1.1.1 — Climate Change

TASK by Sulitest **Subject Knowledge Navigational Chart**

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

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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)

Planetary Boundary Control Variable: The safe operating space for climate change is determined by atmospheric CO_2 concentration of no more than 350 parts per million (ppm) and change in the stratospheric energy absorption balance relative to preindustrial levels. (Steffen *et al*, 2015)

Planetary Boundary Status: It was established in 2015 that the boundary of the safe operating space is transgressed. (Steffen, 2015)

Key Ideas

1. Earth climate system
2. Greenhouse effect
3. Climatology / Climate science
4. Anthropogenic climate change
5. Climate change impacts: On Earth Systems
6. Climate change impacts: On Human Welfare
7. Climate change prevention
8. Climate change adaptation
9. Climate change mitigation
10. Climate Justice
11. Climate engineering
12. Climate change "controversy"

Key International Regulatory Initiatives

- Intergovernmental Panel on Climate Change (IPCC) 1988
- UN Framework Convention on Climate Change-UNFCCC (1994
- Conference of the Parties (COP) (1995-2023
- 2015 Paris Agreement (Paris Climate Accord) (COP21)
- IPCC 6th Assessment Report (AR6) 2021-2023
  - The Physical Science Basis (WG1) (2018)
  - Impacts, Adaptation and Vulnerability (WG2) 2022
  - Mitigation of Climate Change (WG3)

1. Earth climate system

- Climate—weather—season
- Causes of natural climate variation
  - Climate carbon cycle variation
  - Solar radiation variation
  - Earth orbit variation
  - Volcanic activity variation
- Annual global mean surface temperature (GMST)
- The Holocene epoch
- Ice age CO_2: 200 parts per million (ppm)
- Interglacial (Holocene) CO_2: 280 ppm
- Photosynthesis

2. Greenhouse effect

- Solar radiation reflection / absorption
- Earth energy balance
- Earth energy budget
- Natural GHG: Greenhouse gases / Heat-trapping gases
- Water vapor / clouds
- Carbon cycle
- Carbon sinks

3. Climatology / Climate science

- Greenhouse gases: CO_2, N_2O, CH_4, CFC, H_20 (clouds)
- Atmospheric CO_2 concentration (PPM)
- Climate sensitivity
- Climate equilibrium / disequilibrium
- Radiative forcing
- Climate feedback / Feedback loops
- Climate threshold / Tipping points
- Climate modeling (e.g., the "hockey stick" graph)
- Parts per million (PPM)
- Albedo feedback loop

4. Anthropogenic climate change

- The Anthropocene epoch
- Anthropogenic GHG emissions
- Fossil fuels
- CO_2 and CO_2 equivalent (CO_2-eq) emissions
- Black carbon (soot)
- Current Anthropocene CO_2:(420 ppm) and Global Warming (+1.1°C)
- The "Great Acceleration"
- Global dimming

5. Climate change impacts: On Earth Systems

- Air temperature rise (Global warming)
- Water scarcity: Wildfire / Desertification
- Sea-level rise (via thermal expansion, ice melt)
- Ocean current change
- Global ice loss
- Ocean acidification (e.g., impact: Coral bleaching)
- Biodiversity loss
- Marine habitat loss
- Species migration / extinction
- Flooding / erosion

6. Climate change impacts: On Human Welfare

- Migration
- Climate refugees
- Pandemic / Infectious disease
- Human health
- Food security (terrestrial and marine)
- Water scarcity / Freshwater contamination
- Energy security
- Coastal and river flooding
- Extreme weather event

7. Climate change prevention

- Paris accord target / pathway to 1.5°C increase
- Global carbon budget
- Carbon tax
- Decarbonization
- Low / zero carbon economy
- Climate action
- Methane emissions reduction
- CO_2 capture and storage (CCS)
- Overshoot pathways: +1.5°C increase

8. Climate change adaptation

- Climate resilience
- National adaptation plans
- National *Climate Action Plans*
- Adaptive capacity
- Small island states
- MAPA—*Most Affected People and Areas*
- Highly vulnerable populations

9. Climate change mitigation

- Carbon emissions reduction / Carbon neutrality
- Net-zero carbon emissions
- Carbon offsetting / onsetting / carbon credits
- Agroforestry / reforestation / afforestation
- Participation of indigenous people
- Blue carbon
- Peatland / wetland restoration
- Economics of climate change mitigation
- Climate impact reduction
- Disaster risk reduction
- *UN Sustainable Development Goals*

10. Climate Justice

- Environmental justice
- Transformative justice
- Intergenerational equity
- Historical carbon footprint
- "Polluter pays" principle
- "Loss and damage" principle
- Climate legislation, litigation, protest (Greenpeace, Thunberg, Extinction Rebellion, etc.)
- Green Climate Fund
- International climate finance
- Just transition (workers' rights)

11. Climate engineering

- Geoengineering
  - Carbon Dioxide Removal (CDR)
  - Solar Radiation Management (SRM)
  - Passive Daytime Radiative Cooling (PDRC)
- Carbon sequestration
- Ocean engineering
- Afforestation

12. Climate change "controversy"

- Scientific consensus on climate change
- Critical thinking / Scientific method
- Uncertainty / Precautionary principle
- Manufactured uncertainty (e.g., Urban heat island effect)
- Climate change denial
- Climate action delay
- Fossil fuel lobby
- Conspiracy theory
- Pseudoscience

Learning Objectives — Climate Change

Knowledge Type	*The sustainability literate learner will be able to …*
Definitions *Descriptive knowledge*	1. Explain the meaning of climate change and describe the key characteristics of the phenomenon 2. Describe the physical principles, processes, and significance of greenhouse gases (GHG) and the greenhouse effect 3. Explain the origin and meaning of the terms Anthropocene and anthropogenic 4. Identify and differentiate among the factors that contribute to either climate stability (equilibrium) or climate disruption (disequilibrium) 5. Differentiate climate change from weather and seasonal meteorological change 6. Identify and explain the control variable used to establish the Planetary Boundary for climate change (I.e., both temperature and CO_2)
Current State & Trends *Contextualized knowledge*	1. Determine humanity's current location vis-à-vis the Planetary Boundary for climate change 2. Describe the amount, rate of change, and significance of anthropocentric global temperature rise and compare it to previous periods of climate change 3. Identify the main natural and anthropogenic greenhouse gases present in the Earth's atmosphere that contribute to climate change 4. Describe trends in GHG emission reductions since the 2015 Paris Agreement and follow-up climate commitments 5. Categorize countries and regions with high/low GHG emissions and situate each in terms of responsibility for—and vulnerability to—climate disaster 6. Identify the key local, state, and non-state actors in climate change and the role each plays in either driving or mitigating climate change
Major Causes *Causal knowledge*	1. Identify the main sources of anthropogenic GHGs by sector of human activity (i.e., individual, local, national, and global) 2. Describe the physical factors and feedback loops that increase or decrease the speed and/or intensity of climate change 3. Identify systemic economic and market-related factors that contribute to GHG emissions and global warming 4. Articulate related structural, attitudinal, and behavioral patterns that contribute to—or help mitigate—climate change 5. Identify related drivers of climate change other than anthropogenic GHG emissions 6. Identify major actors and activities that contribute to—or help mitigate—climate change
Systemic Impacts *Integrated knowledge*	1. Describe the types, nature, and intensity of climate change hazards at the local, national, and global levels 2. Define the concept and significance of tipping points and provide examples related to climate change 3. Explain the consequences on other Earth systems of CO_2 emissions and additional increments of climate change 4. Categorize climate change hazards into immediate, mid-term, and long-term threats 5. Describe the most probable disaster scenarios—and related risks to human health—of climate change

Key Resources — Climate Change

IPCC (2021) Climate Change 2021: The Physical Science Basis. Contribution of WG1 to the Sixth Assessment Report of the IPCC. Retrieved from https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

IPCC (2022) Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of WG2 to the Sixth Assessment Report of the IPCC. Retrieved from https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf

IPCC (2022) Climate Change 2022: Mitigation of Climate Change. Contribution of WG3 to the Sixth Assessment Report of the IPCC. Retrieved from https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SummaryForPolicymakers.pdf

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UNESCO Learning Objectives & Discussion Topics (Full report). Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000247444

1.1.2 — Biosphere Integrity

TASK by Sulitest **Subject Knowledge Navigational Chart**

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

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Definition: "The biosphere integrity boundary thresholds [sic] the ability of ecosystems to continue to provide goods and services to human society, and the risk of these benefits being threatened due to biodiversity loss". (Hurley & Tittensor, 2020)

Planetary Boundary Control Variable: The safe operating space for biosphere integrity is determined by two variables: global extinction rate, which reflects genetic diversity, and the Biodiversity Intactness Index, which reflects functional diversity.

Planetary Boundary Status: It was established in 2015 that the safe operating boundary is transgressed and is in a zone of uncertainty (i.e., high risk). (Steffen *et al*, 2015)

Key Ideas

1. Terminology of biodiversity
2. The 6th extinction
3. Indirect drivers
4. Indirect-to-direct drivers: Actions that directly affect nature
5. Direct drivers
6. Animal welfare and ecosystem rights
7. Climate change & biodiversity
8. Ecosystem services: Nature's Contribution to People (NCP)
9. Integrated approaches for sustainable development
10. Sustainable marine and coastal governance
11. Biodiversity in economics

Key International Regulatory Initiatives

- International Panel on Biodiversity and Ecosystem Services (IPBES)
- Convention on International Trade in Endangered Species of Wild Fauna & Flora (CITES), 1973
- Convention on Biological Diversity (CBD), 1992
- Nagoya Protocol on Access to Genetic Resources and Fair and Equitable Benefit Sharing (Nagoya Protocol), 2010
- Kunming-Montreal Global Biodiversity Framework (GBF), 2022: Transboundary protected areas

1. Terminology of biodiversity

- Biosphere integrity
- Genetic diversity
- Functional diversity
- Ecosystems, species
- Natural capital
- Species interdependence
- Marine ecosystems
- Freshwater ecosystems
- Terrestrial ecosystems

2. The 6th extinction

- Mass extinctions
- Extinction rate (E/MSY)
- Biodiversity Intactness Index (BII)
- Red List Index
- Migration speed
- Transboundary protected areas
- Pandemics and zoonoses

3. Indirect drivers

- Demographic: population dynamics, urbanization
- Technological changes: agriculture, biomass energy
- Economic: concentrated production, trade, financial flows
- Governance: market, local communities, states, and policies

4. Indirect-to-direct drivers: Actions directly affecting nature

- Fisheries, Aquaculture and Mariculture
- Agriculture and grazing (crops, livestock)
- Forestry (logging for wood & biofuels)
- Harvesting (wild plants and animals)
- Mining (minerals, metals, oils, fossil fuels)
- Infrastructure (dams, cities, roads)
- Illegal activities with direct impacts on nature

5. Direct drivers

- Land/sea-use change: destruction (deforestation, desertification), artificialization, fragmentations
- Direct exploitation of organisms
- Climate change
- Pollution: emissions into the atmosphere, contaminants dissolved in/carried by water, disposal or deposition of solids
- Invasive alien species (IAS)

6. Animal welfare and ecosystem rights

- Animal-industrial complex
- Animal testing
- Speciesism
- Anti-speciesism, animal rights movement
- Legislation
- Ecosystem rights, rights of nature
- Environmental personhood
- Ecocide
- Nature-Culture divide

7. Climate change and biodiversity

- Effects of climate change on natural environments: temperature rise, sea-level rise, ocean acidification…
- Effects of climate change on living beings: species range shifts, impacts on phenology, increased disease risk…
- Role of ecosystems in mitigating climate change impacts (mitigation and adaptation)
- Climate actions affecting biodiversity (positively/negatively)
- Biodiversity actions affecting climate (positively/negatively)

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

- Regulating services: habitat creation and maintenance, pollination; regulation of air quality, climate, ocean acidification, freshwater quantity, freshwater quality, soils, extreme events, detrimental organisms, and biological processes
- Provisioning services: energy, food, materials, medicinal and genetic resources
- Cultural services: learning and inspiration, physical and psychological experiences, supporting identities
- Supporting services: maintenance of options

9. Integrated approaches for sustainable landscapes

- Agriculture: regulate commodity chains, promote organic, genetic diversity, dietary transitions, reduce food waste
- Forests: monitoring, improve certification, reduce, and control logging
- Protected areas: improve and expand them, address illegal wildlife trade, manage invasive alien species
- Ecosystem restoration: expand it, improve financing

10. Sustainable marine and coastal governance

- Conservation funding for the oceans
- International waters: improve shared governance, mainstream NCPs
- Coastal waters: conservation in sectoral management, on fisheries in particular

11. Biodiversity in economics

- Ecosystem accounting
- Dual materiality
- Valuation of the ecosystem services
- Sustainable use of resources
- Theory of the Commons
- Reforming environmentally harmful subsidy and tax policies

Learning Objectives — Biosphere Integrity

Knowledge Type	*The sustainability literate learner will be able to …*
Definitions *Descriptive knowledge*	1. Describe the nature, structure, components, and characteristics of the biosphere and what we call biodiversity and biosphere integrity 2. Identify the principles, processes, and components of Earth's principal ecosystems and describe their respective roles in climate regulation 3. Define what is meant by ecosystem services and provide examples from marine and terrestrial ecosystems that benefit humans 4. Explain the concept and multiple manifestations of land-system change and its impact on both climate and biodiversity 5. Identify and explain the dual criteria used to establish the planetary boundary for biosphere integrity (i.e., functional diversity and genetic biodiversity)
Current State & Trends *Contextualized knowledge*	1. Identify the main types of habitats, ecosystem, and biosphere degradation and corresponding biodiversity loss due to human activity 2. Assess the extent of life-form extinctions currently taking place and compare the current extinction rate to the historical background rate 3. Categorize the hazards of biosphere degradation and biodiversity loss into immediate and long-term threats to humans and human well-being 4. Describe the nature and extent of land-use and ocean-use change by human activity 5. Identify and describe strategies for protecting and restoring biosphere integrity (e.g., conservation/preservation, sustainable land use, legislation, etc.)
Major Causes *Causal knowledge*	1. Identify the major causes of biodiversity loss and species extinctions (e.g., habitat loss, deforestation, animal exploitation, invasive species, etc.) 2. Identify the multiple forms and sources of human-generated pollution (e.g., ecosystem, habitat, marine, terrestrial, freshwater, atmospheric, invasive species, etc.) 3. Quantify the official boundary thresholds established for addressing biosphere integrity and the extent to which these boundaries have been transgressed 4. Discuss to what extent humans engage in responsible production, consumption, and effective waste management in order to protect biosphere integrity 5. Account for the apparent lack of concern by humans of the rights, needs, and intrinsic value of the animal and plant kingdoms
Systemic Impacts *Integrated knowledge*	1. Identify the multiple hazards and consequences of biodiversity loss for both Earth's regulating systems and human welfare systems 2. Describe the impact on biodiversity from excessive use and misuse by humans of the land, oceans, and atmosphere 3. Imagine and describe the risks and worst-case scenarios stemming from the collapse of biodiversity 4. Explain the importance of respecting the fragility, balance, and interlinkages of Earth systems and natural biosphere processes 5. Articulate structural, attitudinal, behavioral, and legislative changes required of humans if they are to avoid the collapse of Nature

Key Resources — Biosphere Integrity

IPBES (2019). Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Retrieved from https://doi.org/10.5281/zenodo.3831673

IPBES-IPCC co-sponsored workshop report on biodiversity and climate change; IPBES and IPCC. Retrieved from https://www.ipbes.net/events/ipbes-ipcc-co-sponsored-workshop-biodiversity-and-climate-change

Linn Persson, et al. (2022). Outside the Safe Operating Space of the Planetary Boundary for Biosphere Integrity. Environmental Science & Technology, 56(3), 1510-1521. https://doi.org/10.1021/acs.est.1c04158

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1.2.1 — Freshwater Use

TASK by Sulitest **Subject Knowledge Navigational Chart**

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

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Definition: "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)

Planetary Boundary Control Variable: Global: Maximum amount of consumptive blue water use ($km^3.yr^{-1}$). Basin: Blue water withdrawal as % of mean monthly river flow. For Green water: Monthly root-zone soil moisture deviates from Holocene variability (Wang-Erlandsson et al., 2022)

Planetary Boundary Status: Blue water: remains in the safe zone but with increasing risk. Green water: safe operating boundary transgressed and in a zone of uncertainty (i.e., high risk) (Wang-Erlandsson et al., 2022)

Key Ideas

1. Natural cycle and processes
2. Types of blue water
3. Green water distinctive features
4. Human use and misuse of (blue) freshwater
5. Water pollution
6. Threats to freshwater use
7. Freshwater ecosystems and biodiversity
8. Impacts of water scarcity and overabundance
9. Water governance and policy
10. Sustainable freshwater use and management

Key International Regulatory Initiatives

- The 1977 United Nations Water Conference
- The Dublin Statement on Water and Sustainable Development, 1992
- Ramsar Convention on Wetlands, 1971
- UNESCO International Hydrological Program
- UN Watercourses Convention, 1997

1. Natural cycle and processes

- Global water cycle
- Hydrological cycle and the role of freshwater
- Carbon and nutrient cycles in freshwater systems
- Evapotranspiration and precipitation
- Sea-to-land moisture transport: Influence on rainfall, implications for agricultural regions
- Water scarcity: Causes (drought, overuse), impacts (shortages, restrictions, rationing)
- Water abundance: Causes (heavy rainfall, rapid snowmelt), impacts (flooding, soil erosion)
- Proportion of freshwater to salt water
- Proportion of accessible freshwater to freshwater stock

2. Types of blue water

- Blue water
- Global scale vs Basin scale; regional hydrological cycles
- Surface water: Lakes, rivers, reservoirs, their ecological and economic importance
- Groundwater: Aquifers, wells, importance for agriculture and drinking water supply
- Interaction between surface/groundwater: recharge and discharge zone, impacts on water availability
- Global freshwater distribution
- Freshwater resources and supply

3. Green water distinctive features

- 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…
  - Evaporation: agriculture and pasture expansions, CO2 emissions…
  - Soil moisture: agricultural intensification/expansion, urbanization, precipitation, and evaporation alterations
- Differentiated impact of activities (e.g., deforestation) on blue and green water

4. Human use and misuse of freshwater

- Concept of virtual water, water footprint
- Agricultural use: Irrigation and livestock
- Industrial use: Manufacturing, waste disposal
- Domestic use: Drinking, sanitation, and recreation
- Aquaculture: fish and shellfish
- Energy: Hydropower, cooling water for power plants
- Political and legal aspects: Water rights, transboundary conflicts, water legislation
- Economic water scarcity: Lack of infrastructure to access water, primarily in developing nations

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…
- Habitat destruction: Dam construction, river diversions, wetland drainage, urbanization
- Land conversion: Loss of biodiversity, increased carbon emissions, loss of natural flood defenses
- Water storage: mega-basins

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
- Eutrophication impacts: Algal blooms, red tides, dead zones… (see 1.2.5)
- Threats to coastal ecosystems
- Freshwater food webs: Trophic levels, keystone species, impact of species loss
- Deforestation impacts: Increased runoff, reduced infiltration, siltation of water bodies

8. Impacts of water scarcity and overabundance

- Health impacts: Waterborne diseases, malnutrition due to crop failure
- Social impacts: poverty, environmental refugees…
- Water conflict, water war (*Tigris and Euphrates Rivers, Egypt and Ethiopia, Colorado…*)
- Water and education: impact of water-related chores on school attendance, especially for girls
- Flood risk management: Infrastructure, land use planning, early warning systems
- Drought risk management: Water conservation, drought-resistant crops, climate forecasting

9. Water governance and policy

- Policy instruments: water pricing, water rights
- Role of local communities, NGOs, and international organizations in freshwater management
- Community-based water management: Local stewardship, traditional knowledge, capacity building
- Transboundary water management: International treaties and cooperation, cooperative models
- Water privatization: pros and cons, impacts

10. Sustainable freshwater use and management

- Technologies for water conservation: efficient irrigation methods (drip, sprinkler), wastewater reuse systems, rainwater harvesting, soil conservation
- Integrated water resources management (IWRM)
- Desalination: Methods, potential, environmental impact
- Nature-based solutions: Wetland conservation, reforestation, green infrastructure
- Resilience building in freshwater management

Learning Objectives — Freshwater Use

Knowledge Type	*The sustainability literate learner will be able to …*
Definitions *Descriptive knowledge*	1. Explain the meaning and key characteristics of freshwater use and identify key corresponding bibliographical references 2. Characterize the importance of access to freshwater to life, Human welfare, and Earth systems 3. Describe the multiple types and characteristics of freshwater scarcity, virtual water and Integrated Water Resources Management 4. Describe the natural cycles, processes, distribution, sources, and proportion to total water on Earth of freshwater resources 5. Identify multiple types of health-related services and ecosystem services provided to humans by freshwater resources 6. Identify and explain the control variable used to establish the Planetary Boundary for freshwater use
Current State & Trends *Contextualized knowledge*	1. Determine humanity's current location vis-à-vis the *Planetary Boundary* for freshwater use 2. Estimate past, current, and projected freshwater needs, and corresponding available resources 3. Estimate the past, current, and projected status of freshwater-related ecosystems. 4. Identify countries and/or regions that are particularly rich in freshwater resources and/or vulnerable to water scarcity or water quality
Major Causes *Causal knowledge*	1. Identify and rank the direct causes of the transgression of the Planetary Boundary such as misuse, and water quality deterioration 2. Identify and rank the underlying structural drivers of the transgression of the Planetary Boundary 3. Explain the factors and processes leading to increased demand for freshwater 4. List the major causes of water stress, declining water quality, and the deterioration of water-related ecosystems 5. Identify major local, state, and non-state actors and the role each plays in contributing to preserving or depleting freshwater resources
Systemic Impacts *Integrated knowledge*	1. Identify and evaluate the major consequences of respecting or transgressing the Planetary Boundary for freshwater use 2. Identify and evaluate the consequences of disrupting natural water cycles and freshwater resources 3. Identify the multiple hazards and consequences of freshwater loss for both Earth's regulating systems and human welfare systems 4. Categorize the hazards of freshwater loss into immediate, mid-term, and long-term threats to human well-being and ecosystem stability 5. Imagine and describe the risks and worst-case scenarios stemming from the decline of freshwater resources

Key Resources — Freshwater Use

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1.2.2 — Land-System Change

TASK by Sulitest **Subject Knowledge Navigational Chart**

TASK Framework: Earth Systems → **Domain:** Regulating Planetary Boundaries → **Subject:** 1.2.2 – Land-System Change	*Click here for User Guidelines*

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 (effects on local environment and human wellbeing) and global (factors of global environmental change) consequences. According to Steffen, forests (by their presence or absence) have a larger effect on the global climate than other changes in land systems.

Planetary Boundary Control Variable: The safe operating space for land-system change is determined at two levels: 1) *Global*: the area of forested land as % of original forest cover; 2) *Biome*: the area of forested land as % of potential forest. (Steffen *et al*, 2015)	**Planetary Boundary Status:** The safe operating boundary is transgressed and in a zone of uncertainty (i.e., increasing risk).

Key Ideas

1. Land uses and land ecosystems
2. Ecosystem services
3. Forest ecosystems
4. Land degradation mechanisms
5. Agricultural expansion and intensification
6. Soil health and management
7. Rural development considerations
8. Nature-based solutions
9. Land use planning

Key International Regulatory Initiatives

- FAO Food and Agriculture Organization (UN)
- State of the World's Forests – UN FAO: Food and Agriculture Organization
- UNEP – UN Environmental Program
- IPBES - Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
- Global Forest Goals Reports – UN Department of Economic and Social Affairs

1. Land uses and land ecosystems • Human land use, food, housing, transport etc. • Systemic perspective, land system science • Cropland • Ecosystems: forest, woodlands, savannah, grasslands, shrublands, tundra	**2. Ecosystem services** • Food production, pollination, resources • Climate regulation, water provision • Natural resources • Cultural, religious, ritualistic services • Biodiversity: functional and genetic	**3. Forest ecosystems** • De-, re-, afforestation • Primary forests • Drivers of deforestation • Forest cover rate • Tropical, boreal, temperate forest biomes • Carbon sinks	**4. Land degradation mechanisms** • Irrigation and salinization • Destruction of natural habitats • Fertilization and eutrophication • Physical, chemical, biological treatments • Overgrazing, deforestation • Artificializing • Soil erosion
5. Agricultural expansion and intensification • Green Revolution (Haber-Bosch) • Population growth • Mechanization, specialization • Irrigation • Pollutions (soil, water, air) • Resource intensive	**6. Soil health and management** • Degradation of soils • Soil fertility and (over) fertilization • Long term consequences • Limited soil adapted to agriculture for human use • Soil life, chemistry, structure essential for production and life • Conservation Agriculture, organic agriculture	**7. Rural development considerations** • Rural—urban inequalities • Rural Development policies (world social report 2021) • Right to land, natural resources for indigenous populations • Land grabbing • (Indigenous) Rights to land, territories, and resources	**8. Nature-based solutions** • Agro-ecology, agroforestry, closed cycle agriculture • Ecosystem service remuneration • Biomimicry • Nature Conservation: rewilding, restoration, monitoring
9. Land use planning • Land Use Policy on local, regional, national, and international level • Sustainable Land Management • Inclusive land use planning regarding indigenous populations and rights • EU: Common Agricultural Policy 2023-2027 • Access to Land, small-holders protection against land grabbing			

Learning Objectives — Land-System Change

Knowledge Type	*The sustainability literate learner will be able to …*
Definitions *Descriptive knowledge*	1. Explain the meaning of *land-system change* and describe the key characteristics of the phenomenon 2. Identify, describe, and differentiate among the major types of land ecosystems, major land uses, and land-system change processes 3. Explain and differentiate among agriculture concepts such as irrigation, cropland, arable land, soil health, land rights, and ownership 4. Describe the basic principles of sustainable agriculture as well as the main drivers of—and obstacles to—sustainable agricultural practices 5. Identity and describe ecosystem services and the beneficial role they play in climate adaptation and mitigation 6. Identify and explain the control variable used to establish the *Planetary Boundary* for land-system change
Current State & Trends *Contextualized knowledge*	1. Determine humanity's current location vis-à-vis the *Planetary Boundary* for land-system change 2. Describe past, current, and projected changes in land-system use by geographical region 3. Estimate the global proportional distribution of land types for both major ecosystems and land use and describe how they are changing 4. Identify countries and/or regions that have experienced the greatest amount of land-system change over time 5. Identify and describe impediments to respecting the *Planetary Boundary* on land-system change as well as the stakes of transgressing it
Major Causes *Causal knowledge*	1. Identify and rank the main factors contributing to land-system change at respective local, national, and global levels 2. Identify and rank the underlying structural drivers of land-system change by economic sector 3. Describe the role land-use efficiency plays in contributing to, or exacerbating, land-system change 4. Explain the factors and processes contributing to and incentivizing land-system change 5. Identify major local, state, and non-state actors and the role each plays in contributing to—or resisting—land-system change
Systemic Impacts *Integrated knowledge*	1. Identify and evaluate the major consequences of respecting or transgressing the *Planetary Boundary* for land-system change 2. Evaluate and relate the potential of ecosystem services for climate mitigation and adaptation and provide examples of nature-based solutions 3. Evaluate and relate the necessity of sustainable agricultural practices and be able to give examples and argue for such practices 4. Describe the impact of agricultural policies and market principles on other planetary boundaries 5. Describe the consequences of land-system change on climate change and biodiversity

Key Resources — Land-System Change

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1.2.3 — Ocean Acidification

TASK by Sulitest **Subject Knowledge Navigational Chart**

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

Click here for User Guidelines

Definition: "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 (CO2) 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)

Planetary Boundary Control Variable: The safe operating space for ocean acidification is determined by aragonite saturation of no less than 80% of pre-industrial levels in mean surface ocean water (Carbonate ion concentration, average global surface ocean saturation state with respect to aragonite). (Steffen *et al,* 2015)

Planetary Boundary Status: The oceans remain in the safe zone but with increasing risk.

Key Ideas

1. Principles of ocean acidification
2. Natural causes
3. Anthropogenic causes
4. Ocean acidification and climate change
5. Impact on marine life
6. Impact on coral and coastal ecosystems
7. Socio-economic impact
8. Water ecosystems: acidification beyond the oceans
9. Mitigation and adaptations strategies

Key International Regulatory Initiatives

- UNESCO IOC : Intergovernmental Oceanographic Commission
- Global Ocean Acidification Observing Network (GOA-ON)
- Expert group: Ocean Acidification International Reference User Group (founded 2005)

1. Principles of ocean acidification

- pH and the pH scale
- Carbon cycle
- Sea-water composition and chemistry
- Regional differences

2. Natural causes

- Volcanic activity
- Decomposition of organic matter
- Respiration processes of marine organisms

3. Anthropogenic causes

- CO2 emissions absorption
- Nitrogen absorption, by acidified rainfall/runoffs, particularly near coasts (cf. Biogeochemical flows)
- Sulfur compounds absorption (from fossil fuels)

4. Ocean acidification and climate change

- Relationship between ocean acidification, global warming, and the carbon cycle
- Potential feedback loops (the warmer the ocean, the more acidic it is, so the less carbon it absorbs)
- Role of oceans in global carbon balance
- Ocean act as a heat reservoir
- Impact of melting polar ice

5. Impact on marine life

- Negative effects on calcifying organisms (corals, mollusks, and some plankton)
- Threat on fish and other non-calcifying organisms
- Threat to food chain and ecosystem implications
- Disruption of behavioral and physiological processes

6. Impact on coral & coastal ecosystems

- Coral reefs
- Seagrass, kelp forests, mangroves…
- Coastal protection
- Implications for reef-associated human communities

7. Socio-economic impact

- Food security implications (on fisheries and aquaculture)
- Health effects: seafood toxicity, diseases…
- Impacts on economies dependent on marine resources (tourism, …)
- Especially for coastal populations, which represent a significant proportion of population

8. Water ecosystems: acidification beyond the oceans

- Freshwater, brackish systems
- Interactions between marine and non-marine aquatic systems
- Potential acidification on non-marine aquatic ecosystems and impacts
- Impact on estuaries and deltas

9. Mitigation and adaptation strategies

- Projected trends and scenarios
- Policy and regulatory responses
- CCS, ocean alkalinity enhancement
- Enhancing ocean resilience (marine protected areas, ecosystem-based management)
- Changes in land-use practices and energy production
- Adaptation strategies for impacted communities and industries

Learning Objectives — Ocean Acidification

Knowledge Type	*The sustainability literate learner will be able to …*
Definitions *Descriptive knowledge*	1. Explain the meaning and key characteristics of ocean acidification and identify key corresponding bibliographical references 2. Describe the natural and human-generated chemical processes that lead to ocean acidification 3. Explain the process by which oceans act as a carbon sink via the absorption of atmospheric CO2 4. Describe the role carbonate plays in the developmental processes of the marine ecosystem including corals, shellfish, and marine fauna 5. Identify and explain the control variable used to establish the Planetary Boundary for ocean acidification
Current State & Trends *Contextualized knowledge*	1. Determine humanity's current location vis-à-vis the Planetary Boundary for ocean acidification 2. Describe past, current, and projected changes in the amount and pace of ocean acidification 3. Estimate current levels of greenhouse gas emissions absorbed by the oceans 4. Identify the most vulnerable marine areas and human activities to ocean acidification
Major Causes *Causal knowledge*	1. Identify and rank the direct causes contributing to global ocean acidification 2. Identify and rank the underlying structural drivers of ocean acidification by economic sector and national origin 3. Describe how the oceans respond to increased atmospheric greenhouse gases 4. List the main effects of climate change on oceans and ocean acidification 5. Identify major local, state, and non-state actors and the role each plays in contributing to—or resisting—ocean acidification
Systemic Impacts *Integrated knowledge*	1. Identify and evaluate the major consequences of respecting or transgressing the Planetary Boundary for ocean acidification 2. List and rank the main consequences of acidification of the oceans 3. Estimate the level of coral destruction at a climate warming of 1.5°C and 2°C 4. Describe specific potential economic, social, and geopolitical consequences of acidification of the oceans 5. Describe the systemic interactions—such as feedback loops—of ocean acidification

Key Resources — Ocean Acidification

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1.2.4 — Novel Entities

TASK by Sulitest **Subject Knowledge Navigational Chart**

TASK Framework: Earth Systems → **Domain:** Regulating Planetary Boundaries → **Subject:** 1.2.4 – Novel entities | *Click here for User Guidelines*

Definition: Novel entities 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)

Planetary Boundary Control Variable: The safe operating space is exceeded when annual production and releases of *Novel entities* increase at a pace that outstrips the global capacity for assessment and monitoring.

Planetary Boundary Status: It was established in 2022 that the safe operating space boundary has been transgressed. (Persson, 2022)

Key Ideas

1. Chief characteristics
2. Technology-critical elements (TCE)
3. Household and commercial chemicals (PFAS)
4. The promise of nanotechnology
5. Current innovations in genetic engineering
6. Use and discovery of early chemicals
7. Plastic use and pollution
8. Release of NEs into the environment
9. Commercial factor driving production
10. Use and impact on farming and agriculture
11. Toxicity and impact on human health
12. Importance of precautionary Principle

Key International Regulatory Initiatives

- The Stockholm Convention on Persistent Organic Pollutants
- UN Strategic Approach to International Chemicals Management (SAICM-UNEP)
- Basel Convention on the Control of Transboundary Movements of Hazardous Wastes & Their Disposal
- EU REACH (Registration, Evaluation, Authorization and Restriction of Chemicals)
- The Cartagena Protocol on Biosafety (2003)

1. Chief characteristics

- Exist in both natural and synthetic forms
- Persistence in nature: *"Forever chemicals"*
- Mobility & dispersion (Long-range transport potential)
- Variety and diversity
- Unknown or poorly known toxicity
- Impacts: additive, multiplicative, unpredictable, Irreversible
- Xenobiotic organic chemicals

2. Technology-critical elements (TCE)

- REEs (17 Rare-Earth Elements); heavy metals
- Use in renewable energy and green technology: electric cars, wind turbines, solar cells & panels
- Battery technology
- Radioactive materials: nuclear energy

3. Household and commercial chemicals (PFAS)

- 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
- Non-PFAS-free waterproof and stainproof textiles
- Presence of lead: in paint, pipes, gasoline, food, food containers (e.g., pottery), coolant fluids
- Benzene: in dyes, detergents, some plastic bottles
- Garden fertilizers, pesticides, insecticides

4. The promise of nanotechnology

- Nanomaterials
- Next-generation nanotechnology
- Nano-safety
- Nano-ethics
- Digital novel entities: Blockchain technology (Crypto-currency, Bitcoin, etc.); Artificial intelligence; excessive energy consumption

5. Current innovations in genetic engineering

- Cellular agriculture
- Genetic engineering and gene editing
- Cloning
- GMOs (Genetically modified organism)
- Engineered bio-based materials
- Synthetic biology and green chemistry
- Biotechnology
- Clustered Regularly Interspaced Short Palindromic Repeats – CRISPR

6. Use and discovery of dangers of early chemicals

- POPs — Persistent organic pollutants e.g., Dioxin
- CFCs — Chlorofluorocarbons (Halocarbons)
- DDT — Dichlorodiphenyltrichloroethane
- PCBs — Polychlorinated biphenyl
- ODGs — Ozone-depleting gases
- GHG — Greenhouse gases
- EPPP — Environmental persistent pharmaceutical pollutants (e.g., antibiotics)
- Arsenic, Lead, Mercury, Cadmium (heavy metals)

7. Plastics use and pollution

- Plastic polymers, monomers, and solvents
- Plastic waste
- Macro-plastics
- Micro-plastics
- Xenobiotic organic plastics
- Nurdles, flakes, powder, and microbeads
- Plastic entanglement
- Plastic ingestion

8. Release of NEs into the environment

- Increasing demand & production volumes
- Release via mining, extraction, refining, processing, production, disposal
- Low levels of recycling: (1% of REEs)
- Land degradation
- Waste and e-waste pollution
- Deforestation (acid rain)
- Biodiversity loss (pollinators)
- Bioaccumulation / chemical intensification

9. Commercial factors driving production

- Pace of technological innovation
- Potential global environmental benefits
- Benefits to science, industry, medicine
- Role of lobbying and disinformation

10. Use and impact in farming and agricultural

- Pesticides, insecticides, rodenticides, fungicides
- Contamination: aquifers, ecosystem, soil,
- Chemical fertilizers
- Neonicotinoids (bee killers)
- Hydrological contamination
- Harmful effects on flora and fauna
- Entry into human, plant, and animal food chains
- Chemical preservatives, conservatives

11. Toxicity and impact on human health

- EDCs (Endocrine-disrupting chemicals)
- Carcinogenetic potential
- Presence in dietary supplements & cosmetics
- Vulnerability of infants, children, elderly, pregnant
- Mercury in seafood and shellfish
- Exposure, ingestion, contamination
- PFAS ingestion by flora and fauna

12. Importance of Precautionary Principle

- Cascading environmental effect
- Unknown planetary boundaries threat
- Law of unintended consequences (Murphy's Law)
- Known unknowns / unknown unknowns
- Risk-benefit analysis / Cost-benefit analysis
- Uncertainty principle
- Publicity campaigns to alert the public

Learning Objectives — Novel Entities

Knowledge Type	*The sustainability literate learner will be able to …*
Definitions *Descriptive knowledge*	1. Explain the meaning of novel entities and describe the key characteristics of the phenomenon 2. Describe the origins, varieties, properties, variables, toxicity, and uses of novel entities (and related chemical pollution) 3. List the main types of novel entities and categorize them as old/new and natural/man-made 4. Explain why novel entities are considered "new" or "novel" and why this "newness" is significant 5. Describe official government initiatives and popular cultural efforts to alert the public of the dangers of novel entities 6. Identify and explain the control variable used to establish the Planetary Boundary for novel entities
Current State & Trends *Contextualized knowledge*	1. Determine humanity's current location vis-à-vis the Planetary Boundary for novel entities 2. Quantify the current state of the human use of novel entities: (e.g., types, number, producers, volumes, uses, release into nature, regulation, etc.) 3. Articulate the dangers that novel entities present to the health of humans, flora, fauna, habitats, and ecosystems 4. Categorize the potential dangers of novel entities into immediate, short-term, long-term, and unknown hazards 5. Assess the current state of knowledge about the potential dangers of novel entities 6. Describe the historical use and misuse of novel entities over the past century 7. Identify and describe impediments to respecting the Planetary Boundary on novel entities as well as the stakes of transgressing it
Major Causes *Causal knowledge*	1. Identify the primary technological and market forces driving the invention and commercialization of novel entities 2. Describe the impediments to the regulatory process of monitoring, testing, and certifying the safety of novel entities 3. Identify the principles of good practice ignored in regulating novel entities such as the Precautionary Principle 4. Explain the tension between the potentially positive and negative attributes of novel entities that contribute to innovation in developing them 5. Analyze and account for human mindsets, values, and attitudes that encourage the development, commercialization, and release of NEs
Systemic Impacts *Integrated knowledge*	1. Provide examples of the harmful impacts of the unregulated use of novel entities in the recent past 2. Describe the potential current impacts of novel entities on human health, biodiversity, habitats, and ecosystems 3. Imagine and describe the risks and worst-case scenarios stemming from the release of novel entities into nature 4. Articulate attitudinal, commercial, regulatory, and systemic responses designed to reduce the dangers of novel entities 5. Defend the proposition that novel entities are among the most extensively transgressed planetary boundaries (with Biosphere extinctions & Biogeochemical flows)

Key Resources — Novel Entities

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1.2.5 — Biogeochemical Flows

TASK BY Sulitest **Subject Knowledge Navigational Chart**

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

Click here for User Guidelines

Definition: "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)

Planetary Boundary Control Variable: The safe operating space for the Nitrogen cycle is determined by the eutrophication of aquatic ecosystems. The safe operating space for the Phosphorus cycle is determined at two levels: 1) *Global*: P flow from freshwater systems into the ocean; 2) *Local*: P flow from fertilizers to erodible soils. (Steffen *et al*, 2015)

Planetary Boundary Status: The safe operating boundary is transgressed and in a zone of uncertainty (i.e., increasing risk) (Steffen *et al*, 2015).

Key Ideas

1. Key natural biogeochemical cycles: Water, Carbon, Nitrogen, Phosphorus
2. The Nitrogen (N) Cycle and its disruptions
3. The Phosphorus (P) Cycle and its disruptions
4. Eutrophication and its impacts
5. Other ecological impacts of altered nutrient cycles
6. Socio-economic impacts of biogeochemical disruptions
7. Restoration and management strategies

Key International Regulatory Initiatives

- Mediterranean Action Plan
- EU Water Framework Directive
- Gulf of Mexico Hypoxia Action Plan
- Danube River Basin Management Plan

1. Key natural biogeochemical cycles: Water, Carbon, Nitrogen, Phosphorus

- Biogeochemical cycles
- Water (H2O) cycle
- Carbon (C) cycle, natural sources, and sinks
- Nitrogen (N) cycle, natural sources, and sinks
- Phosphor (P) cycle, natural sources, and sinks
- The close interactions between N, C, P as key biological nutrients
- Other cycles: methane, marine, rock cycles...

2. The Nitrogen (N) Cycle and its disruptions

- N Cycle processes: N fixation, nitrification, assimilation, ammonification, denitrification
- Key Players: 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 (N2O), soil acidification
- Case studies and examples *(e.g., The Gulf of Mexico's "Dead Zone" and the Mississippi River Basin)*

3. The Phosphorus (P) Cycle and its disruptions

- 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
- Case studies and examples *(e.g., Phosphate mining in Nauru)*

4. Eutrophication and its impacts

- Definition and overview
- Causes: Nutrient runoff from agriculture, urban stormwater, wastewater discharge, atmospheric deposition
- Role of N and P
- Impacts on Aquatic Ecosystems: Algal blooms, hypoxia (oxygen depletion), fish kills, biodiversity loss, formation of dead zones
- Human health and economic impacts: impacts on drinking water, recreational activities, commercial and sport fishing
- Case studies and examples *(e.g., Lake Erie)*

5. 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

6. Socio-economic impacts of biogeochemical disruptions

- Water quality: nutrient runoff, health risks, costs for water treatment
- Algal 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

7. Restoration and management strategies

- Nutrient redistribution: techniques and technologies for redistribution of P and N, role of organic farming
- Improved nutrient management: precision farming, use of cover crops, crop rotation, nutrient management plans, reduction in synthetic fertilizer use
    - Agriculture: integrated pest management, regenerative agriculture practices
    - Aquaculture: improving feed efficiency, reducing waste, integrated multi-trophic aquaculture
- Waste management: wastewater treatment, stormwater management, composting and recycling
- Wetland restoration: role of wetlands in nutrient filtration, methods of restoration, ecosystem services benefits
- Phytoremediation, riparian/stream buffers
- Cases studies and examples *(e.g., The Everglades Restoration Plan, Nutrient Management in the Netherlands)*

Learning Objectives — Biogeochemical Flows

Knowledge Type	*The sustainability literate learner will be able to …*
Definitions *Descriptive knowledge*	1. Identify the main life-giving elements on Planet Earth 2. Describe and distinguish the global natural Phosphorus and Nitrogen cycles 3. Identify the main human disturbances of the N and P cycles 4. Explain eutrophication and its various manifestations (red tides, dead zones, algae blooms, dead zones, etc.) 5. Describe the role of N and P in agriculture
Current State & Trends *Contextualized knowledge*	1. Estimate the part of agriculture output related to fertilizer inputs globally 2. Characterize the global distribution of phosphorus fertilizers 3. Describe past, current, and projected use of N and P 4. Characterize the sustainability of P and N production 5. Identify if the planetary boundary of biogeochemical flows has been crossed
Major Causes *Causal knowledge*	1. Identify the main causes of biogeochemical flows disruption 2. Identify the main drivers of biogeochemical flows disruption 3. Analyze and distinguish the sustainability of N and P fertilizers
Systemic Impacts *Integrated knowledge*	1. List the ecological consequences of fertilizer production and use 2. Describe the impacts of eutrophication and its various manifestations (red tides, dead zones, algae blooms, dead zones, etc.) 3. Identify the relations between N fertilizer, climate change, and stratospheric ozone depletion 4. Define the concept of chemical precursor in the context of agriculture fertilizers

Key Resources — Biogeochemical flows

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1.2.6 — Atmospheric Aerosols Loading

TASK BY Sulitest **Subject Knowledge Navigational Chart**

TASK Framework: Earth Systems ⟶ **Domain:** Regulating Planetary Boundaries ⟶ **Subject:** 1.2.6 – Atmospheric aerosols loading	*Click here for User Guidelines*

Definition: "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)

Planetary Boundary Control Variable: The safe operating space for atmospheric aerosols loading is determined by the radiative forcing associated with aerosol concentrations in the atmosphere (W/m^2).	**Planetary Boundary Status:** Not yet quantified.

Key Ideas

1. Air pollution, aerosols, particulate matter
2. Natural sources of aerosols
3. Anthropogenic sources of aerosols
4. Air pollution prevention, monitoring, and levels
5. Health consequences
6. Climate and weather effects
7. Impacts on ecosystems and biodiversity
8. Prospects & reduction of aerosol emissions

Key International Regulatory Initiatives

- Convention on Long-Range Transboundary Air Pollution Convention (CLRTAP), 1979
- The Clean Air Act (United States)
- Gothenburg Protocol, 1999 (Europe)
- Air Quality Guidelines, World Health Organization

1. Air pollution, aerosols, particulate matter

- Air pollution (aerosols and gaseous pollutants)
  - Non-aerosol air pollution (SO2, NO2…)
- Aerosols
- Types of particulate matter (PM10, PM2.5, etc.)
- Primary and secondary pollutants, aerosol precursors
- Smog

2. Natural sources of aerosols

- Volcanoes
- Forest and grassland fires
- Wind erosion
- Sea spray
- Biogenic emissions
- Fungal and plant spores
- Pollen

3. Anthropogenic sources of aerosols

- Fossil fuel combustion (soot/black carbon, ash…)
- Industrial manufacturing
- Agriculture
- Deforestation and land-use change
- Waste incineration
- Construction and demolition
- Vehicle/aircraft/shipping emissions

4. Air pollution prevention, monitoring, and levels

- Estimation of aerosol loading
- Regional differences and hotspots
- Air quality regulations and standards
- Air quality monitoring
- Air pollution episodes and trends

5. Health consequences

- Respiratory and cardiovascular health effects
- Mortality and morbidity related to air pollution
- Vulnerable populations and environmental justice
- Economic and social costs of air pollution
- Mental health impact

6. Climate and weather effects

- Direct radiative effects (cooling or warming)
- Cloud formation and precipitation
- Acid rain
- Amplification or mitigation of global warming
- Monsoon patterns

7. Impacts 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

8. Prospects & reduction of aerosol emissions

- Emission reduction technologies and strategies
- Nature-based solutions
- International cooperation and research efforts

Learning Objectives — Atmospheric Aerosols Loading

Knowledge Type	*The sustainability literate learner will be able to …*
Definitions *Descriptive knowledge*	1. Define aerosols and particulate matter and identify key corresponding bibliographical references 2. Describe the processes of aerosol removal from the atmosphere 3. Distinguish between natural and human-induced aerosols, between different particulate matter 4. Distinguish air pollution, particulate matter, greenhouse gas and air pollutants 5. Identify the reasons why atmospheric aerosols loading is considered as one of the planetary boundaries
Current State & Trends *Contextualized knowledge*	1. Analyze human's current location vis-à-vis the planetary boundary 2. Describe past, current, and projected trends in aerosol concentration in the atmosphere 3. Describe social and geographic disparities in air pollution at different scales
Major Causes *Causal knowledge*	1. Identify the primary sources of human-induced air pollution 2. Describe why different particulate matters have differentiated impacts of health 3. Identify key actors in the fight against air pollution and *atmospheric aerosols loading*
Systemic Impacts *Integrated knowledge*	1. Identify and evaluate the major consequences of atmospheric aerosols loading. 2. Estimate the number of deaths due to outdoor air pollution per year 3. Identify major health issues related to air pollution 4. Explain the complex interactions between atmospheric aerosols loading and climate change

Key Resources — Atmospheric Aerosols Loading

Bellouin, N., et al. (2020). Bounding Global Aerosol Radiative Forcing of Climate Change. Reviews of Geophysics, 58(1), e2019RG000660. https://doi.org/10.1029/2019RG000660

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of WG1 to the Sixth Assessment Report of the IPCC. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of WG2 to the Sixth Assessment Report of the IPCC. https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf

IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of WG3 to the Sixth Assessment Report of the IPCC. https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SummaryForPolicymakers.pdf

Landrigan, P. J., et al. (2018). The Lancet Commission on pollution and health. The Lancet, 391(10119), 462–512. https://doi.org/10.1016/s0140-6736(17)32345-0

Seinfeld, J. H., & Pandis, S. N. (2016). Atmospheric Chemistry and Physics: From Air Pollution to Climate Change. John Wiley & Sons.

Steffen, W., et al. (2015). Planetary boundaries: Guiding human development on a changing planet. Science, 347(6223), 1259855. DOI: 10.1126/science.1259855

1.2.7 — Stratospheric Ozone Depletion

TASK by Sulitest **Subject Knowledge Navigational Chart**

TASK Framework: Earth Systems → **Domain:** Regulating Planetary Boundaries → **Subject:** 1.2.7 – Stratospheric ozone depletion

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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)

Planetary Boundary Control Variable: The safe operating stratospheric ozone depletion is determined by the O_3 concentration in the atmosphere. The threshold is <275 DU (Dobson Units).

Planetary Boundary Status: It was established in 2015 that the safe operating space boundary remains in the safe zone but with increasing risk. (Steffen, 2015)

Key Ideas

1. Types of ozone
2. Ozone-depleting substances (ODS) and their sources
3. The "Ozone Holes"
4. Health and environmental consequences
5. International response
6. Reasons for success of the response / action
7. Comparison with other environmental issues
8. Lessons from the Montreal Protocol's success for addressing other environmental challenges

Key International Regulatory Initiatives

- Vienna Convention for the Protection of the Ozone Layer
- The Montreal Protocol
- Kigali Amendments
- UNEP's Ozone Action Program

1. Types of ozone

- Stratospheric ozone
- Tropospheric ozone
- Ozone layer
- Solar radiation and ozone

2. Ozone-depleting substances (ODS) and their sources

- Ozone depletion potential (ODP)
- CFCs / HCFCs, used in air conditioning, refrigeration, aerosol propellants, etc. (anthropogenic source)
- Halons, used in fire suppression systems and firefighting (anthropogenic source)
- Nitrous Oxide (N2O) emitted during agricultural and industrial activities, fossil fuels, wastewater management (both natural and anthropogenic sources) - also a GHG

3. The "Ozone Holes"

- Mechanism of ozone depletion
- Definition of "ozone holes"
- Evolution and current state
- Regional differences and hotspot locations
- Impact of climate change on ozone recovery

4. Health and environmental consequences

- Skin and eye conditions (due to increased UV)
- Impacts on human immune systems
- Ecosystem disruption
- Marine life: impacts on phytoplankton, the basis of ocean food chains (due to UV)
- Decrease in crop yield (due to UV)

5. International response / action

- The Montreal Protocol: goals and achievements
- Multilateral fund
- Kigali amendments
- Other international and national regulations

6. Reasons for success of the response

- The "localization" of the ozone depletion problem
  - Limited to specific and downstream industries
  - Ability to target and regulate a relatively small number of chemical compounds
- 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

7. Comparison with other environmental issues

- Systemic issues affecting entire socio-economic system based on extractivism and fossil fuels
- Strong resistance from powerful lobbies (e.g., fossil fuel industry)
- Difficulty of achieving global consensus: varying national interests, economic implications, perceptions of fairness
- Scientific complexity and uncertainty: more complex and less linear than ozone depletion, leading to greater uncertainty and room for denial or delay
- Lack of immediate, easily implementable alternatives

8. Lessons from the Montreal Protocol's success for addressing other environmental challenges

- Importance of scientific consensus
- Need for enforceable international agreements
- Value of viable alternatives to damaging technologies/practices
- Role of public awareness, NGOs, and advocacy
- Need to overcome/circumvent resistance from interest groups

Learning Objectives — Stratospheric Ozone Depletion

Knowledge Type	*The sustainability literate learner will be able to …*
Definitions *Descriptive knowledge*	1. Identify the stratospheric ozone effect on solar radiation and identify the key corresponding bibliographical references 2. Define the ozone hole and ozone layer 3. Identify the key international protocol and its amendments to address stratospheric ozone depletion 4. Distinguish stratospheric ozone depletion from climate change and tropospheric from stratospheric ozone 5. Identify and explain the control variable used to determine the corresponding planetary boundary
Current State & Trends *Contextualized knowledge*	1. Determine human's current location vis-à-vis the planetary boundary 2. Describe past, current, and predicted state of stratospheric ozone depletion 3. Describe the inertia of ozone-depleting substance in the stratosphere 4. List the mains sources of ozone-depleting substances 5. Identify current challenges to eradicate ozone-depleting substances 6. Identify geographical disparities of stratospheric ozone depletion and ozone-depleting substances emissions
Major Causes *Causal knowledge*	1. Identify the primary source of anthropogenic ozone-depleting substances 2. Identify current most significant ozone-depleting substance emission 3. Identify the underlying drivers of stratospheric ozone depletion 4. Describe the process of stratospheric ozone depletion 5. Identify major actors contributing to –or resisting– the transgression of the planetary boundary
Systemic Impacts *Integrated knowledge*	1. Enumerate the major consequences and hazards of stratospheric ozone depletion 2. Identify the emerging threats to stratospheric ozone remediation 3. Describe the relations between ozone-depleting substances and climate change

Key Resources — Stratospheric Ozone Depletion

Farman, J., Gardiner, B., & Shanklin, J. (1985). Large losses of total ozone in Antarctica reveal seasonal ClOx/NOx interaction. Nature, 315, 207–210. https://doi.org/10.1038/315207a0

IPCC. (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate. Cambridge University Press. Retrieved from https://www.ipcc.ch/report/ar5/wg1/

IPCC. (2021). Summary for Policymakers. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Retrieved from https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

Molina, M., & Rowland, F. (1974). Stratospheric sink for chlorofluoromethanes: chlorine atom-catalysed destruction of ozone. Nature, 249, 810–812. https://doi.org/10.1038/249810a0

Steffen, W., et al. (2015). Planetary boundaries: Guiding human development on a changing planet. Science, 347(6223). DOI: 10.1126/science.1259855

UNEP. (2018). Scientific Assessment of Ozone Depletion: 2018. United Nations Environment Programme. Retrieved from https://ozone.unep.org/sites/default/files/2019-05/SAP-2018-Assessment-report.pdf