4 Environment

UNIT SPECIFICS

Through this unit we have discussed the following aspects:

- ***Environment, Global Warming and Climate Change***
    - *Global warming phenomena and GHG emissions,*
    - *Pollution Mitigation – Measures and Approaches,*
    - *Non-stationarity*
- ***Environmental Metrics and Monitoring***
    - *Environmental Monitoring*
    - *Global Climate Indicators and Essential Climate Variable (ECV)*
    - *Environmental Performance Index Indicators*
    - *Other Sustainability measures*
- ***Innovations and methodologies for ensuring Sustainability***
    - *Environmental Impact Assessment (EIA)*
    - *Life cycle Assessment (LCA)*
    - *Strategic Environmental Assessment (SEA)*

Besides giving a large number of multiple choice questions as well as questions of short and long answer types marked in two categories following lower and higher order of Bloom's taxonomy, a list of references and suggested readings are given in the unit so that one can go through them for practice.

There is a "Know More" section, which has been carefully designed so that the supplementary information provided in this part becomes beneficial for the users of the book. It is important to note that for getting more information on various topics of interest some QR codes have been provided which can be scanned for relevant supportive knowledge This section mainly highlights applications of the subject matter for our day-to-day real life or/and industrial applications on variety *of aspects, case study related to environmental, sustainability, social and ethical issues whichever applicable, and finally inquisitiveness and curiosity topics of the unit.*

RATIONALE

This foundational unit on environment and the impact associated with it, offers understanding of the various views on the state of the environment at present; and provides knowledge on mitigation strategies and policies, metrices and indicators, and most importantly, methodologies and tools that are applied to assess environmental impact, to empower the civil engineer in practice.

UNIT OUTCOMES

List of outcomes of this unit is as follows:

U4-O1: Understanding of Global warming phenomena, Climate change and Pollution Mitigation

U4-O2: Knowledge of Environmental Monitoring & Metrics

U4-O3: Knowledge on innovations and methodologies for ensuring Environmental Sustainability

Unit-4 Outcomes	EXPECTED MAPPING WITH COURSE OUTCOMES (1- Weak Correlation; 2- Medium correlation; 3- Strong Correlation)						
	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6	CO-7
U4-O1	2	2	3	1	2	3	2
U4-O2	3	3	3	1	3	3	2
U4-O3	3	3	3	1	3	3	2

"A clean, healthy and sustainable environment is a human right" – was adopted as a landmark resolution by The United Nations Human Rights Council in October 2021. India's Environment (Protection) Act, 1986, Section 2, defines Environment as follows; "*environment includes water, air and land and the inter-relationship which exists among and between water, air and land, and human beings, other living creatures, plants, micro-organism and property*". This Act was instituted by the Govt. of India following the nation's participation in the UN Conference on the Human Environment, Stockholm in June 1972, to prioritise the protection and improvement of environment, and prevent hazards to human beings, other living creatures, plants and property. Climate change and Global warming are commonly used today, almost interchangeably, to imply hazardous impacts on all life and argue the need for Environmental consideration and sustainable consumption.

4.1 ENVIRONMENT, GLOBAL WARMING AND CLIMATE CHANGE

The term '**global warming'** refers to the long-term heating of the Earth's surface observed since the beginning of the Industrial Era due to 'greenhouse effect' caused by human activities, primarily attributed to burning of fossil fuels and industrial processes, and deforestation which leads to significant greenhouse gas emissions. This term should not be used interchangeably with Climate change, as the latter refers to the long-term change in the average weather patterns – temperature, precipitation, wind and tidal patterns, and is not limited to the adverse effects of human activities alone. Natural causes such as, volcanic activity, cyclical ocean patterns, orbital changes, may also contribute to climate change. **Climate change** has far-reaching consequences beyond temperature increase, as it affects ecosystems, agriculture, water availability, human health, and socio-economic systems. Key indicators of Climate change are; frequency and severity changes in extreme weather such as hurricanes, heatwaves, wildfires, droughts, floods, and precipitation; ice loss at Earth's poles and in mountain glaciers; rising sea levels; cloud and vegetation cover changes, as well as the global land and ocean temperature increases. It maybe oversimplified to state that global warming leads to climate change.

4.1.1 Global warming phenomena and GHG emissions

The phenomenon of global warming occurs when greenhouse gases or GHG, such as, carbon-dioxide (CO_2), chlorofluorocarbons, water vapour, methane (CH_4), and nitrous oxide (N_2O), which are heat-trapping pollutants create a layer in the Earth's atmosphere which disallows the solar radiation emitted by the earth's surface to escape and instead absorbs the heat, thereby increasing the surface temperature. This **greenhouse effect** is a natural process that is essential for maintaining Earth's habitable temperature. However, human activities, especially the burning of fossil fuels (coal, oil, and natural gas), deforestation, and industrial processes, have significantly increased greenhouse gas emissions over the past century. The burning of fossil fuels for electricity generation, transportation, and industrial processes is the primary source of CO_2 emissions. Agricultural practices, such as livestock production and rice cultivation, contribute to CH_4 and N_2O emissions. As the concentration of greenhouse gases increases, more heat is trapped within the Earth's atmosphere, causing a rise in average global temperatures, in turn, leading to the melting of polar ice caps and rising sea-level. Increased CO_2 absorption by the oceans can lead to ocean acidification, which have detrimental effects on marine life, including coral reefs and shell-forming organisms. The changing temperatures can intensify extreme weather events, such as, hurricanes, heatwaves, droughts, and alter precipitation, which disrupts the ecosystem and affects plant and animal species' distribution and migration patterns.

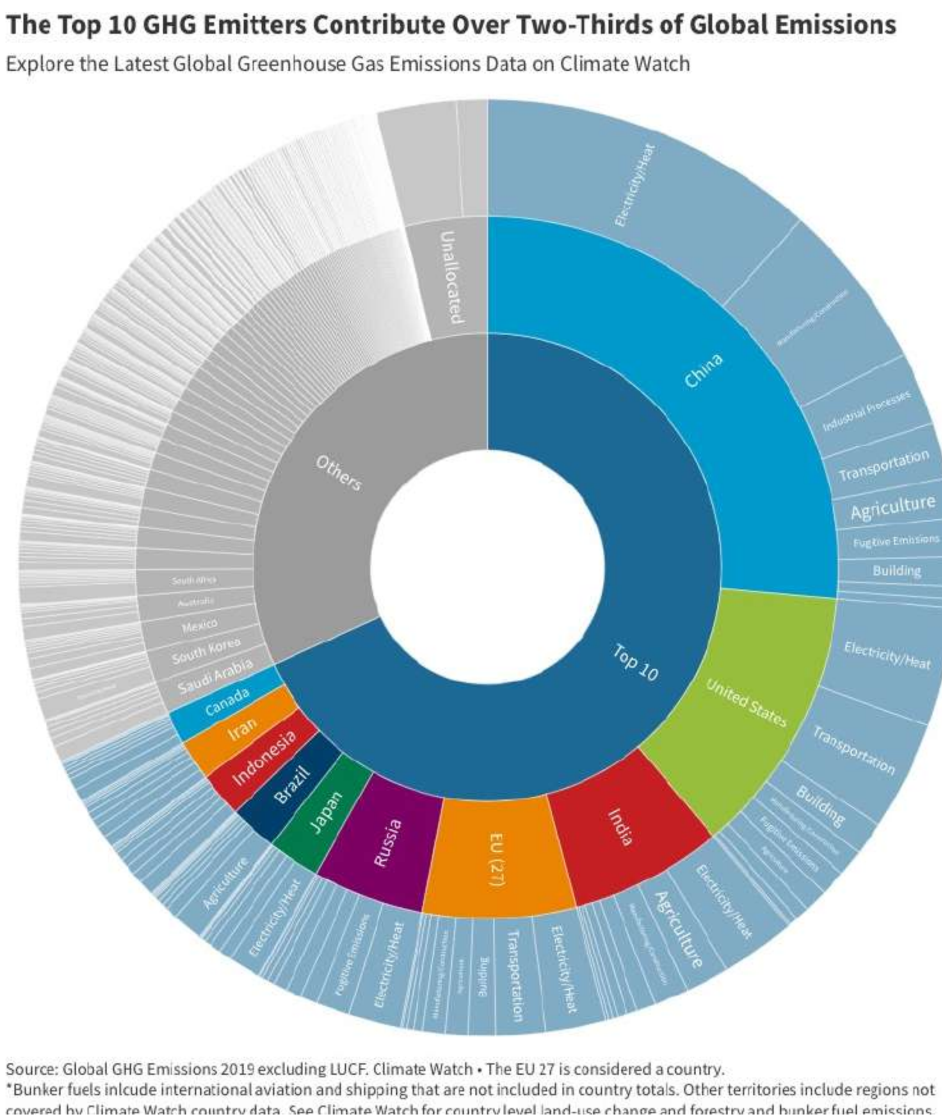

Fig. 4.1: Global GHG Emissions, 2019, by Country and Sector (source:www.climatewatchdata.org)

The biggest GHG emitting nations are China, USA, Russia, and India. The ***top 10 emitters*** (country-wise) account for over **two-thirds of annual GHG emissions**, together accounting for over 50% of the global population and 75% of the world's GDP. GHG emissions are usually measured in *CO_2 equivalent*, as CO_2 alone accounts to almost 76-78% of global GHG emissions, however the jury is still out on the strength of CO_2 to cause warming and its factual effects directly on global temperature rise, as a certain amount is essential in the atmosphere to support all life on this planet, as it is an important nutrient for trees, plants and crops. Other gases need to be converted to this unified unit by multiplying its emission to its Global Warming Potential (GWP), which is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2). GWP acknowledges the fact that many gases are more impactful at warming Earth than CO_2, per unit mass.

The UN's Intergovernmental Panel on Climate Change (IPCC) forewarns that to limit global warming to 1.5°C, GHG emissions must peak before 2025 at the latest and decline 43% by 2030, as they indicate that crossing the 1.5°C threshold risks unleashing severe climate change impacts, including more frequent and severe droughts, heatwaves and rainfall. A landmark, multilateral climate change process – the **Paris Agreement**, binds 196 parties (nations) together to combat climate change and adapt to its effects, was adopted at the UN Climate Change Conference (COP21) in December 2015. Each Party has set 2030 targets in their Nationally Determined Contributions (NDCs) to align with the Paris Agreement temperature goal and has formulated '*long-term low greenhouse gas emission development strategies*' (LT-LEDS) that provides long-term horizon to the NDCs. Under an '*enhanced transparency framework*' (ETF), due to start in 2024, countries will be able to report transparently on actions taken and progress in climate change mitigation, adaptation measures and support provided or received, and feed the information into the **Global stocktake** which will assess the collective progress towards the long-term climate goals. Presently, this is undertaken by various organisations, such as, US Environment Protection Agency, European Environment Agency, International Energy Agency, or World Data Lab, who launched the *World Emissions Clock* at COP27.

The EPA tracks the total emissions in the United States by publishing the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, and their 2021 report notes that the primary sources of GHG emissions by economic sector are ; Transportation (28%), Power/electricity generation (25%), Industry (23%), Commercial and Residential (13%), Agriculture (10%) and Land use and Forestry (12%). Globally, Power and Energy sector is the largest contributor towards GHG emissions, and transportation and buildings have the major most activities that include both direct emissions from fossil fuel combustion, as well as indirect emissions such as use of electricity. The three sectors that stand out as the fastest-growing sources of GHG emissions since 1990 are - Industrial processes (grew by 203%); Electricity and heating, a subsector of energy (by 84%); and Transportation, also a subsector of energy (by 78%) as noted by EPA (Climate watch, 2021).

4.1.2 Pollution Mitigation

Mitigating global warming requires collective efforts and a comprehensive approach involving various sectors and stakeholders, by leveraging and building on existing mitigation measures and by incorporating sustainable approaches to ensure long-term resolution.

Emission and Pollution Mitigation Measures

Some **key strategies** for mitigating GHG emissions and pollution are as follows:

1. ***Transitioning to Renewable Energy:*** Renewable sources, such as, solar, wind, hydro, and geothermal power from fossil fuels reduces greenhouse gas emissions associated with electricity generation and decreases reliance on carbon-intensive energy sources. Another potential source for generating electricity is from nuclear energy rather than the combustion of fossil fuels.
2. ***Energy Efficiency:*** Largely, it can be achieved by; "*increasing the efficiency of existing fossil fuel-fired power plants by using advanced technologies, substituting less carbon- intensive fuels, and shifting generation from higher-emitting to lower-emitting power plants*" and by "*reducing electricity use and peak demand by increasing energy efficiency and conservation in homes, businesses, and industry*." (Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, chapter 6, 2021). Improving energy efficiency in transportation, buildings, and industrial processes can significantly reduce greenhouse gas emissions. This can be achieved through measures, like; switching to alternate fuels like biofuels, hydrogen, and electricity from renewable sources, or fossil fuels that are less CO_2-intensive; improving fuel efficiency and employing operating practices that minimize fuel use across all sectors. Encouraging the use of active transportation modes, like, walking and cycling, alongside improving public transportation systems and promoting it, reducing travel demand, especially office commute, through policy and urban planning to address long daily commutes will help reduce emissions from the transportation sector. In the building and allied services sectors, measure such as, improving insulation and building envelope design; incorporating efficiency strategies in heating, cooling, ventilation, and refrigeration systems; using LED lighting and passive heating and lighting to take advantage of natural sunlight; using energy-efficient appliances and electronics; incorporating energy efficiency practices into water and wastewater plants, solid waste management, and urban processes, etc. have great potential to curb emissions.
3. ***Forest Conservation and Reforestation*:** Forests act as carbon sinks, absorbing CO_2 from the atmosphere, therefore, protecting existing forests, preventing deforestation, and implementing reforestation and afforestation projects can help sequester carbon and mitigate global warming. Carbon Capture and Sequestration (CCS) where CO_2 is captured as a by-product of fossil fuel combustion, before it enters the atmosphere, and transporting to inject it deep underground at carefully selected and suitable subsurface geologic formation to be securely stored is also a potent mitigation strategy.
4. ***Sustainable Agriculture and Land Use*:** Implementing sustainable agricultural practices that reduce emissions from farming activities by emulating natural processes, promoting

agroforestry, and minimizing land-use change and deforestation in favour of carbon-rich ecosystems can contribute to global warming mitigation. "*It uses up to 56 per cent less energy per unit of crops produced, creates 64 per cent fewer greenhouse gas emissions per hectare and supports greater levels of biodiversity than conventional farming*." (UNEP, Trade and Environment Briefings: Sustainable Agriculture, 2012).

Circular Economy Approach to mitigate

The EPA endorses the "**Circular economy for all**" approach (Circular Economy systems diagram, 2019, Ellen MacArthur Foundation) to reduce waste and hazardous materials, and reuse critical minerals in manufacturing, as natural resource extraction and processing contributes to about half of all global GHG emissions (United Nations' International Resource Panel). The UN Conference on Trade and Development (UNCTAD) elaborates that circular economy is an economy where, "*all forms of waste, such as clothes, scrap metal and obsolete electronics, are returned to the economy or used more efficiently*" and "*entails markets that give incentives to reusing products, rather than scrapping them and then extracting new resources*".

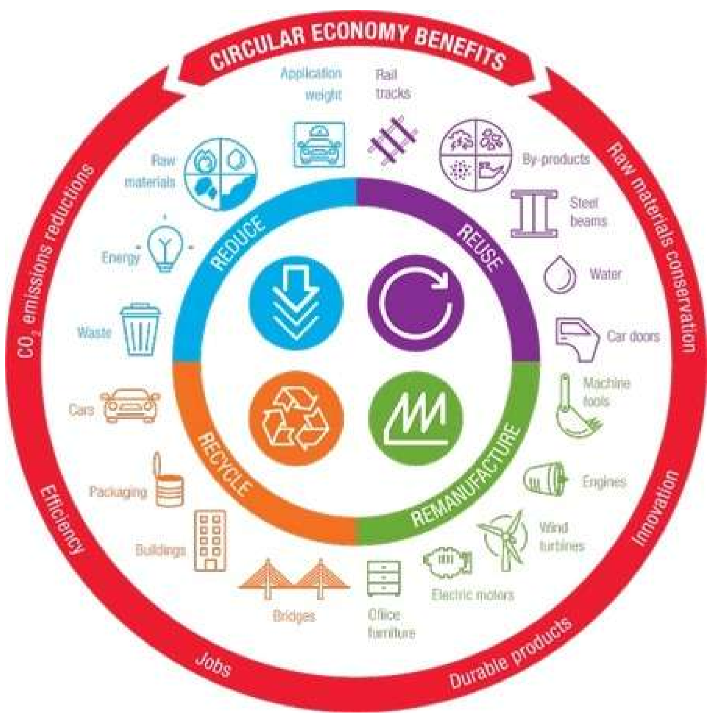

Fig. 4.2: Circular Economy, UNCTAD

The **policies and strategies** developed in line with this approach for mitigating global warming are :

1. ***Waste management and Industrial Best Practices:*** Emphasizing the principles of 4R synonymous to the concept of circular economy, i.e., reduce, reuse, recycle and remanufacture, can help reduce emissions associated with, raw material extraction through conservation, across the entire life of the product from production till disposal. Encouraging industries to adopt cleaner production techniques, such as using less toxic materials, implementing energy-efficient processes, and optimizing resource usage, can help reduce pollution emissions and minimize environmental impacts.
2. ***Sustainable consumption and production:*** Individuals can contribute to global warming mitigation by making sustainable choices in their daily lives, which includes conserving energy, reducing food waste, supporting eco-friendly products, and advocating for sustainable practices. SDG 12 is about ensuring sustainable consumption and production patterns, as present unsustainable behaviour is the root cause of pollution, biodiversity loss and climate change. This is also key to sustain the livelihoods of current and future generations. The UN further adds that "*Governments and all citizens should work together to improve resource efficiency, reduce waste and pollution, and shape a new circular economy*." Moreover, raising awareness about pollution-related issues, educating the public on the importance of pollution prevention, and promoting environmentally friendly behaviours can lead to positive changes in individual and collective actions. "*Around 90 per cent of countries report that education for sustainable development and global citizenship education are at least partially mainstreamed in national education laws and policies, curricula, teacher education or student assessments in primary and secondary school.*" (SDG Report 2022). The UNCTAD is also working on research into 'incorporating sustainability into consumer protection policy aims to make a contribution to the UNCTAD RPP Research and Policy Analysis Area: The role of competition law and policy and consumer protection in economic and social development and poverty reduction, and more specifically the Sub-Element: The role of consumer protection in social development and poverty reduction.' The UN also organizes the Climate Action Summit, a high-level event that brings together global leaders, businesses, and civil society to enhance climate ambition and accelerate action, and has UN Environment's vision for Environmental Education & Training for Sustainable Development (EETSD).
3. ***International Cooperation, Environmental Rights and Rule of Law:*** Governments play a crucial role in implementing and enforcing environmental regulations and policies that set pollution control standards and promote sustainable practices, which may include emission limits, waste disposal guidelines, pollution prevention requirements, and ensuring environmental justice. International agreements, such as the Paris Agreement for climate change mitigation, facilitate collaboration among nations to address pollution issues on a larger scale, supported by bodies of UN such as the UN Environment Program (UNEP).
   The core objectives of the UNEP are to serve as an authoritative advocate for the global environment, to support governments in setting the global environmental agenda, and to promote the coherent implementation of the environmental dimension of sustainable development within the UN system, at the global and regional levels. One such means is to promote and support development and implementation of international environmental law. In 2013, UNEP's Governing Body adopted Decision 27/9, on *Advancing Justice, Governance*

and Law for Environmental Sustainability, to establish the term '**Environmental rule of law**'. The Environmental rule of law is defined as "*the rule of law as a principle of governance in which all persons, institutions and entities, public and private, including the State itself, are accountable to laws that are publicly promulgated, equally enforced and independently adjudicated, and which are consistent with international human rights norms and standards*." (Report on the Rule of Law and Transitional Justice in Conflict and Post-Conflict Societies). International environmental law is "*a branch of public international law - a body of law created by States for States to govern problems that arise between States. It is concerned with the attempt to control pollution and the depletion of natural resources within a framework of sustainable development*." (UNEP, 2017).

The UNEP also hosts the Climate Technology Centre and Network (CTCN), the implementation arm of the Technology Mechanism of the United Nations Framework Convention on Climate Change. The Centre promotes "*the accelerated transfer of environmentally sound technologies for low carbon and climate resilient development at the request of developing countries. The CTC provides technology solutions, capacity building and advice on policy, legal and regulatory frameworks tailored to the needs of individual countries by harnessing the expertise of a global network of technology companies and institutions*". Addressing global warming requires international cooperation and the implementation of effective policies at the national and international levels. This includes setting ambitious emission reduction targets, implementing carbon pricing mechanisms, and fostering collaborations to support technology transfer and capacity building in developing countries.

4.1.3 Non-stationarity

Statistical analysis of the difference between mean CO_2 concentration (ppm) in the 1980s and mean CO_2 concentration in the 2000s, captured by Mauna Loa, Hawaii, which has the longest continuous record of direct atmospheric CO_2 measurements, showed that there has been a significant change in mean maximum temperature from decade to decade, mean maximum temperature from decade to decade for spring, mean maximum temperature from season to season, and further established that there is statistical evidence to claim that climate variables are changing over time (causeweb.org). The climate system is constantly changing across time, and these changes are usually associated with the temporal (time related) variation of the statistical properties of climatic variables, such as temperature, precipitation, wind speed, relative humidity, volcanic activity, seasonal change, and solar radiation levels. Thus, statistically it poses non-stationarity, i.e., the status of a time series whose statistical properties are changing through time, and is opposite of a stationary time series which has statistical properties or moments (e.g., mean and variance) that do not vary in time. Beuno de Mesquita, et al. (2020) define **non-stationarity** as "*a change in the relationship, either in direction or magnitude (from a significant relationship to no relationship and vice versa) between variables over time*". They further add that "*such non-stationarity is often combined with the additional hurdle of needing multivariate statistics*" as the changes in climate have become exceedingly erratic such that previous thought to be coupled climatic characteristics, such as, temperature and drought, are no longer behaving in tandem but now need to be considered as potentially independent.

4.2 ENVIRONMENTAL MONITORING & METRICS

Environmental impact is succinctly described as "*changes in the natural or built environment, resulting directly from an activity, that can have adverse effects on the air, land, water, fish, and wildlife or the inhabitants of the ecosystem. Pollution, contamination, or destruction that occurs as a consequence of an action, that can have short-term or long-term ramifications is considered an environmental impact.*" (Abdallah, 2017). These impacts require a system or standard of measurement, i.e., metric, that indicates the state of a system and measures the its behaviour. Therefore, the term '**indicator'** is commonly used to refer to these metrics for ascertaining the content and performance of a system, corresponding to any of the three dimensions of sustainability - ecological metrics, economic metrics, and sociological metrics (Sikdar,2003). However, holistic understanding, measuring and monitoring can only be achieved at the intersection of these three dimensions, as most systems are complex and are inadequately represented. Therefore, '**true sustainability metrics'** are 3-Dimensional and are classified as follows;

Group 1 (1-D): economic, ecological, and sociological indicators
Group 2 (2-D): socio-economic, eco-efficiency, and socio-ecological indicators
Group 3 (3-D): sustainability indicators

4.2.1 Environmental Monitoring

A large number of sustainability indictors have been thematically classified with respect to the 17 SDGs and discussed in earlier Unit, and there are various means for each to be measured and monitored. *The systematic collection, analysis, and interpretation of data on various aspects of the environment, involving measuring, observing, and assessing environmental indicators to understand the current state, changes, and trends in natural systems and human-induced activities* is referred to as **Environmental monitoring**. The data collected through environmental monitoring helps in assessing the effectiveness of environmental policies, identifying potential risks and hazards, and informing decision-making processes related to resource management, conservation, and pollution control. It encompasses a wide range of parameters, including air quality, water quality, soil health, biodiversity, climate variables, noise levels, and pollution levels, and involves the use of various monitoring techniques, such as sampling, remote sensing, sensor networks, and data analysis tools, to gather accurate and reliable information for environmental assessment and management.

Below enlisted are some common types of **environmental monitoring and the tools/methods** used for each:

1. ***Air Quality Monitoring:***
    - Tools: Air quality monitors (with CO_2 and O_2 sensors), air sampling equipment, Temperature and Humidity monitors, particulate matter (PM) samplers, gas analysers.

- Methods: Continuous monitoring stations, passive samplers, mobile monitoring, remote sensing, and modelling techniques.

2. ***Water Quality Monitoring:***
   - Tools: Water quality sensors, water samplers, pH meters, turbidity meters, dissolved oxygen meters, Conductivity probes.
   - Methods: Grab sampling, automated water quality monitoring stations, remote sensing, and satellite imagery.
3. ***Soil Monitoring:***
   - Tools: Soil sampling equipment, soil moisture sensors, pH and nutrient analysers.
   - Methods: Soil sampling and analysis, soil moisture monitoring, soil fertility testing, spectrometry (to measure contamination in soils), remote sensing (to monitor salinity in soils).
4. ***Biodiversity Monitoring:***
   - Tools: Camera traps, acoustic sensors, GPS devices, binoculars, species identification guides.
   - Methods: Field surveys, transect sampling, mark and recapture techniques, bio-acoustic monitoring, remote sensing.
5. ***Noise Monitoring:***
   - Tools: Sound level meters, noise dosimeters, acoustic monitoring systems.
   - Methods: Point measurements, continuous monitoring stations, noise mapping, community noise surveys.
6. ***Pollution & Waste Monitoring:***
   - Tools: Gas analysers, spectrometers, emission measurement devices, pollutant-specific sensors.
   - Methods: Source emission sampling, ambient air monitoring, industrial effluent monitoring, pollution source tracking, production and consumption patterns.
7. ***Radiation Monitoring:***
   - Tools: Radiation detectors, dosimeters, Geiger-Muller counters.
   - Methods: Radiation monitoring stations, personal monitoring, environmental sampling, remote sensing.
8. ***Climate Monitoring:***
   - Tools: Weather stations, temperature loggers, rainfall gauges, anemometers, radiometers.
   - Methods: Meteorological observations, climate stations, satellite-based measurements, climate modelling.

4.2.2 Global Climate Indicators and Essential Climate Variable (ECV)

The *World Meteorological Organization (WMO)* **State of the Global Climate** uses seven Global Climate Indicators - Surface Temperature and Ocean Heat (Temperature and Energy); Atmospheric CO2 (Atmospheric composition); Ocean Acidification and Sea-level (Ocean and Water); Glaciers and Arctic and Antarctic Sea Ice Extent (Cryosphere) —to monitor the domains most relevant to climate change, "*without reducing climate change to only temperature*". In addition to the seven headline indicators, a supplementary set of subsidiary indicators is complimentarily available to offer information and contribute to a more comprehensive and detailed depiction of the evolving trends in their respective areas. These indicators are derived from analysis and interpretation of fundamental measurements or parameters for characterizing and understanding the Earth's climate system.

An **Essential Climate Variables (ECV)** is defined by WMO as "*a physical, chemical or biological variable or a group of linked variables that critically contributes to the characterization of Earth' s climate*". These are compiled into datasets to, provide empirical evidence that helps understand and predict the evolution of climate, and assess risks and enable attribution of climate events to underlying causes. EVC datasets *(refer Fig. 3)* further guide mitigation and adaptation measures, and supports the United Nations Framework Convention on Climate Change (UNFCCC) and Intergovernmental Panel on Climate Change (IPCC) efforts for assessment and creating climate services. Assessments provide policymakers and the public with synthesized information on the state of the climate system, projected future changes, and associated impacts, by quantifying the observed changes and attributing them to human activities. Climate services provide tailored climate information and predictions to various sectors, such as, agriculture, water resources, energy, and disaster management, and helps develop climate models, downscaling techniques, and decision support tools.

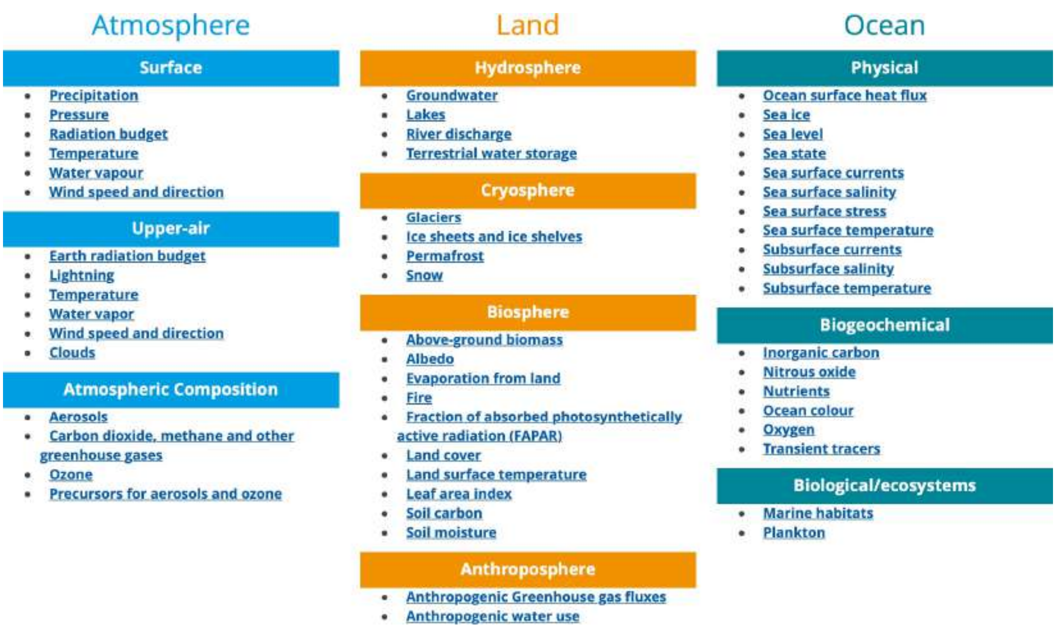

Fig. 4.3 : Essential Climate Variables, WMO (source : https://gcos.wmo.int/en/essential-climate-variables)

The National Centers for Environmental Information (NCEI) of the U.S. National Oceanic and Atmospheric Administration (NOAA) and the U.S. GCOS Program at NCEI, maintains the Global Observing Systems Information Center (GOSIC) which provides further background, definitions, requirements, network information and data sources for ECVs. These variables are monitored as per the GCOS Climate Monitoring Principles (*agreed by the Committee on Earth Observation Satellites (CEOS) and adopted by the Congress of the World Meteorological Organization (WMO) and Conference of the Parties (COP-9, 2003) to the UNFCCC*), which provide a standardized framework for monitoring and measuring key climate parameters consistently across different regions and over extended periods. The ECVs also help in validating and calibrating climate models, ensuring they accurately represent the observed climate variability and trends.

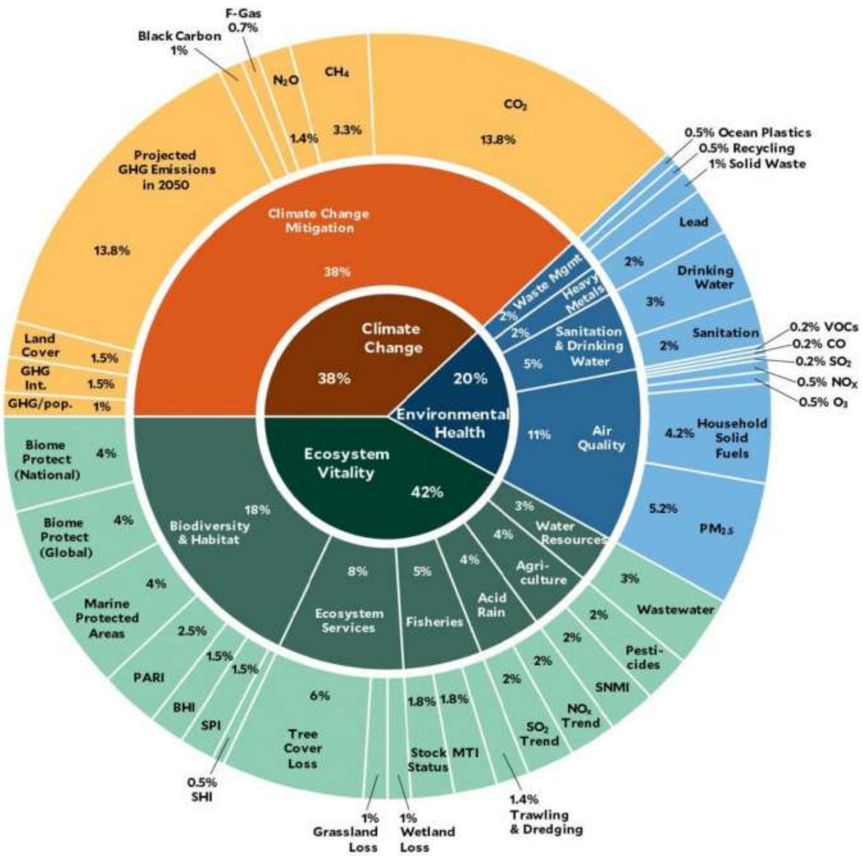

Fig. 4.4 : 2022 EPI Framework (source : https://epi.yale.edu)