestation • Primary forests • Forest biomes: tropical, boreal, temperate • Drivers of deforestation • Forest cover rate • Forest management, timber production	**3. Major driver: People & economies** • Population growth and urbanization: rising demand for food, housing, and infrastructure • Changing consumption patterns: higher meat and dairy intake, growing demand for palm oil, timber, and agricultural commodities • Rising living standards: expansion of built-up areas and energy-intensive lifestyles • Globalized food and commodity trade: shifts in local land-use to serve export markets; pressure on local food sovereignty	**4. Major driver: Modern agriculture** • Green Revolution (Haber-Bosch), mechanization, specialization, intensification to meet population and food demand • Resource-intensive systems with unaccounted environmental and social impacts • Loss of soil health and fertility, with long term consequences • Mechanisms of land degradation: irrigation, salinization, fertilization and eutrophication, overgrazing, deforestation, soil erosion, desertification, physical-chemical-biological treatments (pollution), destruction of natural habitats and ecosystems.
5. Major driver: Urbanization • Demographic transition of the 2nd half of the 20th century: urban population growth (70% now live in cities) • Human settlements patterns for housing: urban, high density, peri-urban sprawl, rural communities • Increased land use for industrial, transportation, and commercial needs • Urbanization land degradation mechanisms: artificialization, soil compaction, water related issues, eutrophication, physical and chemical pollution.	**6. Emerging drivers** • Energy production: land demand for solar farms, biofuel crops, hydropower, and other renewable infrastructures • Mining and extractive industries: direct habitat destruction, pollution, and long-term soil and water degradation • Timber extraction: deforestation and biodiversity loss	**7. Rural factors and considerations** • Rural exodus, rural impoverishment, concentration of inequalities • Rural development policies • (Indigenous) rights to (access to) land, territories, and resources • Land grabbing, neo-colonial practices, corruption, killings	**8. Impact of land-use change** • Climate impacts: land ecosystems (forest, grasslands, wetlands) as carbon sinks • Biodiversity loss: natural habitat destruction accelerating biodiversity collapse • Ecosystem feedback: degraded ecosystems weaken climate regulation, disrupt water and nutrient cycles, and reduce food security • Human and cultural impacts: local livelihoods, food systems, and Indigenous cultures

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TASK Framework: Earth Systems → **Domain**: Regulating Planetary Boundaries → **Subject**: 1.2.3 – Ocean Acidification

Definition: Ocean acidification is a reduction in the pH of the ocean, accompanied by other chemical changes (primarily in the levels of carbonate and bicarbonate ions), over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide (CO_2) from the atmosphere, but can also be caused by other chemical additions or subtractions from the ocean. Anthropogenic ocean acidification refers to the component of pH reduction that is caused by human activity. (IPCC, 2011, p. 37)

1. Principles of ocean acidification
- Lowered pH of ocean water (i.e., higher acidity)
- Acidification as part of the carbon cycle through CO_2 absorption
- Role of oceans in global carbon balance: ocean and coastal carbon sinks
- Sea-water composition and chemistry

2. Causes and impact on climate change
- Natural causes: volcanic activity, decomposition of organic matter, respiration processes of marine organisms
- Anthropogenic causes: excessive CO_2 emissions absorption, historic CO_2 concentrations (expected to continue rising)
- Ocean acidification from land-based runoff (i.e., nitrogen run-off)
- Economic sectors contributing to acidification: CO_2 emitters
- Positive feedback loop between ocean acidification, global warming, and carbon
- Cycle deregulation

3. Impact on marine life and coastal ecosystems
- Negative effects on calcifying organisms (corals, mollusks, and some plankton): reduced ability to form skeletons and shells, increased vulnerability to predators, and reduced survival rate
- Biodiversity decline
- Threat to fish and other non-calcifying organisms
- Threat to food chain, with ecosystem implications

4. Socio-economic-health impact
- Food security implications (for fisheries and aquaculture)
- Impacts on coastal diets, especially in low-income and island nations
- Negative health effects: seafood toxicity, disease
- Impacts on employment in fisheries and processing industries
- Impact on marine tourism

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Key International Regulatory Initiatives

- United Nations Convention on the Law of the Sea (UNCLOS) — 1982
- United Nations Framework Convention on Climate Change (UNFCCC) — 1992
- Aichi Biodiversity Targets (Convention on Biological Diversity) — 2010
- Monaco Declaration (Second International Symposium on the Ocean in a High-CO_2 World) — 2008
- Paris Agreement (UNFCCC) — 2015

1.2.4 — Novel Entities

TASK Framework: Earth Systems → **Domain**: Regulating Planetary Boundaries → **Subject**: 1.2.4 – Novel entities

Definition: Novel entities (NEs) are new substances, new forms of existing substances and modified life forms, including chemicals and other new types of engineered materials or organisms not previously known to the Earth system as well as naturally occurring elements—for example, heavy metals—mobilized by anthropogenic activities, all of which have the potential for unwanted geophysical and/or biological effects. (Persson, 2022)

1. Chief characteristics of Novel Entities

- Exist in both natural and synthetic forms
- Also xenobiotic organic chemicals (e.g., plastics)
- Variety, diversity, mobility, persistence, dispersion (Long-range transport potential, e.g., acid rain)
- Unknown or poorly known toxicity
- Impacts: localized, additive, bioaccumulative, multiplicative, unpredictable, irreversible, pervasive, chemical intensification
- Potential benefits to science, industry, medicine
- Use in renewable energy & green technology: electronics, electric cars, batteries, wind turbines, solar panels, fiber optics, but with e-waste

2. Dangers of early chemicals

- POPs — Persistent organic pollutants (dioxins)
- DDT — Dichlorodiphenyltrichloroethane
- PCBs — Polychlorinated biphenyl
- EPPP — Environmental persistent pharmaceutical pollutants (e.g., antibiotics)
- VOC — Volatile organic compounds
- Presence of lead: in paint, pipes, gasoline, food, food containers (e.g., pottery), coolant fluids
- Benzene: in dyes, detergents, plastic bottles
- Famous cases:
  - Chemical: Bhopal, Love Canal, Flint Michigan, Agent Orange, AZF, Sandoz, Seveso, Beirut
  - Nuclear: Chernobyl, Fukushima, Three Mile Island, Sellafield, etc.

3. Plastics — waste, hazards, ocean pollution

- Plastic polymers, monomers, and solvents
- Macro- (>5mm), Micro- (<5mm), Nano- (<1µm)
- Nurdles, flakes, powder, textile fibers, microbeads, etc.
- Leach of toxic chemicals (phthalates) from plastics
- Plastic entanglement, ingestion, entry into food webs
- Found in air, clouds, soil, snow, ice, etc.
- Most uncontrolled plastic waste ends up in oceans
- Additives for color, flexibility, stability, ultraviolet resistance, water repellence, flame retardation, etc.
- Top generators: Coca-Cola, PepsiCo, Nestlé, Unilever
- *Great Pacific Garbage Patch* (and others)

4. PFAS and "forever chemicals"

- Huge PFAS (polyfluoroalkyl substances) family
- Types of PFAS (PFOS, PFBA, PFOA, PFNA, etc.)
- Found in soils, rainwater, artic sea ice, air, meltwater, food, etc.
- Long-chain PFAS—1940s; short-chain—1970s
- Found in cleaning products, paints, fire-fighting foams, stain and water-resistant fabrics, textiles, carpets, food ware, plastic ware, Teflon, non-stick cookware, non-biodegradable compostable bowls and plates, waterproof and stainproof textiles, etc.
- Despite toxicity, PFAS chemicals are useful

5. Genetic engineering / Nanotechnology

- GMOs (Genetically modified organisms)
- Animal and plant cloning
- Cellular agriculture and lab-grown meat
- Gene splicing and editing
- Engineered bio-based materials
- Synthetic biology, green chemistry, biotechnology
- Nano-safety and nano-ethics
- Digital novel entities: Blockchain technology (crypto-currency, Bitcoin, etc.)
- Artificial intelligence (high energy consumption; risk to humanity, impact on human cognition)
- Impact of microchips on water use

6. Release of NEs into the environment

- Intentional vs. accidental
- Driven by pace of technological innovation (e.g., greenhouse gases; ozone-depleting gases; CFCs)
- NE production outpaces assessment capacity
- Increasing demand & production volumes
- Release via mining, extraction, refining, processing, production, usage, disposal
- 17 rare-earth elements; toxic heavy metals: mercury, lead, chromium, cadmium, arsenic, beryllium, nickel

7. Toxicity and impact on Earth systems

- Pesticides, insecticides, rodenticides, fungicides
- Hydrological contamination: streams, rivers, lakes, aquifers, soils, wetlands, etc.
- Often leads to land degradation
- Soil contamination via chemical fertilizers
- Biodiversity loss (e.g., amphibians, insects.)
- Neonicotinoids (impact on pollinators, bees)
- Harmful effects on flora and fauna
- PFAS ingestion by flora / fauna (+600 species)
- Entry into human, plant, and animal food webs

8. Toxicity and impact on human health

- EDCs (Endocrine-disrupting chemicals)
- Carcinogenic / mutagenic potential
- Vulnerability of infants, children, elderly, pregnant
- Presence in dietary supplements, cosmetics, pharmaceuticals
- Mercury in seafood and shellfish
- Exposure, ingestion, contamination
- Fire-retardant asbestos: toxic and carcinogenic
- Chemical preservatives, conservatives

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1.2.5 — Biogeochemical Flows

TASK Framework: Earth Systems → **Domain**: Regulating Planetary Boundaries → **Subject**: 1.2.5 Biogeochemical flows

Definition: "Biogeochemical flows describe the continuous movement of essential life elements, like nitrogen and phosphorus, between living organisms (the 'bio' part), the earth (the 'geo' part), and through chemical reactions. These elements are the building blocks of all life, cycling through air, water, and soil to support everything from the smallest microbe to the largest forest." (Sustainability Directory) As such, "biogeochemical cycles involve the fluxes of chemical elements among different parts of the Earth: from living to non-living, from atmosphere to land to sea, and from soils to plants" (Galloway et al., 2014)

1. Principles, processes, characteristics

- Definition: pathways of elements and compounds flowing between living organisms and the environment
- Essential to organic & inorganic processes
- Important distinction between stocks and flows
- Major flows: water, nitrogen, phosphorus, carbon
- Close interactions between H_2O, N, C, P as key biological nutrients
- Minor flows: methane, sulfur, mercury, calcium, etc.
- All subject to human disruption
- Several important flows have been modified beyond safe thresholds

2. The Water (H_2O) cycle

- H_2O cycle processes: evaporation, condensation, precipitation, infiltration, runoff
- Key components: oceans, lakes, rivers, glaciers, groundwater, soil, atmosphere
- Natural H_2O fluxes: continuous circulation between atmosphere, land, and oceans through evaporation, transpiration, and precipitation
- Anthropogenic influences: climate change altering rainfall patterns; overextraction of groundwater; dam construction; pollution and land-use change disrupting flows
- Consequences of disruptions: droughts, shifts in precipitation (more rain, less snow), declining soil moisture and wetland loss, ecosystem degradation

3. The Nitrogen (N) cycle

- N cycle processes: N fixation, nitrification, assimilation, ammonification, denitrification
- Key components: atmospheric N, soil bacteria, plants, animals
- Natural N fluxes: biological fixation, atmospheric fixation (lightning), industrial fixation (Haber-Bosch process)
- Anthropogenic influences:
  - Intensive agricultural practices: use of synthetic fertilizers, impacts on soil health, runoff issues
  - Industrial processes: fossil fuel combustion, NOx emissions, contribution to smog and acid rain
- Consequences of disruptions: eutrophication, acid rain, climate change (N_2O), soil acidification

4. The Phosphorus (P) cycle

- P cycle processes: mineralization, immobilization, sedimentation, weathering
- Key components: phosphate rock, soil minerals, organic and inorganic P in soil and water
- Natural P fluxes: weathering of rock, absorption by plants, return to soil via decomposition, sedimentation in aquatic systems
- Anthropogenic influences: mining, fertilizer use in food production, wastewater discharge, P-based detergents
- Phosphate availability: resource depletion concerns, implications for food security, recycling potential
- Consequences of disruptions: eutrophication, soil fertility loss, freshwater contamination

5. The Carbon (C) cycle

- C cycle processes: photosynthesis, respiration, decomposition, ocean–atmosphere exchange, combustion
- Key components: C reservoirs and sinks (atmosphere, oceans, biosphere, lithosphere); emitters (fossil fuel combustion, land use change)
- Natural C fluxes: fast C exchanges among atmosphere, oceans, biosphere; slow geological C cycle through rock formation and weathering
- Anthropogenic influences: fossil fuel combustion and deforestation intensifying greenhouse effects; ocean CO_2 absorption causing acidification
- Consequences of disruptions: accelerated climate change, ocean acidification, and soil carbon loss disrupting the green water cycle

6. Eutrophication and its impacts

- Definition and overview
- Causes: Nutrient runoff from agriculture, urban stormwater, wastewater discharge, atmospheric deposition
- Role of N and P in eutrophication
- Impacts on aquatic ecosystems: Algal blooms, hypoxia (oxygen depletion), fish kills, biodiversity loss, formation of dead zones
- Impacts on human health and economy: drinking water, recreational activities, commercial and sport fishing

7. Other ecological impacts of altered nutrient cycles

- Acidification: pH changes in soil and water, impacts on organisms
- Dead zones: Locations, causes, impacts on aquatic life
- Soil health: nutrient depletion, erosion, changes in soil structure
- Biodiversity impacts: species loss, shifts in community structure, impacts on ecosystem services
- P mining impacts: habitat and biodiversity loss, soil erosion, water contamination

8. Socio-economic impacts of biogeochemical disruptions

- Water quality: nutrient runoff, health risks, costs for water treatment
- Algae blooms: red tides, respiratory issues, beach closures, impacts on tourism
- Fishery impacts: changes in fish stocks, economic consequences for fishing industry, food supply issues
- Farming challenges: yield reductions due to nutrient imbalances, increased fertilizer costs, soil erosion
- Phosphate mining: labor issues, local economy impacts, geopolitical issues related to phosphate resources
- Food security: price volatility, availability, impacts on trade and political stability

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TASK 1.2.6 — Atmospheric Aerosols Loading

BY Sulitest

Subject Knowledge Navigational Chart

TASK Framework: Earth Systems → **Domain**: Regulating Planetary Boundaries → **Subject**: 1.2.6 – Atmospheric aerosols loading

Definition: Commonly known as air pollution, aerosols are made up of "a suspension of airborne solid or liquid particles, with typical particle size in the range of a few nanometers to several tens of micrometers and atmospheric lifetimes of up to several days in the troposphere and up to years in the stratosphere. […] Aerosols may be of either natural or anthropogenic origin in the troposphere; stratospheric aerosols mostly stem from volcanic eruptions. […] Atmospheric aerosols may be either emitted as primary particulate matter or formed within the atmosphere from gaseous precursors (secondary production)." (IPCC AR6, 2021)

1. Air pollution, aerosols, particulate matter

- Solid particles, liquid droplets, aerosols, or gaseous matter suspended in air
- Primary and secondary pollutants, aerosol precursors
- Air pollution (aerosols and gaseous pollutants)
- Non-aerosol air pollution (SO_2, NO_2, etc.)
- Types of particulate matter: course-PM10, Fine-PM2.5, Ultrafine—PM0.1
- Smog, haze, soot, dust, CFCs, HCFCs, etc.

2. Air quality and air quality standards

- Air quality indexes
- Indoor air quality (IAQ)
- State, regional, national, and international guidelines: European air quality index, US EPA *National Ambient Air Quality,* WHO PM safety thresholds
- Index of most/least PM polluted cities
- Volatile Organic Compounds (VOC)
- Clean energy for indoor cooking and heating
- Tobacco, oil industry disinformation

3. Natural or biogenic causes (90%)

- Inorganic (Natural)
  - Volcanoes (ash, sulfur, CO_2, acid rain)
  - Dust storms, mineral dust from wind erosion
  - Sea spray/ sea salt
  - Water vapor, clouds, fog, mist
- Organic (Biogenic)
  - Forest and grassland fires (i.e., smoke)
  - Pollen, fungal & plant spores, bacteria, mold

4. Human related causes—Macro

<u>Industry—Agriculture—Commerce—Transport</u>

- Fossil fuel combustion—coal, oil, gas (sulfates, nitrates, organic carbon, soot, black carbon, ash, etc.)
- Burning biomass—wood, crop residue, slash & burn, municipal waste
- Industrial manufacturing—smelting, welding, mining, woodworking, cement, quarries, etc.
- Agriculture—pesticide spraying, plowing, tilling, harvesting, processing, etc.
- Construction, renovation, demolition, asbestos
- Transport—roadworks, car & truck exhaust, aircraft contrails, shipping, ship tracks, etc.
- Non-exhaust emissions: brake pads, tire wear, road dust, etc.

5. Human related causes—Micro

<u>Local—Household—Individual</u>

- Everyday biomass combustion: fireworks, bonfires, outdoor heaters, oil lamps, candles
- Biomass heating, woodstoves, garden waste incineration
- Cooking, frying, boiling, chargrilling, BBQ
- Smoking, vaping, third-hand smoke
- Spray paints, solvents, household aerosols, etc.
- Garden pesticides, insecticides, fertilizers
- Deodorants and body sprays, household dust, skin shedding

6. Impact on human health

- Depends on PM shape, size, concentration, toxicity
- Respiratory, cardiovascular, genetic health effects (e.g., heart and lung disease, asthma, infertility, birth defects, etc.)
- Mortality, morbidity, and mental health related to air pollution (Alzheimer's disease)
- Airborne PM is listed as a Group 1 carcinogen
- Indoor vs. outdoor air quality
- Health effects of coal ash, pesticides, asbestos, sawdust, lead paint dust, etc.
- Vulnerable people and environmental justice
- Economic and social costs of air pollution

7. Impact on CO_2, climate, and weather

- Direct radiative effect (cooling/warming)
- Amplification or mitigation of global warming
- Scattering of light
- Cloud formation, air circulation, precipitation
- Acid rain (water vapor + sulfate aerosols)
- Monsoon systems and rain patterns
- Interaction with ozone

8. Impact on ecosystems and biodiversity

- Effects on photosynthesis and plant productivity
- Acidification of soils and water bodies
- Impacts on wildlife and food chains
- Influence on pollinator behavior
- Deforestation and land-use change

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1.2.7 — Stratospheric Ozone Depletion

TASK Framework: Earth Systems → **Domain**: Regulating Planetary Boundaries → **Subject**: 1.2.7 – Stratospheric Ozone Depletion

Definition: "The stratosphere contains a layer in which the concentration of ozone is greatest, the so-called ozone layer. The layer extends from about 12 to 40 km above the Earth's surface. [...] This layer has been depleted by human emissions of chlorine and bromine compounds. Every year, during the Southern Hemisphere Spring, a very strong depletion of the ozone layer takes place over the Antarctic, caused by anthropogenic chlorine and bromine compounds in combination with the specific meteorological conditions of that region. This phenomenon is called the Ozone hole." (IPCC, 2013: 1459)

1. Ozone and ozone holes
- Stratospheric ozone
- Tropospheric ozone
- Ozone layer
- Solar radiation and ozone
- Definition of "ozone holes"
- Evolution and current state
- Regional differences
- Hotspot locations
- Impact of climate change on ozone recovery

2. Ozone-depleting substances
- Ozone depleting substances (ODS) and ozone depletion potential (ODP)
- Mechanism of ozone depletion
- CFCs / HCFCs, used in air conditioning, refrigeration, aerosol propellants, etc. (anthropogenic sources)
- Halons, used in fire suppression systems and firefighting (anthropogenic source)
- Nitrous oxide (N_2O), also a GHG
- N_2O sources: emitted during agricultural and industrial activities, wastewater management, fossil fuel use
- There are both natural and anthropogenic sources of N_2O

3. International response and action
- The Montreal Protocol: goals and achievements
- Multilateral fund
- Kigali amendment (Addition of HFCs)
- Factors contributing to the success of the Montreal Protocol
  - Global consensus and agreement
  - Clear and indisputable scientific evidence
  - Existence of viable, cost-effective alternatives to ODS
  - Enforcement mechanisms, including trade sanctions

4. Health and environmental consequences
- Impacts on health (UV radiation, skin and eye conditions, immune system disruption)
- Environmental disruption (ecosystems, habitats, food webs)
- Marine life: impacts on phytoplankton, the basis of ocean food chains (due to UV)
- Decrease in crop yield (due to UV)

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