Sustainable Environmental Systems and Environmental Change Dynamics

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Abstract

Sustainability is one of the greatest challenges of the twenty-first century, requiring urgent technological, economic, and social changes. Societal efforts toward sustainability must consider interactions between the biophysical and human systems, and possible tipping points in environmental change. A sustainable environmental system prioritizes the understanding and sustainable management of Earth and environmental systems, and the protection and restoration of the supporting and regulating ecosystem services of natural and modified ecosystems. Addressing the major environmental changes caused by human activities and meeting the resource demands arising from population and economic growth are central to promoting and achieving sustainability. Evidence-based reductions of negative anthropogenic impacts and the development of new, benign technologies and management practices should remain a priority. Emerging fields such as green economy, circular economy, and sustainable development offer a framework for addressing these challenges.

Research toward sustainable environmental systems is concerned with the interactions between natural and human systems and how these interactions influence the provision of ecosystem services and the maintenance of the natural capital necessary for social and economic development. Achieving sustainable resource use requires a holistic view of the biophysical systems; with their many coupled processes and scales of operation, it is important to consider not only individual processes but also the connections between them.

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Chapter - 1

Introduction to Sustainable Environmental Systems

A sustainable environmental system is defined as a dynamic and complex system that possesses the ability to satisfy current and future needs, without causing environmental harm, that serves its purpose for an extended period of time, and that can adapt to changing environmental, social, and economic conditions. Environmental systems that exhibit sustainability perform nature's vital functions and provide necessary goods and services without adversely affecting the ability of the system to continue providing these goods and services. The concept of sustainability is derived from the Latin word "sustinere," which means "to hold up." Sustainability encompasses many dimensions-economic, environmental, and social-and implies the ability to meet the needs of the present without compromising the ability of future generations to meet their needs. Every basic requirement that people need for living on our planet should be fulfilled in a sustainable way, including the air, water, food, energy, and ecosystem services. Since the modern society relies heavily on fossil fuel-based energy, such as coal and crude oil, sustainability of energy systems will also severely affect the SU of the entire environment.

The next task is to link the above arguments with environmental systems consisting of atmosphere, hydrosphere, lithosphere, and biosphere. These four major subcomponents interact with each other and together create the earth system. Every coupled subsystem of these four subcomponents, consisting of atmosphere-hydrosphere, atmosphere-biosphere, atmosphere-lithosphere, lithosphere-hydrosphere, lithosphere-biosphere, and hydrosphere-biosphere, together forms a specific environmental system and exhibits sustainability based on the principles of systems thinking. The performance of each subsystem, and indeed that of the entire environment, will ultimately depend on the sustainability of the coupled atmosphere-hydrosphere system, as extreme weather and climate events in the atmosphere produce droughts and floods at regional to local scales [1, 2, 3, 4].

Concepts and Definitions of Sustainability

Sustainability has become a central theme in 21st-century environmental science, with its evolution reflecting increasing awareness of the interconnectedness of environmental, social, and economic systems. Sustainability is the capacity to sustain complex environmental systems over time. There have been many definitions of sustainability. Most definitions focus on the idea of meeting the needs of present generations without compromising the ability of future generations to meet their own needs. Dupuis and Boardman argue that sustainable development and sustainability are determined by an interdependent set of institutional, social, ecological, and technological choices.

The terms sustainability and sustainable development may be associated with different institutions and types of science. Sustainability research is derived primarily from physics and ecology, and often appears in funding programs of environmental sciences, natural science, and engineering. Sustainable development research, by contrast, draws principally from economics, sociology, and political sciences. This scholarship frequently gets funding support through economic development, technology, or social science-based policies. These two bodies of literature are distinct but overlapping. Sustainability embraces a wider range of ecological, technological, institutional, and social change, while sustainable development has a stronger economic orientation and focus on the distribution of resources among countries and people within countries. In particular, sustainable development is often interpreted as supporting economic development and growth in the South. [5, 6, 7]

Components of environmental systems

An environmental system may be defined broadly as a connected set of substances (or materials, including gases and other states of matter) and their associated processes, which operate together to produce observable phenomena of a particular nature. Every environmental system consists of numerous coupled subsystems, such as the atmosphere, hydrosphere, lithosphere, and biosphere, which are, in turn, composed of smaller-scale subsystems and processes. While the Earth itself is the greatest observable environmental system, multiple other complete and incomplete systems exist-for example, the Amazon rainforest and its water drainage basin; oceans, ice caps, glaciers and icebergs; the climate of particular regions and the populations of endemic flora and fauna; and ecosystems of various scales.

An essential characteristic of environmental systems is that matter is frequently exchanged, distributed, transformed, and reused in natural processes. In ecological terms, the biosphere represents a critical subsystem containing populations and communities of organisms, which require external inputs of energy and matter and possess a high degree of complexity; mankind's explosion in population numbers and technological capability creates untold pressures on this subsystem. Matter and energy are therefore fluxes, where energy enters the Earth as solar radiation and dissipates as heat, while the amounts of matter remain invariant. Fluxes may also cross sub-system boundaries-for example, the carbon and water cycles link together the atmosphere, biosphere, and hydrosphere while feedbacks in several forms maintain nonlinear causal interconnections [8, 9, 10, 11].

Principles of systems thinking

Sustainability as the capacity of a system to endure, adapt, and expand its functionality, environment, and scope over time is the overarching theme and perspective of this work. An environmental system is a collection of components interacting to perform one or more functions in support of an overarching purpose. To ensure the continuity of its internal services, such as food and resource provision, the system must remain environmentally friendly. Given our dependency on the Earth and its natural resources, an environmental system is fundamentally a subset of a larger Earth system whose planetary-scale functions, such as climate regulation and the provision of clean air and water, must not only endure but also continue to evolve and adapt under present and foreseeable future conditions.

To achieve this higher-order goal, environmental systems can be regarded as sustainable if they meet the requirements of system sustainability. These requirements can be succinctly recast on the basis of systems theory, which asserts that a whole is greater than the sum of its parts, that the outcome of a system is a product of its inputs combined according to dominant underlying interactions, that the internal and external responses of the system alter the system function, and that the continued existence of the system depends on feedbacks with the environment that operate on timeframes necessary to restore system function. In other words, an environmental system is sustainable if it endures and adapts its internal interactions, functional diversity, and external interactions so that the net effect on the stability of its environment remains positive while also expanding its periodic delivery of desired services to the system's constituents. System sustainability is a more general approach than ecological sustainability, since it embraces all forms of sustainability, including economic and social sustainability, whose ultimate goal is the internal sustainability of the environmental system which is standardly taken to focus on ecological services only [12, 13, 14].

Sustainability metrics and indicators

Various metrics, indicators, and indices have been developed to monitor environmental systems and assess their status and sustainability. They provide guidance for environmental policies, evaluation of environmental impact assessments, and decision-making. However, care should be used in the choice and application of these measures, as different stakeholders may have different objectives or insights into the status and sustainability of environmental systems, and there is always a risk that multifaceted issues will be oversimplified by a few synthetic measures.

Indicators are simply measurable properties of the Earth System that provide insights into other states or processes. However, not all individual indicators are necessarily useful; they should be selected based on their sensitivity, reliability, robustness, predictability, and data availability. Therefore, the ongoing process of identifying and developing climate indicators depends on the demand for information;

modification and improvement are also key when original indicators no longer fulfil their intended function. Care is required when aggregating multiple indicators, as combining too many can obscure important information or differences. To enhance understanding of global environmental sustainability, multiple descriptive indicators are often combined into a smaller number for analysis, such as for the Sustainable Development Goals and a variety of ecological footprints, surpluses, or balances [4, 15, 16].

Global Environmental Challenges

Many environmental problems have existed for thousands of years, but they have escalated dramatically in recent decades. The clear evidence of current environmental degradation and the dramatic changes that lie ahead involves large-scale changes in land use, intensive fertilization of ecosystems, fossil-fuel-burning chemicals, and, consequently, global climatic and ecological change. Today's changes are also taking place at an unprecedented rate and to an unprecedented extent. The scale of modern change and its associated effects have the potential to trigger an increasing number of negative consequences, including unexpected species losses, planetary feedbacks, and altogether new types of systemic failure.

Humans are now achieving a level of impact on the environment and climate system once thought only possible through planetary impact by a large meteorite. Compounding problems delimiting worldwide environmental sustainability are increased rates of global material throughput, energy flows, and climatic and ecological change. Per capita demand for resources is rising rapidly as developing countries try to better satisfy the basic needs of a growing population. Pressures are also increasing as consumption growth responds to rising affluence and attention to status in life. These combined pressures are, in fact, pushing physical sustainability boundaries in many areas of the globe, notably in terms of soil and freshwater resources, greenhouse-gas emissions, mineral and fossil fuel reserves, and biological species. The general consensus is that, unless these pressures are reduced, a deteriorating and potentially much more dangerous future will eventually have to be faced [17, 18, 19].

Chapter - 2

Earth System Processes and Interactions

The global environment is organized into major component systems, including the atmosphere, biosphere, hydrosphere, and lithosphere, which interact with one another to form the Earth System. These natural systems are coupled with human systems through the flows of energy and matter between natural resources and consumption activities. Earth System science investigates the interactions and feedbacks between component systems to provide an integrated and holistic view of environmental change dynamics. These interactions and feedbacks exist at multiple spatial and temporal scales, from local to global and from seconds to geological time. At times, natural systems undergo abrupt transformations that cause rapid environmental regime shifts or non-linear responses to disturbances, conditions described by the concepts of thresholds and tipping points.

Natural and anthropogenic environmental forces act on these coupled natural-human systems, generating complex dynamics of environmental change. Global environmental concerns are the result of interactions among several drivers acting at various temporal and spatial scales. Natural drivers include changes in solar irradiance, volcanic eruptions, El Niño and La Niña oscillations, and tectonic processes. These natural drivers are complemented or overwhelmed by the well-documented influence of humans on the environment through rapid industrialization, rising population density, intensive land-use change, global trade and transport, and other global phenomena. These environmental change drivers, combined with system control mechanisms (such as water or nutrient availability and temperature), induce pressures on the system components (e.g., land, water, energy, and biodiversity) and, in turn, affect the provision of essential ecosystem services. This can ultimately compromise the resilience of natural systems, make them more vulnerable to climate variability, and expose human systems to greater risk. [20, 21, 22]

Atmosphere, Hydrosphere, Lithosphere, and Biosphere

The Earth system encompasses four interdependent subsystems: atmosphere, hydrosphere, lithosphere, and biosphere. System interactions regulate current and past climate, biodiversity patterns, biogeochemical cycles, and the provision of essential ecosystem services. Atmosphere and hydrosphere processes redistribute energy and moisture, while temperature and precipitation patterns control terrestrial and oceanic production and carbon storage. Releases and uptake of greenhouse gases and aerosol-forming compounds influence radiative forcing. Land surface modifications through urbanization, deforestation, and agriculture, together with anthropogenic emissions, shape local and regional climates. Biosphere dynamics interact closely with geochemistry, geology, and microbiology. Geological processes modulate atmospheric gas concentrations and climate over long timescales. Human activity has become a significant driver of environmental change. Hallmarks of the Anthropocene include habitat conversion, biodiversity loss, novel biogeochemical cycles, in situ pollution, toxic atmospheric composition, and rapidly changing climate boundaries.

The dominant climate change signal originates from enhanced greenhouse-gas forcing. Concentration increases in CO2, CH4, and N2O arise from fossil-fuel combustion, cement production, agriculture, land-use change, and waste. Global carbon management is therefore both urgent and complex. Initial warming stabilizes at equilibrium beneath a warming-dependent buffering of the Southern Ocean or an immobile vast water-bag configuration-later hiatuses can arise from dust alone between 5°C and 6.9°C on a surface boundary condition. New yellow-green dust emissions enhance warming on dry Northern Hemisphere land. Climate-resilient aspects of future variability and change >7°C are consistent with evidence from deep-sea sediment, terrestrial flora and fauna, and ice cores, challenging assumptions of stable T & P controls, demonstrating the existence of climatic "weather patterns" that shaped prehistoric extinctions and an expected future trajectory beyond +6°C that involves increased frequencies and intensities of monsoonal extremes, hurricane sequential formation and landfall, and enhanced characteristics of El Niño and La Niña events. [23, 24, 25]

Energy and Matter Fluxes

Matter, energy and information circulate in waves through continuous cycles. Matter appears and disappears in transformations. Energy enters the system from sunlight, is transformed and dissipated as warmth. Organisms capture, consume, store, transform, release and utilise energy. Reserves of energy or matter are temporarily available; the abundance of renewable reserves is constantly replenished; but others are finite; some interactions in the heat engine of nature drive biological global changes in sediments, soils and atmosphere. The rate of production of atmospheric pollutants determines the rate of natural tending and self-cleaning. Sources acting faster than sinks of reserve matter set-up irreversible changes, until a new steady state is attained. The Earth system is out of equilibrium and responding violently.

The atmosphere behaves as an active heat engine. Variation of temperatures, starting from the heated tropics, produce curving density waves which move from tropics to poles and from west to east. The movement of air masses conveys a part of the water from the sea over the continents. Compared to the contributions from the oceans, the reserves contained in the atmospheric reservoirs are negligible. Nevertheless, the latent heat released during the precipitation increases the temperature of the air masses and offers the energy for new disturbances. The hydrologic cycle, fed chiefly by the evaporations of the oceans, carries the water, salt-free, and some matter in solution, over the continents. The cycle is, however, reversible [26, 27, 28, 29, 26, 27, 28, 29].

Earth System Feedback Mechanisms

Feedback has two different general meanings. The first refers to feedback interactions within the internal operation of a system, while the second refers to feedback mechanisms that lead to changes in the overall state of the system. In the context of Earth System processes, the first type of feedback refers to internal processing of energy and matter related to the climatic, hydrological, and biogeochemical cycles developed in the previous sections. The evolution of the atmosphere, hydrosphere, lithosphere, and biosphere represents a complex universe of interactions and feedback mechanisms leading to energy and matter exchanges between the different components of the Earth System.

The contributions of different interactions and processes are described as positive or negative feedbacks. Positive feedbacks enhance a given process, while negative feedbacks dampen it. The second type of feedback is a mechanism that leads to a different state of the System. For instance, the gradual increase of atmospheric levels of water vapour and greenhouse gases from natural and anthropogenic sources, enhances the absorption and re-emission of longwave radiation which, in turn, warms the atmosphere. Some portion of Earth's surface will warm and increase the rate of evaporation, releasing more water vapour into the atmosphere. The internal feedback creates more warming. However, as warming continues and the Earth's Ice Cover melts, albedo decreases, and more solar radiation is absorbed. The combination of these mechanisms could eventually exceed a threshold and create a different state for the System.

Coupled Human-Natural Systems

The impetus for using the term "environment" lies in the desire to achieve greater integration of the sciences and better understanding of the European environment and its changes as both a primary gene pool of the human species and a source of resources. It must be recognised that these environment systems are already strongly influenced by human activity, hence are becoming coupled human-natural systems. The natural system's components, structure and processes are still defined by the boundaries of the atmosphere, hydrosphere, lithosphere and biosphere. The interaction cannot be seen as balanced development because it is unstable in its economic and ecological aspects. The natural system does not have an unbounded capacity to absorb waste, yet that capacity is exploited to the limit. It is impossible to burn fossil fuels in massive amounts for millennia without disturbing the greenhouse effect. The complexity of the coupled human-natural systems is further augmented by the uncertainty of many flows and processes.

Both the human and the natural subsystems are open systems. The wealth- or resource-generating processes are concentrated in a few zones; the residuals from production and consumption are concentrated elsewhere. Forest cover is sharply diminishing in the system's peripheral zones; both the zone of the richest land for agriculture and the mismatching of rainfall and temperature in the monsoonal zone are also experiencing instability. The natural structure of the system is threatened by strong developmental pressure in some places and weak pressure in others, leading to desertification and a diminishing speciation in the rich biodiversity zones. Hence it is the interaction of the two subsystems that forms the fundamental behaviour and defines the properties of the coupled human-natural system. [30, 31, 32, 33]

System Thresholds and Tipping Points

Certain thresholds within the Earth System, crossing which can irreversibly drive natural or human systems towards alternate equilibria, are named tipping points. Tipping point explanations suggest that stability properties of a system may be miscomputed when analyses only account for the forcing of gradual, small perturbations. They highlight the importance of feedback interactions and transversal bifurcations: perturbations accentuated by structure change-and revival, not necessarily large, may shift attracting state. Tipping points also indicate risk of abrupt, unanticipated changes even for processes traditionally considered gradual, but may leave the full dynamics of these processes misunderstood. Moreover, simple explanations can conceal their occurrence in the axis-only dynamics of bi-dimensional systems, even reduced models.

Tipping points are also a serious concern in human-induced climate change and other global-change related problems. The scientific literature lists possible future points of no-return in the function of the present system: gradually crossed, they will likely provoke a change of system regime; abruptly crossed, they may cause an irreversible catastrophe [34, 35, 36, 37].

Chapter - 3

Environmental Change and Global Drivers

Global changes in environmental systems are driven by natural and anthropogenic factors operating at global and regional scales. Anthropogenic drivers observed over the past few centuries have had more rapid, yet not necessarily greater, impacts than natural drivers acting over millennia or millions of years.

Climate is changing because of a combination of increases in greenhouse gas concentrations, tropical land-use change, stratospheric ozone depletion, changes in cloudiness and land-surface properties, and internal variability. Increased greenhouse gas concentrations are the major driver of trends in global mean temperature, hot extremes, precipitation frequency and intensity, ocean heat content, sea-level rise, and ocean acidification, although land-use change has had a detectable influence on temperature and precipitation. Influences on northern hemisphere climate such as ozone depletion and tropical land-use change contributed to recent trends, particularly in the frequency of mid-latitude storms and the number of cold nights. Natural forcing has exerted some influence on climate change, particularly within the larger variability associated with natural internal processes, such as ENSO. Continued increases in greenhouse gas concentrations and changes in ozone-depleting substances are expected to drive further changes. [38, 39, 40]

Natural vs. Anthropogenic Drivers

The dynamics of the Earth System are shaped by two classes of drivers-natural and anthropogenic-that operate at various spatial and temporal scales. Natural processes operating on a vast temporal scale such as carbon cycling, glacial-interglacial cycles, or tectonic activity contribute to the Earth’s modes of natural variability. Shorter-term sources of variability, such as the solar cycle and volcanic eruptions, additionally alter climate. The atmosphere and oceans play an important role in elucidating the linkages between these natural drivers of change. These complex interactions will continue to operate, albeit with different amplitudes, in an evolving climate.

In addition to these modes of natural variability, long-lived greenhouse gases produced by human activity have altered the composition of the atmosphere. Rates of accumulation of carbon dioxide, methane, and nitrous oxide sensors are higher now than at any other time during the past millennia, influenced by emissions associated with industrialization, changes in land use and land cover, and increased agricultural activity. These changes in atmospheric composition have been correlated with instrumental changes in climate record and with other anomalies in the Earth System. Increased concentrations of greenhouse gases are expected to increase temperatures, affect global precipitation patterns, alter hydrological cycles, change atmospheric and oceanic circulation patterns, and increase the frequency and magnitude of extreme weather events. [41, 42, 43]

Climate Forcing Factors

A number of natural processes operate on Earth that influence climate and associated climatic patterns of weather, fauna, flora, and ocean currents. Among the most significant of these processes are variations in the Earth’s rotation and climate-modulating cycles associated with solar activity, volcanic eruptions, circulation patterns of the atmosphere and oceans, and changes to vegetation. Human activities have accelerated the natural greenhouse effect and amplified climate forcing at rates and magnitudes unprecedented over geological time. Anthropogenic perturbations of the natural environment, which arise from the extraction of resources to fuel economic growth and infrastructure development, constitute a second, distinct component of climate forcing. The improvidence and inequity of resource use push natural systems towards critical thresholds beyond which major changes in climate, weather, ocean current circulation, marine and terrestrial ecosystems, and feedbacks on the physical environment are likely to occur.

Such tipping points encompass the collapse of the Greenland ice sheet, a sway in the North Atlantic oceanic conveyor belt, the loss of the Amazon rainforest, and a circumnavigation Al increase in the temperature and acidity of the ocean. These critical transitions, while potentially destructive of human endeavour and endeavour, can nevertheless present opportunities for oval-emerged ways from apparently irreversible decline. On the one hand, extreme climatic changes and unmanageable natural disasters call for augmented political resolve to strive towards sustainability. On the other hand, the social and technical innovations of green economies offer moral encouragement and economic opportunities for resource-rich developing countries. [44, 45, 46]

Land Use and Land Cover Change

Land use and land cover change (LULCC) is a global process induced by natural events or human actions that alter the land surface and vegetation cover of a region. LULCC inherently modifies land surface properties, which determines major features of natural environmental processes, including the soil-water balance, energy budget, and carbon storage. It also fuels several ecosystem processes, such as rainfall interception, soil erosion, carbon sequestration, and biodiversity. Altered biophysical and biochemical properties of the surface may further alter regional climate and hydrological responses. Human-induced LULCC has accelerated in recent decades with the expansion of agriculture, urban-related development, forestry, and mining and is expected to continue over the next few decades due to an increasing population and the associated demand for resources.

Globally, land degradation and desertification processes have intensified as a result of unsustainable land use. Deforestation fires, drainage of wetlands, soil erosion, salinization, and depletion of soil fertility have increased and will continue increasing the area of degraded lands that contribute to carbon emissions and the loss of carbon sinks. The expansion of world cities and the associated population concentrations have worsened the environmental conditions of their surroundings and impacted the global environment. However, these adverse changes have stimulated awareness for conducting research on ecological restoration and management of degraded lands. Intensified attention on all these aspects should continue in the future to monitor LULCC in order to improve environmental quality, reverse negative trends, and enhance ecosystem services at global, regional, and local scales. [47, 48, 49]

Industrialization and Urbanization

The combined processes of industrialization and urbanization represent two of the most impactful transformations in human history. Industrialization refers to the transition from a preindustrial economy characterised by agrarian production and trade to one dominated by a mechanised manufacturing sector. The second key force, urbanization, denotes the increase in the size and number of cities as populations flock to urban areas in search of economic opportunities. Both processes are inherently coupled, as industrial expansion is a major driver of urban growth, and the rise of cities provides the labour and markets to sustain industrial centres. This section outlines the ongoing and projected global trends in both industrialization and urbanization.

There is evident divergence in the trends in population growth and urbanization rates among the global regions; for example, in 2020, the annual growth of the population of the Africa region was approximately three times greater than the corresponding growth of urban populations. After 2020, as these trends converge, urbanization cannot be expected to totally absorb population growth in Africa over the next 30 years. Globally, it is likely that more than 80 per cent of the total increase in population over this period will take place in urban areas, but the absolute number of city dwellers in Africa will continue to grow more slowly than the total population of the region. [50, 51, 52]

Globalization and Resource Demand

Within the global system, globalization represents a process of transnational, accelerated sliding of ideas, goods, services, and information that transcends culture, territories, and people, as well as the growing interdependence of national suppliers, businesses, and communities. Common cultural trends and globalization of economies are in constant contact with regional and local aspects. The approach of different cultures supports innovation and is created by dialogue.

Globalization helps the formation of comparative advantages and creates opportunities for countries and companies to take part in shaping the world's economy. It needs to be considered a fixed process that has not only positive but also negative aspects. As all macroeconomic models do not account for validation errors and deviations, the need for distance growing relative to evolution demands the submission of the process to an adaptation law.

Globalization represents a known and well-studied aspect of the modern world economy as well as aspects of technosphere and biosphere aging and market saturation. The process must be tracked and monitored according to different criteria and generalized in time to identify excesses. The modern aspect of the world economy is characterized by excessively high costs and a hypersupply of many goods. Two categories of goods may present opportunities for nations willing to follow globalization: energy and food. Energy prices grow higher than inflation, but it is necessary to assess whether there is a permanent shortage of world energy resources, especially for nonrenewable resources and especially for oil. [53, 54, 55, 56]

Chapter - 4

Climate Change Dynamics

Climate change is identified as one of the major global environmental challenges. It is attributed to the increase in the concentration of greenhouse gases (GHGs) in the atmosphere, mainly as a result of fossil fuel consumption. Rising global temperatures trigger climate variability and extremes, affecting natural and human systems. Climate models based on the physics of the atmosphere are important tools to understand climate change dynamics and to assess potential impacts, adaptation requirements, and disaster risk reduction strategies at regional and local levels.

The global concentration of carbon dioxide (CO_2) and methane (CH4) in the atmosphere have increased significantly during the last century and a half due to human activities. The relentless increase in GHGs, together with other climate forcing factors, is expected to raise the global average temperature to about 3 to 4 °C above pre-industrial levels by the end of this century. Global warming is projected to continue beyond 2100, even if GHG concentrations are reduced drastically, because of the long residence time of CO_2 in the atmosphere, possibly bringing about profound changes in the Earth's climate system. [57, 58, 59, 60]

Greenhouse gas emissions

The primary cause of global warming and climate change is the increasing concentrations of greenhouse gases (GHGs) in the atmosphere. Rapid increments are noted in the atmospheric concentration of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N2O), and some other greenhouse gases during the last hundred years. Burning of fossil fuels such as coal, oil, gas, deforestation, and certain agricultural practices are the major anthropogenic sources of greenhouse gases. Other natural sources include wetlands, oceans, geothermal vents, and volcanic eruptions.

Carbon Dioxide: The atmospheric concentration of CO_2 has vastly increased from approximately 280 ppm during pre-industrial times to over 400 ppm in the 21st century. This increase is primarily due to fossil-fuel combustion, cement production, and land-use change, in particular, deforestation and land-use conversions in tropical and temperate regions that reduce CO_2-fixing biological productivity. Planting of trees and conversion of land to peatland must not only compensate, but also bring down rapidly the atmospheric CO_2 before the climate enters a runaway greenhouse state. In addition, other long-term natural earth processes such as weathering, photosynthesis, and the dissolution of carbonates in the ocean are related.

Methane: Methane (CH_4) is the second most influential greenhouse gas after carbon dioxide, accounting for about 15% of the enhanced greenhouse effect compared to the pre-industrial period. For the period 1750-2000, methane increased from approximately 700 ppb to more than 1770 ppb (over a 150% increase). The most significant source of anthropogenic CH4, especially since the late 20th century, is assumed to be cattle raising and rice cultivation. However, methane has a relatively short atmospheric lifetime of about a decade, permitting reductions in the atmospheric burden.

Nitrous Oxide: Nitrous oxide (N_2O) concentrations rose from about 270 ppb in 1750 to over 315 ppb by the late 1990s (about a 15% increase) and its growth rate has accelerated markedly since the 1970s, matching the increasing use of N fertilizers in intensively cultivated areas. Nitrous oxide also contributes to stratospheric ozone depletion and atmospheric N_2O concentrations are therefore of great concern. Methane emissions control measures are also likely to benefit atmospheric N_2O concentrations. [61, 62, 63, 64]

Climate variability and Extremes

An emerging body of research highlights that climate-related hazards have increased worldwide, with the frequency of heatwaves, rainfall extremes, droughts, and other natural hazards becoming more pronounced and intense in various regions. Many forward-looking modeling efforts further suggest that the severity of thermal extremes will continue to increase in many areas of the world over the twenty-first century, with significant implications for both ecological and human systems and the functioning of crucial cultural and economic sectors. The major effects on human systems, and in particular health and labor productivity, are among the more frequently cited impacts of climate extremes and variability, as well as the costs to the economy and the ecosystem services that support it.

Research, encompassing a wide array of human systems, has applied structural gravity models to capture distant trading linkages through an import demand and export supply framework within a specifically designed computable general equilibrium model. This approach relies on international trade data structured in accordance with so-called partner of partner trade linkages-a distinctive methodology that relates trade flows at the product level. The encompassed costs allow considering effects on labor productivity due to less favorable climatic conditions in the home region of workers, as well as associated health impacts. More recent modeling specifically investigates the relationship between anomalies in extreme hot days and nights and human mortality rates. [65, 66, 67, 68]

Climate Modeling and Projections

General circulation models (GCMs) are used to understand the response of the climate system to greenhouse gas (GHG) and/or aerosol forcing and to project the climate for the next century and beyond. GCMs simulate the coupled atmosphere-ocean-cryosphere-land surface system on a full 3D grid with interactive exchanges of energy and moisture between the components. Several GCMs use different physical formulations for the atmospheric and ocean components, as well as for land and sea-ice processes. To evaluate the range of expected climate change responses, most international climate assessments include simulations with a hundred or more GCMs. The comprehension of natural variability, inherent or chaotic, of the climate system was addressed by producing long GCM integrations with constant external conditions, and running coupled GCMs in a perturbed initial conditions ensemble mode.

Transient GCM experiments offer Earth System Models the opportunity to simulate not only the "mean" climate state, but also the time-dependent evolution toward a warmer climate, which includes increases in the seasonal and interannual variability. For analyzing the mechanisms responsible for the future changes in the difference between the warm and cold seasons in the tropics, a single GCM is often preferable so as not to mask the signals with systematic model errors. Regional climate models are nested into GCMs to simulate the mean or transient climate change at a higher resolution over a region of interest with interactive vegetation. [69, 70]

Impacts on natural systems

Climate change is affecting natural systems through a wide range of direct and indirect pathways. The geophysical states of local and regional natural systems are increasingly outside the range of variability experienced in the Holocene epoch, the last 11,700 years of interglacial conditions before the onset of the Anthropocene. Local geophysical conditions are already so different that the distinctive flora and fauna of many ecosystems no longer exist. Biological populations and species are responding to the shifting climate in diverse ways: adapting, moving, and in some cases, going extinct. As the climate becomes less predictable, many organisms and ecosystems that cannot adapt, migrate, or escape increasingly become vulnerable to collapse. Natural systems such as forests, ecosystems, and oceans, on which a vast number of people depend for their livelihoods, are experiencing increasing stress from climate change, leading to declining provision of ecosystem services.

The ongoing warming of the climate system is driven by increasing concentrations of greenhouse gases (GHGs) in the atmosphere, resulting from human activities and their associated emissions. This multifaceted change leads to shifts in climatic means and variances across space and time, resulting in unprecedented rates of change in the Earth’s temperature, precipitation, and wind patterns. Evidence and understanding of climate variability and change at different scales, including extremes, is advancing rapidly. Each of the components of the climate system-atmosphere, cryosphere, hydrosphere, lithosphere, and biosphere-is responding to ongoing warming in ways that influence weather and climate, sometimes in ways that remain imperfectly understood. Multiple lines of evidence show elevated global average sea levels and declining Arctic sea ice, glaciers, precipitation, and terrestrial snow cover. There is increasing understanding of how changes in land use, land cover, and atmospheric composition are contributing to regional climate changes. [71, 24, 72, 73]

Impacts on human systems

Disruption of physical and biological systems in human societies can have severe consequences, affecting food and water resources and ecosystems. Climate projections predict more extreme weather events, reduced agricultural productivity in vulnerable regions, increased pressure on freshwater resources, and widespread loss of biodiversity. Rubber, maize, and rice supply shocks could increase food prices again, with propagation effects across countries.

Climate change multiplies human vulnerabilities and increases the challenge of adaptation, although global poverty reduction remains a key priority. Adaptation still lags behind. Even if the Global South is the most vulnerable region, climate change could pose challenges for both the Global North and South as migration and security issues widen. Economic shocks and food production reductions might aggravate climate-induced instability in regions already struggling with sociopolitical tensions. Reducing the risks, costs, and impacts of extreme weather events and related disasters is an important global priority. Financial support for adaptation and recovery remains critical, especially for low-income countries already vulnerable to climate impacts.

Freshwater resources are also essential for human food and energy supplies, and the water cycle is being altered by climate change, leading to severe droughts in some regions and floods in others. As extreme rainfall events increase, the risk of pollution from urban and agricultural runoff is rising, decreasing water quality. Future water demand will exceed supply unless agriculture dramatically improves efficiency. [74, 75, 76, 77]

Chapter - 5

Water Resources and Hydrological Sustainability

Global freshwater resources are limited and unevenly distributed, and climate change is expected to alter both the amount and availability of freshwater. Population growth and industrialization have led to increased demand for freshwater, raising concerns over scarcity and pollution. Consequently, the need for water sustainability has become more pressing. A sustainable future water system requires a coherent understanding of the dynamics of the global water cycle and the relationship between water and other natural systems, as well as appropriate strategies for managing water quality and quantity. It is also crucial to recognize that the management of water resources cannot be viewed in isolation, as it interacts strongly with land, energy, and other systems.

The integrated management of water resources, taking account of current and future availability, demand, and quality, is essential for sustainable development. Therefore, the capacity of groundwater resources to provide security in periods of drought must be enhanced, while ensuring continued and sustainable access to clean water for all. In many regions, however, groundwater is being mined; achieving sustainability will therefore depend on replenishing and maintaining long-term balance between recharge and abstraction. Furthermore, improving access to sufficient and reliable water of adequate quality for vulnerable communities and addressing water quality problems, including pollution by pathogens and nutrients, are both vital for health and ecosystem services. [78, 79, 80, 81]

Global Water Cycle

There are many natural systems on Earth that impact each other and define life as we know it. One that is often overlooked is the global water cycle, or hydrological cycle. Properly described, and with the impact of climate change in mind, the global water cycle can be considered the natural processes and phenomena that describe the movement, use, and exchange of water and ice in and across the atmosphere, oceans, lakes and rivers, the land surface and subsurface, and all ecosystems. To further break this down, there are, at minimum, the definitions and descriptions of the hydrological cycle, the main gases in the atmosphere, precipitation, the oceans, lakes and rivers, surface and groundwater, glaciers and polar ice caps, biota, explicitly defined fluxes, scales of the cycle, the influence of climate change, and interconnections and consequences for other natural systems like the water-energy-food nexus.

When the concept of the global water cycle is introduced for the first time, students often confuse it with the concept of the hydrological cycle. There is indeed considerable overlap between the two concepts. However, for the purposes of understanding the global water cycle, it is necessary to bring in some of the major ideas in climate science, as well as other supporting scientific disciplines. In general, the hydrological cycle is a condensation of elements of the global water cycle, focusing specifically on water vapour and liquid water, along with snow, frost, and ice. In contrast, the global water cycle brings together the larger integrations of the system: namely, see volume and reservoirs. When those ideas are considered carefully, and at the scale of the entire planet, it allows for the definition of the global water cycle. [82, 83, 84, 85, 86]

Integrated Water Resources Management

(IWRM) is a new approach to water resources management seeking to bring various stakeholders, communities, government, and institutes together to plan for the management of water resources among the competing users and make water development sustainable. It promotes a coordinated approach to ensure the unified planning and management of land and water resources. Water resources management includes careful planning and management of the water, soil, and land resources for equitable and integrated development to maximize the benefits of these resources, taking into account the long-term environmental sustainability of the resource base.

The concept of IWRM embraces the management of surface, ground, flood, and wastewater resources as a complete unit. The framework of action emphasizes developing an integrated water resources management plan for rain-fed farming, urban water supply, and sanitation, and groundwater resources of the region. The concept recognizes that the development and management of water resources is based on a thorough understanding of natural resources and that cooperation at all levels will foster environmentally integrated land, water, and related resources development. [87, 88, 89, 90]

Groundwater Depletion and Recharge

The groundwater storage at the global level, estimated at around 23 million km^3, is about four times that of the water stored in lakes and swamps, 500 times that in the atmosphere, and nearly 70 times that in rivers. Increase in groundwater extraction globally for irrigation projects and for supplying drinking water-especially in Asia-is not followed by a proportionate natural recharge of the aquifers. Out of the estimated annual groundwater withdrawal of about 740 km^3, only about 230 km^3 is naturally replenished.

Around 70% of groundwater extracted from aquifers in India is for irrigation and about 10% for industrial use. However, the increase in extraction of groundwater has had its impact on the natural process of aquifer recharge. The severity of the extraction, coupled with overexploitation as well as deterioration of water quality; development priorities; and increasing demand travel hydrologic, climatic, and geological aspects of recharge sites and areas external to the local region are negatively affecting groundwater recharge. The concerns regarding groundwater recharge upsurge because aquifers are being either drained or contaminated. The challenge is to channel the mobilized water from surface hydrology and stormwater into recharge areas without endangering land and water resources and the receiving water bodies of precipitation runoff. Stormwater management strategies need to be proactive to incorporate aquifer recharge as a goal. Existing structures are often used, requiring little additional investment, except for optimal maintenance and control/surveillance. Generally, no or little costs are incurred for operation and maintenance. [91, 92, 93, 94]

Water Quality and Pollution

Pollution of surface and groundwater is a significant environmental challenge. Water quality across the globe is deteriorating due to both point and nonpoint source pollution. Nutrient enrichment (eutrophication) caused by runoff from agriculture and livestock farms; industrial effluents; untreated sewage; and leaching from landfill sites are major reasons for river and lake pollution in many countries. Heavy metals, pesticides, salts, and sediments are other important causes of water contamination.

Pollution of lakes and reservoirs is aggravated by reduced residence time, which diminishes their capacity to assimilate wastes. In many rivers, water quality is deteriorating to such an extent that its use as a drinking-water source is becoming increasingly expensive, if not impossible. Emerging pollutants, such as pharmaceuticals, hormones, and microplastics, represent new threats to surface and groundwater quality but are still not monitored based on comprehensive data over a long time period.

Water scarcity, mainly brought about by overuse and pollution of freshwater resources, is responsible for deteriorating water quality. Quality deterioration restricts use and renders treatment and pollution control more costly. Groundwater pollution is still not managed in a comprehensive way, mainly due to its large spatial extent and unquantified effects on human health and ecosystems. Contaminated aquifers cause a depletion of clean water reserves and are costly to clean. [95, 96, 97, 98]

Climate change and water security

The water cycle is among the most profound and far-reaching consequences of climate change. Globally, terrestrial vegetation, lakes, soil, and groundwater storage have all exhibited substantial decadal variation. These fluctuations impact the quantity of water available for human, ecological, and industrial use. Changes in land cover, land use, agricultural management, and irrigation are equally noteworthy, as they all have strong impacts on the global hydrological cycle. In addition, increasing temperatures exert pressure on local water resources through heightened evaporation and variation in precipitation patterns; the latter remain particularly difficult to simulate accurately on a regional scale. Together, these shifts challenge perspectives on water security. Changing seasonal supply patterns and shifting temporal demand seriously disturb historical coherence between water supply and demand. Globally, there is diminished confidence in the probability of floods and droughts, shrinking per capita water availability, and rising overall water transaction costs.

Water security in climate-vulnerable areas depends not only on local supply but also on upstream reservoir management. The supply of melting water from glaciers may serve to reduce flooding risk in the medium term, but its eventual reduction is expected to impose substantial water stress. Snowmelt-fed water systems are exceptionally vulnerable to climate change; a reduction in snowmelt supply will lead to decreased water availability during summer, the peak season of demand. Extended dry periods, floods, and high-intensity cyclones challenge infrastructure. [99, 100, 101, 102]

Chapter - 6

Sustainable Energy Systems

Sustainable and environmental energy systems include the use of renewable energy systems, sustainable energy efficiency, and energy conservation. Major renewable energy technologies include solar energy, wind energy, biomass energy, biofuels, geothermal energy, and ocean energy. Energy efficiency and conservation reduce unnecessary energy and electricity usage, allowing consumers to benefit from cost-saving measures. Additionally, energy storage systems, low-or-zero-carbon technologies, smart grids, and life cycle assessment of energy systems play a significant role in achieving sustainable energy systems.

The world is undergoing a major transition in energy systems and processes, and there are many factors driving this change. Climate change and climate-related policies are pushing for energy efficiency, expansion and use of renewable energy technologies, and the reduction of greenhouse gas emissions. Environmental degradation caused through urbanization, industrialization, deforestation, and pollution is encouraging the implementation of clean and green technologies as well as the development of a circular economy. Lastly, the demand for limited fossil fuel resources is creating interest in renewable energy sources. Such transformations are fundamental to sustainable living, because energy underlines all economic and industrial activities and is also a key driver for water and food security featured in the United Nations Sustainable Development Goals (SDGs). Thus, ensuring sustainable energy systems is of paramount importance. [103, 104, 105, 106]

Renewable energy technologies

Sustainable and low-carbon energy supply systems are pivotal to mitigate climate change and its impacts. The development and deployment of modern renewable energy technologies is recognized as a critical part of the long-term strategy to spur the transformation of the global energy system. Renewable energy resources such as solar, wind, hydro, biomass and geothermal are abundant and globally distributed, and their sustainable use would have clean, green, affordable, and sufficient characteristics. Renewable energy technologies are already providing a sizable portion of the world's energy supply and providing primary energy services to billions of people without access to modern forms of energy. Their share continues to increase rapidly.

Solar energy is one of the most abundant sources of energy that is available every day in great quantity and at zero cost. Solar thermal and solar photovoltaic technologies are emerging as viable alternatives for harnessing this ambient resource. Among other renewable sources, biomass exploitation is very important and is the only major source of energy in the developing countries. Wind, small-scale hydro, and geothermal energy represent some of the other forms of renewable energy resourced being harnessed for sustainable energy generation. Ocean energy resources, a constant supply of energy, are also receiving attention in the contemporary energy context. [107, 108, 109, 110]

Energy Efficiency and Conservation

Energy efficiency involves reducing energy consumption while maintaining an adequate level of energy service. In this sense, energy efficiency differs from energy conservation, which refers to reducing or eliminating unnecessary energy use. Thus, energy conservation is a broader term that includes behavior changes, eliminating standby consumption, increasing vehicle occupancy, and so on. Conventional economic analysis reveals that investing in energy efficiency projects is often more profitable than investing in other technologies, and, therefore, energy efficiency projects usually have short payback periods. Installing energy-efficient technologies reduces both energy bills and maintenance costs. Buildings with better energy performance may cost less to insure and tend to sell more quickly and at higher prices than buildings without these measures. Furthermore, improving energy efficiency contributes to reducing greenhouse gas emissions, and it allows to obtain a lower rate of emissions while supporting economic growth. Due to the many potential benefits that energy efficiency could bring, the lack of action and investment in energy efficiency in many sectors is often considered frustrating and confusing.

Advances and breakthroughs in scientific research are developing new energy-efficient technologies in many areas, from energy transformation to transmission, distribution and end use. Smart metering, data analytics and control systems provide further tools for reducing energy consumption and costs. Electric vehicles are a viable sustainable alternative means of transport and represent large energy and emission co-benefits throughout their life cycle when propelled by low-emission electricity systems.

Regulatory, administrative, economic and financial instruments can accelerate investment and innovation in energy efficiency in all areas. The importance of efficiency for security and the large savings in energy costs that efficiency offers are also recognized as drivers for further investment in energy-efficient technologies. While, in many countries, energy efficiency has historically received far less attention than other decarbonization strategies, it deserves priority as the first and cheapest resource for a sustainable energy system. Energy efficiency plays a crucial role in the transition to a sustainable energy future by climate change mitigation and adaptation. [111, 112, 113, 114]

Energy storage systems

The development of efficient, low-cost energy storage systems is critical for energy sustainability. Energy storage systems are needed to supply electricity when demand exceeds generation capacity, to absorb excess flow when generation exceeds demand, and to provide back-up power during outages. Different types of energy storage systems are currently in use or are being investigated. Flywheels are suited for small bursts of short-term power and can process a high number of charge/discharge cycles at high efficiency. Pumped hydro storage is used to store large amounts of electric energy and, unfortunately, is dependent on appropriate geography. Compressed air energy storage can also provide large-scale storage, and research is ongoing to improve the efficiency of the energy conversion process. Battery technologies appear to be the principal means of energy storage for vehicles and other mobile applications and also play a role in grid storage. Metal-air batteries and Li-ion batteries are among the most promising for future use. Supercapacitors are used for applications requiring very rapid charge/discharge and the capacity for very high cycling rates.

Peak demand shifts can also be accomplished by shifting air-conditioning demand to off-peak periods by increasing cool storage (e.g., chilled water), which can be done with precooling or dehumidification techniques, or by auxiliary charging of groundwater aquifers. Substantial ongoing efforts are focused on understanding, quantifying, and increasing the fraction of electric power production supplied by entropy-driven systems. At the moment, these systems are terrestrial power plants with net production from natural heat flows, and the technical obstacles to implementing ocean thermal energy conversion definitely exceed those present for solar, wind, or even small hydro. Nevertheless, various combinations of entropy-driven production for continuous base loading and solar for variable peak supply seem feasible and have the virtue of minimal CO2 emissions. [115, 116, 117, 118]

Smart Grids and Energy Management

Smart grids enable two-way real-time communication between utilities and consumers for enhanced energy management. They integrate software, hardware, and communication technologies in electricity generation, transmission, and distribution. Smart grids grant utilities monitoring and operational control capabilities and narrow the demand-response gap, optimizing electricity usage through price- and incentive-based programs with real-time feedback to consumers. These systems secure high reliability, safety, and efficiency with substantial investment. Smart grids also facilitate quick connection of renewables, energy storage, and electric vehicles.

Proactive management of electricity supply, demand, storage, and transmission with Smart Grid Technology addresses Energy-Water-Climate nexus sustainability challenges. Smart grids augment energy availability through energy efficiency and demand-side management technologies. At the grid operator level, integrating demand-side resources improves operational reliability, yet retrieving demand-side resources in peak load scenarios remains an unsolved problem. Supply-side resources are dispatched in anticipation of load growth. Evaluating the dynamic behavior of storage-based integrated energy systems during heavy-rain earthquake periods helps avoid wasting environmental resources.

Smart meter market growth is evident across nations, with southeastern regions ahead. Smart meters enforce and maintain electricity usage management, automating prolonged data collection for residential customers. These systems shorten confirmation processes, enabling on-time demand response through supply-side regulation. Smart grid real-time pricing promotes peak load control. Government policies and initiatives drive demand response pricing verification, enhancing real-time pricing effectiveness. The retail electricity market's minor customer sector lacks adequate information for active peak load participation. A three-layer architecture for considering consumer services and profiles aids the effective linking of smart grids and data mining resources. [119, 120, 121, 122, 123]

Life Cycle Assessment of Energy Systems

Energy systems are all the physical infrastructure on which the generation, conversion, distribution, and use of energy depend. Emerging technologies, such as energy storage systems, smart grids, or renewables, could be produced, transported, and used in ways that involve less consumption of natural resources and lower emissions of wastes than their conventional counterparts. The environmental benefits or drawbacks of these new technologies must be assessed over their entire life cycle, i.e., from the extraction of raw materials through production, transportation, and use to their final disposal.

Life cycle assessment (LCA) is a powerful and flexible method for evaluating the environmental aspects of a product or process throughout its life cycle. The LCA is based on the following four steps: defining the goal of the assessment, developing a life cycle inventory, performing life cycle impact assessment, and interpreting the results in relation to the goal and scope of the study. From an input-output perspective, an LCA consists of compiling data on all inputs (energy sources, resources, materials) and outputs (product, emissions, waste) associated with the life cycle of a product system.

The assessment must cover the entire life cycle of the product or process, including upstream and downstream activities. An up-to-date LCA library for renewable energy technologies provides information on indicators such as land occupation potential, ecosystem diversity and resource depletion. In practice, LCA makes a valuable contribution in guiding the research and development of new technologies toward low environmental impacts, comparing the merits of alternative concepts, and identifying areas for priority investment in reducing existing impacts. [124, 125, 126, 127]

Chapter - 7

Sustainable Land use and Soil Systems

Soil degradation is a recognized cause of lowering productivity in many areas of the world. Therefore, appropriate management of soils is essential to ensure food security and meet the needs of a growing global population. Sustainable land-use strategies based on carbon sequestration, regeneration of degraded lands, improved land-use planning, and implementing best management practices (BMPs) in agriculture and urban planning are crucial to limit or decrease the carbon footprint. The most important methods currently under research, and development for controlling greenhouse-gas emissions from soil systems are conservation of soil organic matter, limiting tillage, control of waterlogging and flooding, controlling weeds, improving drainage, and management of salt-affected soils to control methane emissions. Modification of the soil physical properties by incorporating waste materials in soil helps enhance crop productivity and control greenhouse-gas emissions. Healthy soils contribute to food security and sustainable development in many ways: increased crop and livestock productivity and support for biodiversity and ecosystem services, such as climate change mitigation and adaptation, water filtration, flood prevention, and regulation of natural diseases and pests.

Soils are major reservoirs of carbon, nitrogen, phosphorus, and other nutrients, and play a key role in the global cycles of these constituents. Fantasy projects of great reforestation of Earth are frequently put forward as a means for addressing greenhouse-gas emissions generated by fossil-fuel consumption. A strategy for moving toward sustainable development suggests an integrated approach, guided by disciplinary, interdisciplinary, and compelled knowledge, to provide the necessary human, social, and natural resources to achieve a broad sustainability transition. Global climate change, water and energy resources, biodiversity loss, land degradation, and unhealthy and poverty-stricken societies are a few characteristics of Earth today, which exacerbate local problems also in business processes and image. These demonstrate an unbalanced development incapable of achieving resilience. [128, 129, 130, 131, 128, 129, 130, 131]

Soil Health and Fertility

Healthy soils are crucial for sustainable food production systems and contribute significantly to global food security. However, soil erosion, salinization, and pollution are leading to severe degradation of soil quality, fertility, and productivity. Over the past two centuries, soil organic carbon (SOC) depletion from the world's cropped soils greatly reduced soil fertility and productivity and increased atmospheric CO_2 levels. Soil management practices that enhance soil health i.e. improve the biological, chemical, and physical properties of soils are important for sustaining food production and mitigating climate change. Soil health is defined as the capacity of a soil to function, within ecosystem and land-use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal.

Sustainable Agriculture Practices

Over the longer term, the food supply needed to feed a growing population can only be provided through sustainable agricultural practices that enhance food production capacity without degrading soil, air, or water quality. The task of growing adequate food also includes reducing local, regional, and global hunger and food insecurity, improving human nutrition, increasing energy efficiency of food production, minimizing agricultural contributions to environmental degradation and global climate change, and increasingly integrating nonfood ecosystem services. On food security, availability of food continues to increase at the global level, but prices are volatile and in some regions demand is outstripping productivity growth, leading to heightened concern about food security.

Breakthrough technologies and practices capable of transforming food systems and making them significantly more productive, inclusive, resilient, and environmentally sustainable are needed. Innovations in basic and applied research, including plant and animal breeding rooted in the principles of agroecology and organic farming, synthetic biology, and big data and artificial intelligence, must be harnessed to rethink the agricultural production paradigm and accelerate the adoption of sustainable practices at scale. Investing in sustainable water use and land–use planning, introducing clean and climate–friendly technologies along the value chain, improving access to markets and reducing postharvest food losses are also important. Meeting future food demands without further compromising the capacity of land and water resources to provide for future generations will require practically all regions of the world to increase their energy use per unit of cropland area, reduce fertilizer application levels, and actively restore degraded ecosystems.

The need for technological advances notwithstanding, upgrading agricultural practices globally and placing agriculture within a broader and more inclusive systems perspective will be critical for the transformation of food systems. Sustainable agriculture is aimed at providing divergent goals-food for the global population while protecting the environment. The new production system would be holistic in character, combining traditional agronomic practices with modern technologies as appropriate. [132, 133, 134, 135]

Land Degradation and Desertification

Land degradation, a major threat to sustainable land use in many regions, refers to a net loss of high-quality ecosystem services required by human society. Degraded land undergoes unnatural processes that lead to soil thinning, salinization, declining fertility, vegetation removal, reduced species diversity, fragmentation, and poor ecological structures. Desertification, a special case of land degradation, stems from climatic and anthropogenic factors and affects dryland areas, which contain 40% of Earth's land surface and host 3 billion people.

Desertification affects 2 billion people, reducing their access to ecosystem goods and services and undermining food production. Estimates of global land degradation vary greatly: 15 million km2 of land, or 12% of Earth's land surface, is reported as having undergone desertification, while 30% of drylands have lost more than 25% of their potential net primary productivity during the past 45 years. The scale and consequences of land degradation and desertification underscore the need for concerted action by governments and other stakeholders for sustainable land use and community livelihoods. Descriptive case studies of countries experiencing desertification can inform prevention and mitigation programs. [136, 137, 138, 139]

Urban Land Use Planning

Although most of the world's population will live in urban areas, making cities the most significant centers of economic development, local, state, and national governments may not plan for sustainable urban development. Metropolitan regions must plan and manage urban areas in ways that enable continued investment and development. Investment models for urban infrastructure must include the public sector's contribution to land development so that citizens and government managers can achieve a sustainable urban environment. Planning must also respect the autonomy of local governments. Cities often cannot plan or finance mass transit systems or provide environmental services without assistance. Government policies that enable people to return to the rural environment should also be encouraged.

Sustainable urban land use planning provides a framework to reduce the continuing and huge discrepancies and inequalities in urban settlements and the challenges associated with migration to mega-cities. Sufficient space containing adequate housing, transport, and social and physical services will have to be made readily available in urban and peri-urban areas by extending urban land use planning laws to rural areas of less than 10,000 population. Mechanisms will also have to be developed for providing the poor with the means to purchase or rent land and houses. [140, 141, 142, 143]

Soil Carbon Sequestration

Soils can sequester large amounts of carbon, and their health and fertility can be enhanced in a way that promotes climate change mitigation. Soils serve as a major reservoir for global carbon, having permanently sequestered roughly 75% of the carbon in the biosphere;

at the same time, the soil system is the most vulnerable carbon reservoir. The approximate size of the global soil carbon pool is 2500 × 1015 g, which is 3.3 times greater than the size of the carbon pool in the atmosphere. Soil-carbon fluxes, however, are not currently in balance, with the soil acting as a source of carbon dioxide to the atmosphere rather than as a sink. Cultivation, land use change, deforestation, and degradation of natural vegetation are the main factors driving this carbon loss. The rapid loss of soil carbon not only reduces soil fertility and soil health, but it also significantly contributes to climate change.

Five practices for sequestering carbon in soil without affecting food production potential have been established and studied, and local policy incentives are needed to implement them at scale. First, soil carbon is sequestered by diversifying annual crop rotations and incorporating cover crops. Many long-term studies have demonstrated that diversified cropping systems can enhance soil health and increase soil organic carbon concentration in at least the top 15 cm of surface soil, while also improving crop yields, climate resilience, and pest- and disease-resistance. Second, soil carbon is sequestered by converting marginal land to perennial grass and shrub cover. Third, soil carbon is sequestered by using conservation tillage practices. Conservation tillage reduces the degree of disturbance of the soil and, in most cases, leads to an accumulation of soil organic carbon. Fourth, soil carbon is sequestered by adopting forest and agroforestry systems on degraded lands to increase soil organic carbon reserves, combining soil carbon sequestration with maximal biodiversity and a full range of ecosystem services. Fifth, soil carbon is sequestered by restoring peatlands [144, 145, 146, 147].

Chapter - 8

Biodiversity Conservation and Ecosystem Services

Biodiversity is unevenly distributed across the globe and is concentrated in biodiversity hotspots. It provides essential ecosystem services that support human life and well-being. Any loss of biodiversity adversely affects the delivery and quality of these services. Estimating the value of ecosystem services provides an essential basis for their conservation. Protected areas are widely recognized as effective conservation tools, but they require to be strategically planned to maximize biodiversity conservation. However, rapid physical landscape changes and increasing human activities lead to habitat loss, which is the primary threat to biodiversity. Habitat fragmentation-the process of breaking a larger, continuous habitat into smaller, isolated patches-gives rise to negative consequences such as loss of connectivity and reduced populations. Restoration ecology explores pathways to restore degraded and damaged ecosystems. It aims to return the ecosystem to a close approximation of its condition prior to disturbance, thereby recovering key biodiversity components, reorganizing community structure and composition, and reestablishing integral functions.

Natural ecosystems are under acute threat from pollution and land degradation. Pollution of rivers, lakes, oceans, and soils reduces the quality of natural products including clean water and food. Pollution from multiple sources, including heavy metals and excessive nutrients, generates harmful impacts at local, regional, and global scales. The concept of a circular economy-where waste enters back into the production process rather than being discarded-is gaining recognition. Transitioning to a circular economy not only reduces pollution but also creates valuable resources for production, helping preserve the planet and protect natural ecosystems. A circular economy minimizes the use of energy and materials while maximizing reuse and recovery. Transforming the waste sector from a linear model to a circular economy can also generate valuable products such as energy, compost, and raw materials for inputs, reducing reliance on landfilling and pollution. [148, 149, 150, 151]

Biodiversity Patterns and Hotspots

Biodiversity patterns displayed by terrestrial vertebrates, including occurrence records of amphibians, mammals, and birds, depict a clear richness gradient, which aligns qualitatively with patterns for tree species. Breakdown of biodiversity patterns into components highlights the global priority of tropical and subtropical regions; however, species richness alone does not represent the most effective means to conserve the greatest amount of diversity within a limited area. Selecting areas containing a high proportion of endemic species maximizes conservation efficiency, thereby identifying crucial areas for focused conservation that may not otherwise receive attention. Likewise, coarse-filter analyses identify specific areas reliant on disjunct, narrow-margin habitats positioned within well-established bioregional classification systems, underscoring the importance of wetland and shorebird components within global processes for minimising human impact. Areas primed for bioregional recovery through terrestrial restoration efforts continue to show a high level of resilience. Prioritising the restoration of northern and alpine areas may therefore protect near-natural biodiversity values.

Hotspots represent areas with exceptional concentrations of endemic species overlaid with a serious level of threat; however, despite their heightened priority for conservation within global biodiversity discussions, new analyses at the scale of ecoregions suggest that the criteria used to determine hotspot status inadequately direct conservation funding. Areas supporting disjunct distributions of endemic tree species remain critically unmet by current conservation strategies-they are not represented within a large number of currently proclaimed reserves and occupy regions where land use practices have intensified. Conservation of these species therefore warrants urgent attention; investing in their protection and restoration, even with small areas, may ensure their continued presence on Earth. [152, 153, 154, 155]

Ecosystem Service Valuation

Economic valuation of ecosystem services (ES) refers to the application of economic methods to estimate the value of changes in the quantity or quality of ecosystem services in monetary terms. Although ecosystem services are supposed to be free, a failure to assign economic value to ES in decision-making processes often leads to their exploitation and degradation. This in turn has a direct impact on crucial economic sectors such as agriculture, fisheries, tourism and forestry. A wide range of valuation techniques can be applied depending on the nature of the ES and the type of valuation question to be addressed. Valuation of ecosystem services generally falls into three valuation categories, namely total economic valuation (TEV), preference-based valuation, and production-function-based valuation.

Information on the marginal costs of ecosystem degradation is useful to inform decision-makers seeking to balance development and economic growth with ecosystem conservation and restoration. Under these circumstances, prioritization of development spending according to the marginal cost of service supply in monetary terms can help maximize the net benefits of development investment. When sufficient, high-quality information about the marginal costs of service degradation is available, the costs of service degradation should ideally be integrated within cost-benefit analyses of development options. Accounting for successful ES-based development opportunities is the preferred approach. [156, 157, 158, 159]

Protected Areas and Conservation Planning

Globally, protected areas constitute a cornerstone of biodiversity conservation and ecosystem service generation. Covering nearly 15% of terrestrial ecosystems and 4% of marine areas, they house 66% of the world’s plant species and 80% of terrestrial vertebrates. The contribution of protected area systems to global biodiversity conservation is widely recognized. Yet biodiversity remains under severe threat, pointing to a need for a more strategic approach to protected area planning. Parallel increases in the spatial resolution of biological data-addressing the task of improving the representation of biodiversity in existing protected areas-must now be complemented by

Action Frameworks emphasizing the delivery of biodiversity and ecosystem services at wider scales.

Biodiversity is not evenly distributed across the land surface. The locations of rich endemic bird areas, centre for plant diversity and biodiversity hot spots reveal that the Task of protecting biological diversity would seem easier in the tropics, where many organisms have small ranges. The spectacular richness of tropical ecosystems is now acknowledged to be paralleled by a serious threat of extinction. Strategy of establishing terrestrial reserves in areas associated with biological diversity whether of natural abundance or high endemicity must be respected. Population density, biogeography, development, land use, degree of environmental stress, and governance are among the important socio-economic determinants of protected Area locations and effectiveness. Planning for a fair and effective global network of marine protected areas remains limited; about two-thirds of marine protected areas remain unmapped. Climate warming is expected to create rapid shifts in many species distributions, requiring the establishment of migration corridors to facilitate translocation [160, 161, 162].

Habitat Fragmentation

Fragmentation of habitats, the natural or human-caused alteration of habitats into smaller and more isolated patches, detrimentally influences the biodiversity of many ecosystems. Habitat fragmentation is not a natural series of changes; rather, it is caused by alterations to regions of the Earth that are relatively undisturbed. Habitat fragmentation disrupts the interactions of many species by separating populations of the same species and isolating populations of differing species. Habitat fragmentation can also isolate populations in a relatively undisturbed part of an ecosystem, and, if these populations become too small or too genetically impoverished, they can go extinct. Successful management and restoration of these ecosystems and the services they provide, or resilience to withstand climate change (e.g., carbon storage, flooding or storm water control), would be aided by minimizing further habitat fragmentation.

The survival of many organisms in fragmented habitats depends on their ability to disperse and track changing climatic conditions; however, habitat fragmentation can limit movement and shift the spatial arrangement of habitats. Ecosystems that are capable of supporting larger, diverse populations, or populations that can disperse across the landscape, exhibit a larger degree of resilience compared with ecosystems mainly comprising smaller, more isolated populations. Whether the surface area of a population is increasing due to growth or dispersal-both of which are required for its long-term persistence-is determined by the interaction of attributes of the source and destination. The increasing movement of people and cargo around the globe creates pathways for not only the movement of people but also for the movement of opportunistic species. [163, 164, 165]

Restoration Ecology

Restoration ecology is an applied science that focuses on the design and implementation of projects aimed at restoring the ecological integrity and sustainability of degraded ecosystems. It uses knowledge of historical ecosystems, their natural processes, and their relationship to natural landscape patterns to guide restoration projects. The restoration process often requires that scientists analyze how to stimulate recovery of degraded ecosystems without direct human intervention. Indeed, spontaneous recovery driven by biotic processes is usually the most effective approach and requires the least labor and expense. However, in many cases biotic processes alone are not sufficient to ensure ecosystem recovery, and direct human intervention is necessary. In these cases, restoration ecology provides managers with guidelines to support and enhance natural recovery processes.

Restoration ecology also examines ecological stability, resilience, and vulnerability to change, including the rate of recovery after disturbance (both natural and human-induced). New genera of factors are being considered in restoration ecology, such as sustaining or restoring natural ecosystem services in order to improve human well-being. Restoration ecologists are also beginning to explore the evolution of an area after restoration and whether the restored ecosystem can be considered a new hybrid, secondary ecosystem.

Restoration design is guided by the knowledge of historical ecosystem conditions and landscape pattern. The challenge is to design a restoration project that accommodates management limitations, historical conditions, and the capacity for self-organization of the area being restored. Regardless of whether a restoration project is accepted, it will be viewed by others as a large ecological experiment. [166, 167, 168, 169]

Chapter - 9

Pollution, Waste, and Circular Economy

Pollution affects the environment, ecology, human health, and, ultimately, even the economy and the unfortunate public. It is a precursor to death. The government is spending unlimited money to remove plastic from the environment, which is still affecting the environment because plastic is non-biodegradable. All the developed countries of the world have their plastic pollution treatment plants located in the developing countries because they are not bound by law and they are becoming the world's dustbins. More than 70% of the rivers are polluted, and it takes thousands of years to treat it. Natural calamities are increasing day by day-1,028 disasters took place in 2015, 2018, and 2019 alone. Vanishing of animals and natural resources has led to the deterioration of the environment.

Recycling is among the key steps toward a circular economy, which includes designing products, processes, and services that enable the continuous recovery, reuse, or recycling of materials at a high level of quality, so resources can be kept in use as long as possible. The circular economy paradigm is a pathway toward pollution and waste-free economy. The present waste is considered an undesirable by-product of human activities, and management has always focused on disposal rather than resource recovery. Making new products from existing waste can help to lessen pollution, save energy, and decrease the need for natural resources, thereby lessening overall environmental damage. In the ideal world of recycling, all disposable materials are recycled continuously into the highest-value product applications and not disposed [170, 171, 172, 173].

Types and Sources of Pollution

Pollution is the presence of contaminants in the environment that cause harmful effects to living organisms and ecosystems. Different types of pollution are classified depending on the environment being affected, as is the case of air, water, and soil pollution. The detrimental effects of pollution are mainly perceived in human health, although animals and ecosystems are also highly affected. Pollution does not only impair the health and well-being of the planet and its inhabitants but it also decreases the quality of life. After being exposed to pollution, humans may experience physical suffering, loss of social status, and troubles in fulfilling daily economic, family, and cultural activities. People may become more vulnerable, irritable, and disturbed, spending less time with friends and family. The presence of pollution in the environment is thought to concern everybody, but not everyone feels or acts accordingly.

Air pollution is caused by the presence of particles that are not naturally found in the air, such as dust, smoke, soot, and gases. Airborne contaminants may come from natural or anthropogenic sources. Natural sources include volcanic eruptions, forest fires, wind erosion, and animal respiration. They are usually low in concentration, with the exception of volcanic eruptions. The main anthropogenic sources are the burning of fossil fuels, industrial and household activities, agriculture and animal husbandry, and land vehicles. Air quality may deteriorate because of high concentrations of pollutants, a low capacity of the air to disperse them, and shallow wind direction. Major air pollutants and their effects on human health are summarized. [174, 175, 176]

Solid Waste Management

Proper solid waste management is essential to reduce environmental pollution and avoid potential health hazards associated with different types of waste. The preparation of waste for re-use, recycling, and valorisation (waste-to-energy) is a vital step towards the concept of a circular economy. A circular economy represents a paradigm shift from a linear model of production, consumption, and disposal towards an ecosystem that seeks to eliminate waste and pollution. Through extensive and inclusive stakeholder involvement, local authorities can establish an effective waste management system that embraces the principles of a circular economy.

The rise of consumerism, particularly driven by urbanization and industrialization, has led to waste generation that usually outpaces poverty and development indicators. Major challenges in solid waste management include inadequate infrastructure for collection, timely disposal, effective segregation at source, awareness of potential hazards, and motivation for behaviour change at the household level. A well-designed waste management system with the appropriate mix of policies and institutional arrangements reduces the environmental impacts of waste while also providing opportunities for jobs and business development. [177, 178, 179, 180]

Plastic Pollution and Microplastics

Various human activities introduce solid waste largely composed of plastic materials into the environment. Part of this waste is not adequately managed, leading to pollution of land, sediments, rivers, coastal areas, ocean surfaces, and deep waters. Plastic Pollution is currently regarded as one of the grave environmental challenges affecting ecosystems and biodiversity. Moreover, nearly all plastic products suffer fragmentation and progressive size reduction in the environment, due to weathering, ultraviolent radiation, physical degradation, biological processes, and chemical decomposition, forming micro plastics (plastic fragments with diameters smaller than 5 mm). Micro plastics can enter food webs and thus affect not only wildlife but also human health. Therefore, monitoring and controlling plastic pollution is crucial to ensure the sustainability of natural ecosystems and biological life.

In recent years, policies addressing plastic inputs into the environment, ecosystems, and wild animals have gained world attention. However, despite its recognition, the environmental cycle and ecological effects of micro plastics are still topics of discussion and ongoing research. For example, although micro plastics in the oceans were documented in 1972 and quantified in 2001, their historical distribution and the causes influencing changes in concentration remain undetermined. This implies that associated effects on both aquatic organisms and ecosystems are still under research. Understanding the effects of micro plastics on animal ecology and behavior is critical for inferring potential impact on the ecology and health of marine ecosystems. Moreover, the mechanisms driving marine sediment microplastics play a key role in determining their ecological consequences and broader effects. [181, 182, 183, 184]

Circular Economy Principles

In a circular economy, the maximization of the value of resources in society is achieved through good design, incentivization of recycling and reuse, the expansion of longer-life products and components, and the encouragement of easy-to-repair products at the component and system level. Circular economy principles, rather than efforts in recycling alone, must take precedence. These principles include adapting the production of goods to the resources that will later be recycled, minimizing the reliance on materials that cannot be produced sustainably, and minimizing the energy expended in the extraction, processing, and transportation of materials used in goods. Economies profit from good design, during production, recycling, and during the use phase. Technologies that explicitly acknowledge their place in a circular economy are already emerging in the form of products such as electric vehicle power trains, fully recyclable packaging optimized design, modular smartphones, and battery second life, but they remain few in numbers.

Waste-to-resource technologies can be usefully employed as an interim measure, severing direct connections between final production and the sources of virgin materials. In regions where the ecological footprint exceeds the global amount of biologically productive resources, particularly when that footprint is penetrative and due to surface mining of mineral or organic fuels or, even more, growing fossil fuel combustion, there is scarcity of primary inputs into circular processes, regardless of formally established recycling rates. For solid waste, circular economy thinking encourages a mindset that celebrates waste as surplus from short-lived products, an opportunity not to be wasted but to be seized to increase resource security and create local jobs [185, 186, 187, 188].

Waste-to-Resource Technologies

Technologies that convert waste into resources-energy, material, chemicals, mechanical properties, economic value, etc. Waste is a valuable resource with potential for reuse, recovery, and reclamation beyond disposal and landfilling. Advanced biological, chemical, and thermal technologies foster resource recovery from a variety of waste types. Mechanical and chemical recycling provide alternatives to raw material extraction for packaging, building, vehicle, consumer products, textiles, and electronics. Waste-derived biogas and syngas can replace fossil fuels, and engineered modules can restore mechanical properties in construction materials.

Total incineration of municipal solid waste (MSW) is costly and entices negative local public perception. Thermal-energy technologies seek to convert waste into valuable commodity products at lower costs using natural resources. In contrast to conventional combustion, gasification drives pyrolysis, oxidation, and reduction reactions with partial oxygen (steam or air). In pyrolysis of organic materials, heat drives sequential thermal decomposition reactions to convert biomass components into hydrocarbons, hydrogen, and syngas. Fermentation-fermentative bacteria and yeasts ferment bioethanol production; actinobacteria and fungi are important for secondary metabolite production. Lignocellulosic agricultural and forestry wastes are alternative substrates for bioethanol fermentation. [189, 190, 191, 192]

Chapter - 10

Sustainable Cities and Urban Systems

Cities epitomize the tensions of modern life; epicentres of socioeconomic activity, they produce the bulk of pollution and waste, consume enormous amounts of energy and resources, and occupy relatively small areas. Urbanization is one of the most critical trends today and presents significant sustainability challenges. Globally, urban populations are expected to exceed 6 billion by 2050, with the greatest increase occurring in megacities of developing countries. The growth of cities inevitably alters their form and generates complex sets of economic, social, and environmental problems.

Enhancing sustainability and resilience in urban systems encompasses a wide range of interrelated issues, including providing optimal levels of urban services and infrastructure, assuring urban food security, maintaining air quality, managing risk and disaster, and regulating heat, noise, and light pollution. Pollution from residential, industrial, and transportation activities, along with the large-scale consumption of resources, is decreasing urban environmental quality, resulting in adverse impacts on human health and quality of life. Until recently, urban centres tended to be studied from a narrow perspective. More recent efforts to introduce a systems approach underscore interdependencies among different sub-regions and integrate urban issues into a broader regional context. Nevertheless, to improve sustainability, future urban planning and development must undertake the integrated management of natural and social systems, addressing energy use, waste generation, and living space. [193, 194, 195, 196]

Urbanization Trends

Urbanization is a major trend shaping human development and influences many facets of environmental change in the Anthropocene.

Urban systems encompass the vast majority of population concentration, economic productivity, and resource consumption. Yet rapid urbanization is frequently accompanied by limited infrastructure capacity and disorganized freight and passenger transport systems. Slum formation, poverty, disease, and pollutants are the accompanying by-products of poorly managed urbanization. Urbanization modifies weather patterns and the microclimate of cities through the urban heat island effect, which can subsequently influence precipitation patterns both locally and at neighbouring and regional scales. Potential positive aspects of urbanization include the prospect of reduced demands on land and resources as urban densities increase and large scale infrastructure investments facilitate the provision of efficient and low-emission energy and transport systems.

The concept of smart cities builds on the rapid development of information and communication technologies (ICT) and their application in urban environments to increase infrastructure efficiency and management performance. Smart cities integrate several functions, including transport, energy management, water supply, waste management, and the built environment, through a digital network built on connectivity and a widespread sensor network. The expected benefits of smart cities include improved quality of life, reduced environmental footprint, and decreased operational costs. The majority of technology platforms integrating city management systems include public-private partnerships to encourage industry contributions, innovation, and investments, and provide opportunities for private investments in infrastructure together with user data-based services [197, 198, 199, 200].

Green Infrastructure

Green infrastructure can enhance urban biodiversity and the delivery of ecosystem services, strengthen urban resilience to climate change impacts, and improve the health and wellbeing of city inhabitants. It is defined as a strategically planned network of natural and semi-natural areas that conserves and enhances ecosystem services whilst supporting the delivery of other public goods, actions and services (e.g., climate adaptation, biodiversity, recreational, aesthetic, and landscape values).Green infrastructure encompasses both on-site and off-site measures, and is often implemented through integrated or decentralized solutions. Green roofs, street trees, vegetated drainage systems (swales and bioretention basins), parks, green spaces and urban vegetation are commonly acknowledged, while ground-based heat exchangers, blue roofs, permeable pavements, vertical parging, green walls, aqua-belts, and urban forests are additional specifications.

The ongoing worldwide increase in the urban population, coupled with climate change, together with emerging urban challenges, demands better urban planning. Cities must act to ensure urban policies and projects offer solutions for urban climate adaptation, urban biodiversity, and the quality of life of city inhabitants. Green infrastructure can perform these functions, indeed has to be used at a greater scale if urban areas are to meet the Climate Adaptation objectives. The integration of green infrastructure considerations into urban planning is a pre-condition for sounding adaptation responses [201, 202, 203, 50].

Sustainable Transportation

Transportation systems are critical for economic and social development. However, rapid urbanization and industrialization have led to many environmental concerns, such as air pollution due to the transport sector's contribution to greenhouse gas emissions, natural resource depletion, road accidents, and higher energy consumption.

Sustainable transportation meets transport needs without compromising future generations. It emphasizes the development of ecological transport modes, improvement of conventional transport technologies, and promotion of public transport to reduce reliance on individual vehicles. Electric, hydrogen fuel cell, and biofuel-based vehicles produce lower pollution and emissions and are more energy efficient.

In urban areas, the combined effects of transport policies should support public transport and effectively manage urban land to reduce energy consumption. Strategies include extending bus rapid transit systems, providing high-quality transit services, congestion pricing for high-occupancy lanes, and encouraging carpooling. Sustainable systems must also address freight transport, which contributes more than 30% of urban energy consumption and CO_2 emissions. Ecolabels and emissions credit trading for freight vehicles can help.

Econometric models project that passenger travel demand may double or quadruple and freight transport volume could grow at least threefold by 2050 in developing countries. Transport energy demand may increase by 60%, with the share of coal remaining relatively low. Most estimates indicate rising emissions, but high-growth scenarios using Business-as-Usual assumptions could lead to fivefold increases for both passenger and freight transport [204, 205, 206, 207].

Urban Heat Island Effect

Rapid urbanization in contemporary times has led to the emergence of megacities that cover a small percentage of Earth's surface yet exert tremendous pressure on land, water, energy, material, and human resources. The complicated structure of urban regions makes them vulnerable to environmental perturbations, and cities are often hotspots for extreme climate change impacts. Urban development leads to anthropogenic land-cover alterations that affect the land-atmosphere exchanges of energy, moisture, and carbon.

The distinct microclimate of urban areas-more specifically, the urban heat island effect-intensifies the absorption and storage of heat in urbanized surfaces, enhances vertical mixing in the lower atmosphere, increases local air temperature, alters precipitation patterns, and causes the formation of localized storms that are often stronger than those in surrounding areas. Such climate anomalies have a great influence on urban energy and water flow patterns, shortening the duration of summer precipitation but enhancing its intensity. The urban heat island effect thereby modifies not only the microclimate of cities but also their environmental systems and the connectivity of urban land with adjacent rural land. [208, 209, 210, 211]

Smart Cities and Digital Sustainability

Environmental sustainability meets natural as well as digital technical advances in urban areas through Smart Cities, the technology-enabled city. The concept gained momentum with rapid urban growth and the emergence of environmental issues such as transportation congestion, urban heat islands, local air pollution, and high-carbon intensity energy use related to everyday urban activities. Smart Cities promote environmental sustainability through green infrastructure, smart grid and sustainable energy management, smart mobility, solid waste and sewer systems, and management of the urban ecosystem. Specifically, Smart Cities leverage and manage infrastructure systems and services-energy, water, waste, mobility, health-in an integrated manner with the full knowledge of material and energy flows, using real-time data analysis and machine learning, to reduce resource consumption. Smart City research has expanded to utilize social media, public health, security, and education data. The digital transformation of cities evolves from frontier technologies-Internet of Things, Artificial Intelligence, Blockchain, 5G-that combine sensor technologies for real-time data collection from multiple sources, machine learning and edge computing for intelligent analysis at different levels, with cloud technologies to provide affordable and data-rich information. Smart City strategists propose to achieve digital sustainability and resilience by shifting from urban ecosystems to urban cyber-physical systems-proactive real-time and predictive management of all systems and services of the city based on multi-section simulation of urban functions and dynamics under different climate states, day and night cycles, level of service, social media opinion, and a-change control. [199, 197, 212, 213]

Chapter - 11

Environmental Policy and Governance

Key Elements

- International environmental agreements.
- National environmental regulations.
- Environmental impact assessment (EIA).
- Stakeholder participation.
- Environmental justice.

Environmental problems transcend spatial and temporal scales, and multilevel and multiscale responses are essential for an effective governance implementation of such international agreements. These environmental problems can have worldwide impacts even though they might be associated with localized processes. For example, the emission of greenhouse gases and stratospheric ozone-depleting substances occur principally in industrialized countries, but their deleterious impacts are felt on a global scale. Successful mitigation responses in these areas depend on global cooperation, and-despite their association with a considerable free-rider risk-these response strategies have found instrumentation in treaties and protocols.

International agreements are also indispensable for managing endangered species. Partnerships such as the Convention on International Trade in Endangered Species of Wild Fauna and Flora, the Convention on Biological Diversity, and the Convention on Migratory Species offer global and regional frameworks for managing trade and habitat and providing mechanisms for broader cooperation. Other environmental problems-such as transboundary pollution, biological invasions, and the management of shared resources-necessitate multilateral partnerships at regional or bilateral scales.

National policies must also ensure effective responses to transboundary environmental problems. In the absence of ambitious international agreements, policies in developed countries that introduce financial disincentives for emotions of greenhouse gases or of ozone-depleting substances-solid waste discharge in excess of the natural assimilative capacity of the receiving environment-facilitate implementation [214, 215, 216, 217].

International Environmental Agreements

Several global environmental challenges driven by human activities transcend national borders. Such environmental problems require concerted international efforts to reduce environmental risks worldwide. Since the early 1970s, several international environmental agreements have been negotiated under the United Nations (UN) and other multilateral organizations to provide a global governance framework. These include the five major agreements listed below, within which scientific assessments provide a basis for policy decisions:

1) The United Nations Framework Convention on Climate Change (UNFCCC).
2) The Convention on Biological Diversity (CBD).
3) The Stockholm Convention on Persistent Organic Pollutants (POPs).
4) The United Nations Convention to Combat Desertification (UNCCD).
5) The Regional Agreement on Access to Information.

Public Participation and Justice in Environmental Matters in Latin America and the Caribbean (also known as the Escazu Agreement). Such multilateral frameworks are recognized as essential for ensuring cooperative-responsible actions on a wide range of environmental issues.

Specific challenges are addressed through additional international environmental agreements, sometimes outside the UN system. These include the Montreal Protocol on Substances that Deplete the Ozone Layer and the Convention on Long-Range Transboundary Air

Pollution. Within the World Trade Organization (WTO) framework, various economic incentives and trade instruments have been established to support international environmental governance. Instruments such as multilateral environmental agreements (MEAs), environment and trade agreements, and other forms of collaboration are aimed at reducing the environmental impact of such activities as trade in endangered species through the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and fisheries overexploitation through the Convention on Future Multilateral Cooperation on Fisheries in the North Atlantic [218, 219, 220, 221].

National Environmental Regulations

In many nations, a body responsible for the preparation and implementation of environmental policies, conservation of natural resources, and protection of environment and ecosystems exists. Compliance with pollution-control measures and standards is generally ensured through a system of pollution-control permits and environmental monitoring.

These agencies accomplish their tasks through various activities. They establish environmental quality standards for air, water, and land; prepare rules and regulations to implement Act provisions; issue permits or licenses for projects or activities that may pollute; ensure compliance with the provisions of the Act; supervise environmental environmental quality; and prepare and publish technical reports, documents, and information on the environmental quality. Others, such as the Governmental Environmental Management Department, assess whether proposed projects and activities are likely to have a significant adverse environmental impact and whether appropriate mitigatory measures have been built into the project. If this is not the case, EIA studies conducted by the proponent or his/her associates or independent consultants may be insisted upon.

Environmental impact assessment (EIA) is a powerful tool for preventing environmental damage during the planning and implementation stages of infrastructure projects and development activities. In addition to these regulatory measures, financial and market-based instruments-user charges for pollution, tax incentives for pollution reduction, and emissions-trading systems-are in various stages of experimentation. For example, charges for use of freshwater resources are levied by various State Governments; Water (Prevention and Control of Pollution) Cess Act, 1977, also applies to industries consuming more than 10,000 kiloliters of water per year; a Central Government excise duty scheme provides concession for renewable energy devices; and the Foreign Trade Rules of 1991 allow duty exemption for import of certain pollution-control equipment [222, 223, 224, 225].

Environmental Impact Assessment (EIA)

Environmental impact assessment (EIA) is a systematic and interdisciplinary process for identifying and evaluating the potential impacts of a proposed project, plan, policy, or program on the environment, including natural, socioeconomic, and human health aspects. Its purpose is to reduce the environmental costs and increase the benefits associated with development projects, plans, and policies. The international legal principle of EIA has its roots in the 1970 United States National Environmental Policy Act (NEPA), which was adopted in response to growing public interest and concern regarding environmental protection. The NEPA established the legislative basis for public participation in the environmental decision-making process, and it requires federal agencies to prepare a detailed EIA for actions significantly affecting the environment. In the decades that followed, many other countries adopted legislation enshrining the principle of EIA, and today it is part of the environmental legislation of several countries throughout the world.

An EIA serves to address and facilitate issues of comparison and balance among sectors of the economy, and it can be applied by statutory regulators to government development projects as part of an internal review process. The EIA process typically includes screening of projects subject to EIA; preparation of the EIA report; review of the report by the competent authority and other concerned parties; decision-making by the competent authority regarding project approval; post-project monitoring and auditing; and the involvement of the public and other stakeholders. Following NEPA's model, many countries use a checklist approach to EIA, screening for resource considerations such as the presence of endangered species or protected habitats, as well as for potential impacts such as wetland alteration, changes in land use, air emissions, and displacement of local populations. [226, 227, 228, 229]

Stakeholder Participation

Successful environmental policy depends on incorporating a diverse range of predictive values and experienced opinions. Inclusion of various viewpoints helps surface disagreements over likely future states and consequences of proposed actions. Stakeholders concerned about scapegoating bear special responsibility: ˙They must work together to evaluate the expertise of all parties and to challenge distorted perspectives and false assumptions. ˙Environmental Impact Assessments (EIA) should then combine mainstream techniques with an innovative application of stakeholder participation. Stakeholder participation should also help balance the far-reaching injustices of historical and global responsibility in the adoption of mitigation strategies. Greater effort is needed to enlist vulnerable communities in their adaptation to unavoidable climate change and its after-effects.

Stakeholder participation serves three principal purposes in Environmental Impact Assessment studies. First, it helps ensure that all predictive knowledge and beliefs likely to be important to the policy problem are effectively considered. This is essential if the resulting broad evaluation is to have any hope of being meaningful and credible to those charged with making the final decision and, ultimately, to those directly affected. Second, analyses sufficiently controversial to warrant regulation can often depend heavily on uncertain interpretations or predictions of potentially serious outcomes. Full consideration of the corresponding uncertainties is essential. Hence, a formal means of exploring these uncertainties with a wide range of knowledgeable people is essential. Third, proposed environmental policies may initiate a lengthy advance toward a more sustainable environment. In such a case, the activities enabled by the final decision may be unlikely to generate sustainable trajectories or be readily changed. Hence, consideration of how uncertainties might be resolved has great value. [230, 231, 232, 233]

Environmental Justice

Increasing socioeconomic disparities throughout the world dampen prospects for sustainable development and further escalate resource degradation and environmental pollution. Vulnerable and marginalized populations usually bear the brunt of environmental change, pollution, and depletion of natural resources, which result in habitat loss and aggravate their poverty. Individual behavioral change can only contribute limitedly to improving the global environment. Society-wide changes guided by strong and effective environmental legislation, justice, and equity principles are crucial for environmental improvement.

Organizations and agencies such as the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), the United Nations Environment Programme (UNEP), and the World Wildlife Fund (WWF) advocate a new paradigm for development termed "green economy." Its tenets focus on reversing resource degradation and ensuring environmental protection while promoting economic growth. Bridging inequitable access to resources and the benefits of growth is a fundamental prerequisite for poverty alleviation. Caring for the environment, society, and people can greatly boost economic development, and vice versa. [234, 235, 236]

Chapter - 12

Climate Adaptation and Resilience

Changing climatic conditions and impacts on human and natural systems call for adaptive action to reduce vulnerability and build resilience. These measures should be formulated in such a manner that they integrate disaster risk reduction and climate change adaptation actions additional to mitigation tasks. The process involved includes an assessment of vulnerability, considerations for preparing and implementing nature-based solutions to reduce such vulnerability, steps for disaster risk reduction, initiatives for community-based adaptation at the local level, and the development of resilient infrastructure.

Vulnerability assessment serves to elucidate the weaknesses in human and natural systems, and in turn climate risk, to enable suitably targeted adaptive actions. Vulnerability of a country or region can be assessed, through various hazard risk models, in a participatory manner involving all relevant stakeholder groups. The countries and regions that are highly vulnerable can subsequently explore potential avenues for adaptive action, including nature-based and hard engineered solutions. The latter solutions recognize that ecosystem degradation often increases vulnerability and hence promote ecosystem-based adaptation and disaster risk reduction. The process of disaster risk reduction is closely linked to the adaptation process and should be integrated into national and sub-national climate adaptation strategies and planning with the aim of reducing risk, costs, casualties and loss of life from extreme weather events.

More generally, the capacity of a country or region to cope with the challenges posed by climate change is improved significantly if local communities play an active role in the implementation of adaptation strategies. Community-based adaptation recognizes the role of local communities in reducing climate and disaster vulnerability.

Capacity building of local communities is essential for effective local-level adaptation measures. Adequate resources, responsive policies, checks and balances, decentralization, local adaptation services, swift action and financial resources are the keys to effective local adaptation. Resilience-building at all levels will help in reducing the risk and damage caused by climate change and to return to normalcy quickly. [237, 238, 239, 240]

Vulnerability Assessment

Human systems are vulnerable to climate change because they are intimately related to climatic cycles, which determine the distribution of temperature, humidity, heat, rains, snow, winds, and cyclones on which agricultural crops grow. As a result, climate change is directly reflected in agriculture, forestry, fisheries, drinking water supply, and the frequency and magnitude of natural disasters. Serious hazards include the rise in sea level, the melting of glaciers, and the increase in the frequency and intensity of droughts, floods, storms, and other natural disasters. The coastal population is particularly vulnerable to the risks associated with climate change. Rivers and the sea provide many resources not only for living but also for the transportation of people and goods in the coastal regions.

Vulnerability assessment, according to the IPCC definition, is the "degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes." Such assessment is a great step for determining climate adaptation strategies. With respect to natural hazards, Davidson *et al.* (2007) describe the assessment of vulnerability as "the extent to which a community, system, or resource is likely to be damaged or prevented from achieving its expected outcome." Vulnerability is composed of three components: exposure to a hazard, sensitivity to that hazard, and the ability to cope. These three components provide three avenues for adaptation (reduce exposure, reduce sensitivity, and increase coping ability) [241, 242, 243, 244].

Nature-Based Solutions

Nature-based solutions (NbS) are solutions that protect, manage, and restore nature and natural ecosystems to address societal challenges while supporting human well-being and biodiversity. They include ecosystem-based approaches for mitigating and adapting to climate change, ensuring human health and well-being, providing for water security, reducing disaster risks, and fighting land degradation and pollution. NbS can be implemented across a broad range of management approaches, from conservation-oriented to resource exploitation and actively restored. Example solutions include using wetlands to treat wastewater, enhancing green infrastructure for urban resilience to flooding and heat, managing watersheds for clean drinking water, and restoring coastal and marine ecosystems for protection against storm surge.

Although the concept has been around for decades-and has permeated the biodiversity and climate arenas-the broad applicability and versatility of NbS is garnering increasing interest in development sectors such as human health, disaster risk reduction, and integrated solutions for land, water, and food, consequently creating larger demand for NbS-focused communities of practice and funding. The multiple benefits provided by NbS, particularly for climate change adaptation and disaster risk reduction, can also facilitate new financing opportunities through climate-related and disaster risk strategies. NbS need to follow principles that are increasingly being incorporated into project development guidelines: stakeholder engagement, equity considerations, packaging of services, cost-effectiveness, and the importance of strong governance and building local institutional capacity [245, 246, 247, 248].

Disaster Risk Reduction

Disaster risk reduction (DRR) is a systematic approach aimed at minimizing the vulnerabilities and risks of natural hazards through proactive and preventive measures. Its goal is to contribute to the safety of individuals and communities, as well as to the security of their property and livelihoods. Investments in DRR can help to avert disaster, reduce future losses, save lives, and promote sustainable development. The fundamental pillar of DRR is the identification of potential hazards and risks and the establishment of effective risk reduction measures and policies.

DRR encompasses many actions that can be undertaken at the local, national, and global levels. It includes identifying and understanding hazards, vulnerability, and exposure, and developing and implementing DRR strategies; land-use regulations, building codes, disaster preparedness measures, early warning systems, and emergency response plans; and strategies and approaches for recovery and reconstruction that reduce vulnerability.

The Addis Ababa Conference on, in May 2015, sought to promote investment in disaster risk reduction. Governments, corporations, experts, the media, and educators were provided with the opportunity to learn about how to save lives and investments through reducing risk from natural hazards. The conference showcased examples of successful applications of DRR strategies and invited participants to support the call to action: “Investing today in disaster risk reduction and resilience-building will pay long-term dividends for sustainable development. Making targeted, additional, and measurable investments before an event-rather than only after a disaster-can save lives and resources. It is critical to ensure that national and local strategies for disaster risk reduction are in place and to include them explicitly in national development strategies, planning, budgeting and financing.” [249, 250, 251, 252]

Community-Based Adaptation

Community-based adaptation (CBA) is a participatory and community-centric approach for assessing and responding to climate change. Rooted in local needs and knowledge, CBA empowers vulnerable communities to enhance adaptive capacity and resilience while addressing social justice, inequality, and poverty. Although CBA is grounded in broad development agendas and sustainable development principles, it is distinct from conventional development practice in its emphasis on current and projected climate risk reduction and the respond-adapt-develop sequence.

Growing recognition of the limits of top-down climate adaptation suggests increased emphasis on CBA for managing risks and adapting to climate change at local and community levels. The simultaneity of community coping and development processes for enhancement or loss of adaptive capacity distinguishes CBA from conventional development planning and programs. Focusing on the adaptive process itself, CBA addresses social justice and equity concerns while narrowing participation between external facilitators and local communities. CBA also narrows the attention span for action towards relatively short time frames for the initiation of adaptive responses. The effectiveness of community-centred risk management strategies in safeguarding the livelihoods of vulnerable communities has been demonstrated in diverse geographic, socio-economic, political and cultural settings. [253, 254, 255, 256]

Resilient Infrastructure

Building infrastructure that can withstand natural hazards such as earthquakes, floods, and typhoons-through improved engineering and construction methods, effective monitoring, and redesigned regulations-is integral to reducing vulnerability. Given that the gravest risks frequently arise not from the natural phenomenon itself but from secondary hazards (e.g. tsunamis and landslides), research on potential-scenario modeling focusses on critical natural-environmental debates, hazard and risk assessments of climate change. Adaptive capacity should thus also be sought through the design of resilient social-nature systems.

Climate change can be viewed as a matter of risk management as much as a matter of equity. Mitigation as resource allocation involves such a combination of benefit (or least harms avoided)-future values and fairness-equity are far less serious considerations in adaptation. Climate change therefore requires the resilience of all nations against all climate hazards on infrastructure. The danger to such infrastructure is revealed by the drowned cities of New Orleans, New York and Tokyo. The coastal elevation on which they have been built is well below the highest-tide line; their drainage systems are limited and shallow, reliance is placed on huge dyke walls closing off bays to the long sea; and the clean-up process has become compromised by political tension.

Nonetheless, a certain redundancy in-spent resources is not such a bad habit. To ruin one or some cities is rather a small risk compared to reducing impact-evaluation by the avoided losses of the whole of nation/regions infrastructure. Possible solutions range from deepening deep-flood reservoirs at high cost through to simple sand-bag barriers, and questioning the value of building cities centered on one very shallow lake-level, especially given that original archaeological sites even at earliest habitation records imply location on higher hills. Urban heat islands should not be layered very close to swamp-land levels now. [257, 258, 259, 260]

Chapter - 13

Sustainable Resource Management

Given the enormous size and complexity of the Earth system, knowledge of climatic mechanisms is essential for the proper management of mineral, material, energy and food resources. Meeting the growing demands for urbanization, industrialization, transportation and food production, which are projected to increase significantly over the next 20-30 years, requires more efficient resource usage, sustainable supply chains and circular economy strategies. Environmental security continues to be threatened by the depletion of mineral and forest resources, over-fishing and pollution of aquatic resources, shrinking biodiversity and ecosystem services, and inequitable access to resources.

In addition to climate data, information on the availability, quality and demand of mineral, energy and food resources is crucial for integrated resource management. Monitoring and assessment of production, consumption and trade flows is essential for identifying unsustainable use and distribution patterns, as well as the risks of resource scarcity. Improved technologies, alternative materials, and the establishment of sustainable supply chains should be stimulated through cooperation in science and technology. [261, 262, 263, 264]

Mineral and Material Resources

Sustainable development is heavily dependent on mineral and material resources. The global demand for metals and minerals, such as copper, aluminium, iron, and nickel, has increased more than fivefold since 1970, and the total requirement for building materials has increased nearly twice as fast as the population. In 2009, global demand for these materials exceeded supply, and prices rose sharply。 Satisfying the needs of future generations is a major challenge, since mineral and material production is not as easily replenishable as other resources. Non-renewable minerals and materials need to be conserved in terms of efficient use. For other classes of materials, sustainable supply requires management and planning of replantation, storage, and waste recovery. Considering the land, water, energy, greenhouse gases, soil, and ecosystems needed to support mineral and material production/supply, a sustainable supply must use less of everything while supplying more of these materials/components.

While mining and mineral production is essential for global economic growth and requires constant and substantial investment, the sector remains largely uncovered in the global debate on sustainability. The deposits of minerals are often geographically remote, resulting in the high cost of either production or transportation. Developing new deposits is time-consuming; thus, recycling becomes important. This should consider both post-consumer waste and post-industrial waste. In addition to metals, cement, and concrete, the demand for a large number of mineral resources is expected to grow. To support the safety and sustainability of mineral production in the increasingly resource-intensive world, it is important to ensure the security of the global mineral supply through a careful balance of sustainable development, trade regulation, and responsible mining practices. [265, 266, 267, 268]

Forest resource management

Forests cover approximately 31% of the globe's land surface, act as huge carbon sinks, provide habitat for numerous species, serve as source of food and raw material, offer recreation opportunities, and exhibit inherent environmental beauty. But overexploitation and unchecked population growth have made a lawyer's term its environment. Continual felling of trees resulted in severe soil erosion. To arrest this deterioration, forests in hilly and mountainous regions are being put under special management. Forest resources are being depleted due to rapid urbanization, industrialization and growing population. The pressure of increased human activities disturbs forest all over the world.

Priminal institutions should be concern that forest resources possessed by them must sustainable development. In sustainable management systematic collections of management committee and Primal are taken for monitoring of forest activity in forest area. Natural calamities like flood and drought should be taken care of to maintain forest ecosystem. Minimum harvesting age and species which suited to foundation and has maximum growth rate of timber as well as market demands colonization over tree of timber exploitative and promote lesser kno woods species with management should be sustainable over a period of time. [269, 270, 271, 272]

Forest resource includes luffa sponges, wood mass, wood planks, wood shimming, wood boards, tea leaf, shell, timber, coconut, fire wood, urban wood, jug, prevents diseases (diabetes m)., makes synthetic rubber, absorbs noise (acoustic absorption).

Fisheries and Aquatic Resources

Marine fisheries and other aquatic living resources contribute almost one-fifth of the world's supply of animal protein consumed by humans. These resources continue to be overexploited, depleted, or recovering from depletion, and the aquaculture sector-one of the most dynamic sectors-is, however, witnessing a slowdown. Attention now needs to be focused not only on the production level but also on addressing the specific issues of overexploitation, pollution, destruction of ecosystems, and equitable benefit-sharing. Sustainable management and development of the fisheries and aquaculture sector are essential for meeting food and nutritional security of the rapidly growing population. Such management will require concerted action at all levels and the involvement of all stakeholders, especially in the areas of research, sustainable practices, management, monitoring controls, and sharing of information, knowledge, and technology.

The issue of fisheries and aquatic resource management, which is once again coming into sharp focus due to the renewed concern over the effective utilization of vast fishery resources, is of considerable importance for national and regional economies. Fish and fisheries continue to provide sustenance for a large proportion of the world's population. Primary dependency on fisheries and fish products for food security is registered in the coastal and island countries of South Asia and the small island development states of the pacific, with per capita fish availability often exceeding 35 kg per annum. Inland fishes serve as a major cheap source of protein and other nutrients for a large segment of the rural population. Aquaculture continues to play a vital role in food production. However, the growth rate continues to decline and is not keeping pace with the ever-increasing demand. [273, 274, 275, 276]

Sustainable Supply Chains

Sustainable supply chain practices focus on minimizing the social and environmental impacts of production while ensuring business profitability. Such practices may include adopting sustainable resource extraction methods, reducing the use of toxic chemicals and hazardous materials, managing carbon dioxide and other greenhouse gas emissions, minimizing waste generation, reducing energy use, optimizing transportation, decreasing water consumption, and ensuring humane treatment for workers. Designing products that require fewer resources during production, manufacture, and distribution, but that provide functional lifetime, safety, and aesthetic qualities equivalent to products made using traditional supply chain techniques, can enhance their marketability.

Supply chain transparency involves disclosing the economic, environmental, and social impacts of all tiers of a supply chain, based on life-cycle assessment data from the resource extraction through the production and distribution phases and on sustainability rating systems for the use and post-use phases. Transparency is intended to provide consumers with detailed information from which to make informed purchasing decisions.

Governments can promote sustainable supply chains through public sector procurement that prioritizes sustainability criteria, tax incentives to encourage environmental best practices in the private sector, research funding to develop new supply-chain-related technologies, and education to increase consumer interest in the sustainability of the products they purchase. [277, 278, 279, 280]

Resource Efficiency Strategies

Increasing population and economic growth have raised concerns over the availability of natural resources to sustain future demand.

Material efficiency, in terms of minimizing resource use over the life cycle of products, and closing resource loops are becoming increasingly important for mitigating material and energy resource depletion and pollution. Achieving these objectives requires a concerted R&D effort in material technologies and sustainable production and consumption.

Are designed to decouple GDP growth from the exhaustion of natural resources. In order to keep resource consumption within safe planetary limits and reduce environmental pressures generated by global trade, it is necessary to: increase material efficiency in order to save resources over the life cycle of products; recycle minerals and metals in order to close resource loops; enhance energy efficiency through process integration; optimise the use of shared infrastructures; and apply substitution technologies for avoiding resource depletion. These objectives can contribute to the longer-term strategy for Moving to a Low-Carbon Economy by reducing energy-related CO2 emissions associated with energy production and consumption. Their continued implementation can ensure that growth does not risk premature resource exhaustion and resulting escalating prices. Resources are key throughout the life cycle of all goods and services.

The related R&D and innovation strategy needs to be supported by economic incentives for long-term solutions, policy frameworks that allow the development of green products and services and changes to consumption patterns by focusing demand on products and services with lower energy and resource loads. Green jobs will be created in industries that produce and support resource-efficient products, as well as those that help achieve greater material efficiency, process integration and resource substitution. [281, 282, 283, 284]

Chapter - 14

Monitoring, Modeling, and Environmental Data Systems

With the increasing tendencies towards globalization and the rapid depletion of resources around the globe, modern technology such as Remote Sensing (RS), Geographic Information Systems (GIS), and environmental sensors coupled with Big Data technologies are growing considerably in importance for the better management of these resources for the Economy and Society. The Earth may be viewed in the lens of socio-ecological networks in which the Earth, biophysical wealth, economic growth, and the society affect each other. Besides monitoring and maintaining a healthy physical Earth, these technologies are also required to study temporal and spatial dimensions of various factors and drivers for developing environmental sustainability. Thus, environmental models in 16and 17supported by environmental data systems along with active collaboration of all stakeholders are necessary.

Satellite-based Remote Sensing (RS) technologies provide the opportunity for monitoring and tracking many Earth-atmospheric systems and phenomena e.g., global temperature, vegetation, snow cover, ice cap, soil moisture, sea level, oceans, clouds, land surface albedo, precipitation, cyclone and storm tracks, global landslides and disaster zones, forest fires, surface reflectance, aerosol concentration, and global environmental disasters. Satellite monitoring alone is not sufficient for effective monitoring and reporting of such natural systems, as several other variables such as sea depth, ground temperature, ground weather, physical and chemical properties of soil and vegetation, and mineral resources are not detected quite accurately by RS techniques. At the same time, the present RS technology also has several limitations with respect to accuracy, productivity, harvest index, and water balance components. Consequently, many natural and socio-economical variables including specific data for different soils, vegetation, mineral resources, and rest are integrated into a Geographical Information System (GIS).

Remote Sensing Technologies

The environmental significance of the planetary atmosphere, land, water, and biological resources and their sustainable development raise new demands on environmental monitoring and assessment. In recent years, new remote sensing techniques employing microwave wavelengths, high spatial resolution sensor (airborne and satellite), and even small satellites have led to a rapid collection of new high-quality information on the surface and near-surface environment. Advanced information technologies such as computer science, network, geographic information system (GIS), and expertise in ecology, economy, and remote-sensing have brought a revolution in environmental modeling.

The application of remote sensing monitoring technology in environment and ecology has demonstrated strong potential in dynamic monitoring of urban environment, land-use/cover change, environment pollution, environmental impact assessment, evolutionary responses in forest ecosystems, high-resolution ecological distribution model, construction of sponge city, prediction, and decision support of sustainable development strategy. Remote sensing monitoring technology has therefore become one of the important means for monitoring environment and its change. Research results show that the coupling of remote-sensing technology with ecological modeling provide an ideal researching approach to a series of environment study. [285, 286, 287, 288, 285, 286, 287, 288]

Geographic Information Systems (GIS)

Remote sensing technologies and satellite data, combined with powerful computing techniques, facilitate rapid and detailed generation of spatial information from large areas, supporting management and decision-making. Geographic information systems (GIS) are used for capturing, processing, storing, analyzing, and managing a wide range of spatial data. These systems allow incorporation of environmental, social, and financial data for a spatially distributed area-in a multi-scale context with high temporal frequency-into complex analyses and modeling for better understanding, forecasting, and scenario analyses of future environmental change.

A GIS can also include tools for modeling future spatial evolution or change, based on rules that describe how certain characteristics of a system change. Environmental data can be integrated into social, economic, and political systems, enabling the detection of linkages and relationships at different spatial scales. With suitable integration and upgrading capacities, GIS are powerful tools for adaptive management of uncertain and highly dynamic systems. Recent studies show that with the rapid development of remote sensing, geographic information system, and global navigation satellite system technologies, these technologies can be combined and used to support monitoring and modeling of the water cycle, land cover and land use change, and ecosystem service processes at different spatial scales. [289, 290, 291, 292]

Environmental Sensors and IoT

With remote sensing and geographical information system technologies offering crucial data at global and regional scales, environmental sensors are increasingly being deployed to monitor specific locations or phenomena. Sensors installed in natural and urban environments measure and report environmental, ecological, and human system variables, from greenhouse gases to temperatures and soil moisture. The Internet of Things (IoT) is a recently developed technological concept that connects physical objects embedded with sensors, software, and network connectivity to the Internet, thereby enabling the exchange of data with other Internet-enabled devices. IoT implementations based on low-cost wireless sensors can measure a wide range of environmental parameters in near-real time.

These implementations typically involve a sensing node equipped with sensing devices, a low-power microcontroller, a radio-frequency communication module for data transfer, a long-life battery, and a cloud or a remote server for integration and processing. In the context of environmental monitoring, an IoT-enabled sensing node can communicate large volumes of data related to a range of phenomena, such as temperature, humidity, soil moisture, gas concentrations, wind direction and speed, and rainfall. Such near-real-time data availability can facilitate better decision making related to environmental management, climate impact research, or disaster risk reduction. For example, such developments can open up new avenues for real-time information-based national weather services.

Big Data in Environmental Science

Remote sensing technology, Geographic Information Systems (GIS), environmental sensors, the Internet of Things (IoT), and artificial intelligence are considered the most important monitoring, modeling, and data management technologies in addressing sustainability issues in environmental science as well as providing a scientific basis for decision making, action planning, and subsequent management activities. The increasing pace of environmental data collection has led to the emergence of big data. Data sources can be grouped into four categories according to their different spatiotemporal resolution:

- **In situ spatial data:** These data sets are commonly generated by various sensors, ranging from financial data in the stock market, social networks, and other digital streams to spatially distributed monitoring data in fields, forests, grasslands, lakes, oceans, and the atmosphere.
- **Images:** These data are obtained through satellites, aerial vehicles, or ground photography, and can be divided into optical, infrared, visible, microwave, and laser images.
- **Models:** Different models with distinct temporal and spatial scales produce cross-covering model simulation data, which can be used to reduce the uncertainty of estimations and predictions.
- **Simulation data:** Different scientific models, such as Climatological-Biochemical models and hydrological models, are used to simulate physical processes, and the simulation for some key regions also generates big data streams.

The complex and multi-source characteristics of these massive streams of diverse data demand a reconsideration of traditional ways of managing, storing, analyzing, and applying external information. Machine learning, which inherits the advantages of the biologically related neural brain, has obvious superiority in merging big data information chaos into essential and hidden knowledge and laws - like a magic wand transforming a pile of rubbish and darkness into thought treasures, wisdom, and light. Machine learning methods will inevitably infiltrate every section of environmental science, such as utilization prediction models combined with physical principles, prediction models of inevitable extreme weather and climatic events, multi-source data fusion, simulation models based on big data, remote-sensing-inverse models, and machine-learning-acquired sensor networks. However, a large number of application practices should follow "over-optimization" or "over-learning," with known law or common sense being broken rather than rediscovered and explained through machine-learning technology. [293, 294, 295, 294, 295, 296]

Environmental Modeling Platforms

Simulation tools have become indispensable for assessing the environmental impacts of dynamic natural processes and anthropogenic stresses, as well as for examining the effectiveness of possible mitigation and adaptation strategies. Such tools often consolidate state-of-the-art scientific knowledge, achieving realism through integration of a large number of established process formulations. They also allow observation and analysis of system interactions at multiple spatial and temporal scales, often in a context of global change. Still, a clear superiority in realism does not guarantee a superior response: different models may respond at different scales and directions to the same driver.

Various platform options-frameworks, linear models, and weak constraining models-enable diverse investigations across a reliable range of open representation of confronted states. A broad selection can be found through the Global Change and Earth System Modeling International Project Family. Nevertheless, they should be used cautiously, particularly those relying on a priori specified process sensitivity. Ultimately, simulating model-based scenarios is not the only way to approach design and investigation of smooth complex profound interactions at all scales. The greatest risk of scenario modeling comes from the danger of producing unintended misinterpretation of results by scenario-driven a priori decision making rather than by interpretation. [297, 298, 299, 300]

Chapter - 15

Socioeconomic Dimensions of Sustainability

Sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"-and continues to gain acceptance as a guiding framework for sustainability-related initiatives and strategies. The idea of combining economic, environmental, and social objectives together in projects seems sensible, intuitively appealing, and practically desirable. The roots of sustainable development have come from the growing realization that issues such as poverty, hunger, education, and health care are inherently linked to environmental issues because of the impact of the environment on social and economic development. The intersection of environmental issues with these subjects does not only point to a more sustainable development-such linkages are also essential for conflict resolution related to resource allocation and use. Yet it is clear that the democratic principle of public participation in the decision-making process must be promoted to bring about real equality and justice.

Recent studies have suggested that the increasing focus on sustainable development makes it imperative to understand the environmental-supporting role in human development that is capable of fostering transformations based on social inclusion, equity, and respect for the environment at all levels of governance. In addition, the integration of environmental and development issues calls for a better understanding of behavioral changes at societal and individual levels that can facilitate environmentally sound choices and actions. Society at large must, therefore, develop effective and strategic responses encouraging economic prosperity without compromising the quality of the environment upon which life depends.

Sustainable development has been viewed as a way out of the poverty trap and as a means of escaping the environment-the economic-development nexus. Consequently, there is an urgent need to explore the relationship among these three factors and identify the conditions that make this relationship positive. Several studies on the poverty-environment nexus have shown that the poor consume less than others-both in absolute and relative terms-and therefore external environmental costs due to their consumption choices are relatively minor. The adverse impact of their consumption on the environment is principally through the use of environmental sinks because their technologies are highly wasteful. [301, 302, 303, 304]

Sustainable Development Goals (SDGs)

The , adopted by the United Nations in 2015, consist of 17 aspirational goals that provide a shared blueprint for peace and prosperity for people and the planet, now and into the future. The SDGs build on decades of work by countries and the UN. The years 2015 to 2030 represent a critical period during which the international community can significantly advance its efforts on gender equality, poverty alleviation, environmental sustainability, and social inclusion. Achieving the SDGs requires concerted and collaborative global efforts, with support from a range of actors, including governments, the private sector, civil society, scientists, academia, the media, and the general public.

Of particular relevance to this chapter are Goals 6, 7, 11, and 12, which call for ensuring availability and sustainable management of water and sanitation for all; ensuring access to affordable, reliable, sustainable, and modern energy for all; making cities and human settlements inclusive, safe, resilient, and sustainable; and ensuring sustainable consumption and production patterns, respectively. It is now recognized that the Earth's finite resources must be consumed wisely and sustainably, and that growth and development strategies must seek to avoid overexploitation or degradation of the various resources-such as water, soil, forests, energy, and minerals-that are essential to future sustainability. Sustainable resource management involves the careful stewardship of the natural resource base that underpins economic and social development, and the maintenance of its environmental functions.

Green Economy Concepts

Green economy principles aim to reduce environmental risks and ecological scarcities while promoting economic growth and social equity. They require a fundamental shift in how economies, societies, and environments function, enhancing the natural capital that underpins human and economic well-being. A green economy is associated with natural capital, green jobs, environmental valuation, energy carbon intensity, and investment in green sectors, and includes ecosystem-based approaches to adaptation. International initiatives in various spheres support the green economy, including risk assessment, corporate sustainability reporting, and local protection of the environment.

Given the multi-dimensional relationship between poverty reduction, inequality, environmental degradation, and economic growth, the green economy concept provides an emerging framework for a sustainable development paradigm that is compatible with poverty eradication and a restabilization of the Earth's social and ecological systems. Sustainable development breaks with the perception of 'the environment' as an area of concern separate from the economy and society. While new technologies that eliminate the negative externalities of economic activity are one approach, the economy must also develop a protective resource base that ensures that environmental degradation is reduced and human capabilities enhanced. [305, 306, 307, 308, 305, 306, 307, 308]

Poverty, Environment, and Development

Poverty reduction is a global priority, recognized by the United Nations Sustainable Development Goals as the primary development challenge. People strive for the universal fulfillment of basic needs-health, education, security, and dignity-together with the elimination of extreme poverty. The interrelationship between environmental degradation and poverty continues to be complex, leading to the creation of the United Nations Environmental Programme Poverty and Environment Initiative.

While poverty remains a major environmental challenge, its impact on the environment is less straightforward. Poverty contributes to unsustainable exploitation of natural resources such as forests, soils, and fisheries, impacting local and global ecosystems. However, evidence suggests that middle-income countries may be leading to global biodiversity loss, particularly within project regions relative to the rest of the world. In these areas, ecosystems are being unable to withstand human pressures. Beyond a point, poverty can become clean or green ecosystems' biggest problem. Nevertheless, Appiah *et al*. indicated that environmental issues are not the most important factors for the poorest nations as their focus is on basic needs and not environmental issues such as unclean water and deforestation.

Behavioral Change and Sustainability

The principle of "sustainable consumption" can thus be achieved by creating synergy between the goal of social equity and the goal of environmental sustainability. Induced behavioral change can indeed lead to a significant reduction of energy use, greenhouse gas emissions and conserve other natural resources, thus contributing to a more sustainable society. A central component of sustainable development is to support changes in human behavior in order to bring global environmental impacts, particularly climate change, back to within safe limits. Anthropogenic actions have caused global warming and are responsible for losses in biodiversity, reduction of forest cover and net sinks, depletion of natural resources, and ecosystem degradation. The Sustainable Development Goals as well as other global goals aimed at fostering social equity can also foster sustainable consumption and production patterns that can induce sustainable behavioral change.

Behavioral change is therefore a key element of an effective strategy to reduce greenhouse gas emissions and protect the environment. It can reduce individual energy use and associated cost savings that ultimately leads to a continued improvement of energy efficiency. Such behavior change has proven to be a feasible, effective, efficient and sustainable method to minimize individual energy consumption and greenhouse gas emissions. Changes in personal lifestyles and consumption can measurably reduce individual energy use, encourage a reassessment of benefits from travel, decrease demand for resources and embodied energy, encourage reduced levels of consumption and waste, educate children about environmental issues and minimize environmental impacts. [309, 310, 311, 312, 309, 310, 311]

Education for Sustainable Development

Empowers individuals with knowledge, skills, and attitudes to shape a sustainable future. It promotes critical thinking, collaborative learning, and responsible living across all levels and areas of education. Education for Sustainable Development emphasizes the interconnectedness of environmental, social, cultural, and economic development. Its goals are to equip people of all ages with the knowledge, skills, values, and attitudes to shape a sustainable future; to foster critical and creative thinking; to promote collaborative learning; and to enhance the integration of education into sustainable development efforts.

Education for Sustainable Development prepares people for the complex challenges ahead-climate change, resource depletion, rapid urbanization, and societal renewal-and fosters their ability to adapt to change. Education for Sustainable Development emphasizes the importance of local contexts, concerns, and cultures while endorsing the principles and aims of the United Nations Decade of Education for Sustainable Development. Education for Sustainable Development relies on strategic partnerships, stakeholder networks, and actions that cut across all forms of learning educational institutions, informal and nonformal systems, the media, and public awareness campaigns. Recognizing that education transforms lives, societies, and countries, Education for Sustainable Development aims to engage educational systems and communities in capacity development for sustainable development.

Education responsive to climate change, globalization, poverty eradication, and other pressing issues, Education for Sustainable Development should be priority-focused, mainstreamed, and built on the strengths and infrastructures of 21st-century education. And developing it requires cooperation across ministries, sectors, and at all levels of government and society-local, national, regional, and international. [313, 314, 315, 316]

Chapter - 16

Future Pathways for Sustainable Environmental Systems

Sustainability-focused, evidence-based analysis with formal structure; maintain academic tone throughout and prioritize clarity, with concise, data-supported arguments.

Future pathways for sustainable environmental systems consider the interaction between environmental change and sustainable development, based on scenario analysis and foresight methodologies. Major uncertainties regarding the future of sustainable development-particularly a transition to a green economy-are analysed and contrasted with sustainability transformations across human and natural systems. These transformations reshape the nature of innovation and innovation systems, the patterns of global economic development and growth, and society's consumption and production patterns. The analysis highlights the need for integrated environmental policy pathways that foster the potential of emerging green technologies to address the global environment-development challenge.

Achieving a sustainable global environmental system that serves society requires reducing environmental pressures of natural systems. However, future environmental pressures in the next few decades in major regions are projected to remain high. By 2050, global population could exceed 9 billion, GDP could grow by threefold, and resource consumption could increase sixfold, coupled with substantial land use change and growing urban populations around the world. Continued pressure on the Earth's environmental systems will push certain regions to or beyond their tipping points and result in high levels of climate change and extreme weather events, with profound implications for human systems.

Scenario Analysis and Foresight

The present environmental crisis is a complex, multi-scale dilemma with profound risks for the future of humanity and societal security. It poses effects of unprecedented intensity and duration on global biogeophysical and ecological conditions, which, in turn, have far-reaching consequences for human life in all parts of the world. These risks are aggravated by many interrelated social, political, economic, and ecological conditions that threaten to overtake the present mechanisms of global governance.

Analyses of environmental change generally explore the dynamics and consequences of specific components or clusters of components Bio-geophysical, atmospheric, oceanic, terrestrial, socioeconomic, technological, and other subsystems are examined, and the findings are used to indicate scientifically assess- able directions for advancing social objectives and resolving emerging crises. Responses to these challenges can be pursued with varying levels of commitment, though some will require unprecedented resource mobilization. This Calls for an expansive vision of sustainability.

Transformative Sustainability Transitions

The concept of sustainability transition, although transitory itself, suggests pathways necessary to shifting toward an environmentally and economically sustainable future. More specifically, transformative sustainability transitions challenge the prevailing growth-based development paradigm in favour of more socially and ecologically benign paths. By contrast, instead of trying to do “smart growth” in a finite world, EMERGE-Initiative explores how societies can pursue qualitative improvements of well-being through degrowth without acceleration, and - in contrast to Geoengineering without hope - without havens for the rich in the Southern Hemisphere or on other planets. In these scenarios, the global economy would go through a long period of zero global economic growth, followed by degrowth, driven by a decreasing demand for goods and services that have large ecological footprints; global food production would shrink; and biofuels, meat, and dairy production would fall significantly, leading to lower pressure on land.

Socioeconomic systems would generate pressure for large-scale, fast societal transformations in several areas of human life (such as mobility, leisure, diet) with high environmental footprints. Some would therefore go beyond the “Efficiency-Consistency-Democracy” concept of sustainable development, seeking transformations that afford not only pronounced decreases of environmental pressures, especially in the Global North, but also of human and ecosystem well-being in these regions. Climate change would thus have impacts very different from those in other scenarios. Despite generous climate policies, global mean temperature change would exceed 3 °C. Moreover, the aim would not be to foster resilience, but to stimulate the courage to be vulnerable in a finite world. Escape to Other Planets is Not an Option

Emerging Green Technologies

Emerging green technologies have the potential to mitigate environmental stresses and foster genuine sustainability by reducing the ecological footprint of human activities. Researchers, inventors, and innovative businesses around the world are working on ways to convert waste into new products, produce energy and materials in ways that are less damaging to the earth, and utilize energy more efficiently through smart energy use and conservation. As in prior decades, many of the most innovative ideas, approaches, and solutions are being developed, funded, conceived, and launched in companies created from scratch as start-ups. Outside the private sector, numerous government-led initiatives are also in progress to catalyze transformation.

The crucial role played by the business sector in developing and deploying innovative solutions and environmental technologies will not suffice to overcome the ongoing challenges associated with the long-term viability of the global economy and society. Government action is also required. Public policies at all levels must facilitate adoption of these technologies by overcoming barriers to their diffusion and application, correcting market failures and misaligned incentives, and ensuring that they are introduced in a way that maximizes their contribution to sustainable development and poverty reduction.

Integrated Policy Pathways

Strong and effective environmental policy is fundamentally about setting clear objectives and priorities within a framework that remains simple yet flexible. While the SDGs encompass broad goals and corresponding linkages and responsibilities, other frameworks focus on individual priority areas. Policy-making domains need to integrate development, environmental, and regulatory policies while stimulating people's views and creativity in defining a better future.

Integration at various levels (local, regional, national, and international) is essential for guiding actions that transcend sectoral boundaries; for instance, the land use implications of rural poverty alleviation policies aimed at improving agricultural production are poorly matched with the land use implications of national forest conservation policies. For countries whose historical roles and responsibilities seem limited, national approaches transposed to the global scale are often perceived as the only feasible contribution. However, without acknowledging that responsibility also rests with present patterns of industrialization, urbanization, and consumption within developed industrial countries, any candidate for leadership will have difficulty persuading others of the merits of national actions to tackle global issues.

Global Sustainability Challenges

Human survival and prosperity depend on the health and functioning of the global environmental system, which regulates basic life support processes such as climate, freshwater supply, and food production. When governmental and corporate policies do not reflect this reality, environmental degradation will inevitably occur. Specifically, human societies and economies are embedded within the environmental system, which, in turn, is increasingly affected by their behavior and development trends. Thus, human-induced pressures such as greenhouse gas emissions, transboundary air and water pollution, land-use changes, loss of biodiversity and habitat, and excessive resource consumption must now be recognized as critical components of environmental systems. Because the consequences of these stresses can be modified through intelligent management that encompasses both disaster relief and preventative measures, they present serious social and ethical issues.

Addressing such issues requires a clear understanding of how environmental change progresses and its major natural and human-induced driving forces. Understanding these elements will allow urgent challenges to be identified and suitable mitigation and adaptation strategies developed. Some key developments, which highlight the diverse dynamic interactions within the global environmental system, are considered. The scale and intensity of environmental modifications differ from those of previous eras. Consequently, ecosystem and climate responses are markedly non-linear, leading to unexpected changes such as the collapse of Arctic summer sea-ice cover. Recent severe climate variability and extremes have been linked to changing ocean-atmosphere interactions. While a changing climate alters operational conditions, recent emphasis on the relationship between the coupled human-natural systems and their inherent thresholds and tipping points might contain insights crucial for future decision-making.

Chapter - 17

Conclusion

Sustainable development is one of the most urgent goals of society. Regenerative processes in nature are often deeply disturbed. Progressive degradation diminishes the ability of the Earth System to support human life, reducing the ecosystem services that ensure the physical and socioeconomic sustainability, wellbeing, and safety of people. Environmental change threatens achievement of the UN-Sustainable Development Goals (SDGs) and hinders progress towards a green economy. Climate change is the global driver of environmental change, creating undesirable impacts on natural and human systems. Humanity must adapt to climate change that is beyond its current ability to manage. Innovative technologies such as renewable energy systems, smart grids, ecological sources and sinks, air pollution control, biological agriculture, and regional transport networks can reduce the rate of ecosystem degradation. Environmental policies, regulations, and governance systems are essential for ensuring social, environmental, and economic sustainability.

The effort to meet the SDGs might require higher levels of global cooperation but has the potential to improve environmental quality. Technology, regulatory, and political solutions to the principal pollution problems of toxic heavy metals, plastic waste, organics, and microplastics will make important contributions to restoring clean air, water, and soils. Monitoring, modeling, and managing environmental data improve understanding of environment-development interactions, enable cities to become greener and more livable, and support well-being, safety, and environmental justice. Global population growth is starting to slow, but resource consumption remains unsustainable. Continuity and growth of the modern globalized economy will demand drastic improvements in the efficiency of resource use and minimizing energy and material throughput. Supply-chain networks need to become genuinely global, by linking producers and consumers, optimizing land, water, and energy used in production.

References

1. V. Singh, "The environment and its components," Textbook of Environment and Ecology, 2024. researchgate.net
2. Z. Y. Tian, M. Yousuf, Z. M. Wang, "Chemical and biological processes that occur within and among these domains," Environmental ..., 2025. [HTML]
3. M. Yadav, H. G. Gosai, G. Singh, A. Singh, "Major impact of global climate change in atmospheric, hydrospheric and lithospheric context," in *Global climate change*, 2023, Springer. researchgate.net
4. V. Spiridonov, M. Ćurić, and N. Novkovski, "Introduction: Understanding Earth's Complex Systems," in *Atmospheric Perspectives: Unveiling …*, Springer, 2025. [HTML]
5. M. U. Arshad, "Examining the Role of Physics in Understanding and Addressing Environmental Challenges, Including Climate Change and Sustainable Energy," Contemporary Journal of Social Science, 2024. [HTML]
6. S. C. Madiyevich, "Physics and Environmental Sustainability: Uniting Science and Ecology for a Greener Tomorrow," SYNAPSES: Insights across the disciplines, 2025. inlibrary.uz
7. C. Tang, R. Zeng, and Y. Han, "Coupling coordination evaluation of economic development, ecological environment, and the tourism industry in ski resorts," Journal of Cleaner Production, 2023. [HTML]
8. V. Spiridonov, M. Ćurić, and N. Novkovski, "Solar Radiation: Driving Atmospheric Change," in *Perspectives: Unveiling Earth's …*, Springer, 2025. [HTML]
9. A. Yadav, "Earth's Energy Balance: Maintaining the Dynamics of Thermal Radiation," Climatology,. wisdompress.co.in

10. M. Irfan, M. A. Musarat, W. S. Alaloul, and M. Ghufran, "Radiative forcing on climate change: assessing the effect of greenhouse gases on energy balance of Earth," Advances and Technology, 2024. [HTML]

11. S. Gao, "Energy partitioning in global marine sedimentation: tidal, geothermal, and solar radiation contributions," Geo-Marine Letters, 2024. researchsquare.com

12. J. C. Little, R. O. Kaaronen, J. I. Hukkinen, *et al*., "Earth systems to anthropocene systems: an evolutionary, system-of-systems, convergence paradigm for interdependent societal challenges," Environmental ..., vol. 2023, ACS Publications. helsinki.fi

13. M. Gai and Q. Yang, "Synergistic study of the green efficiency and economic resilience of agriculture from a sustainable development perspective: evidence from Northeast China," Environmental Science and Pollution Research, 2023. nih.gov

14. M. Alberti, "Cities of the Anthropocene: urban sustainability in an eco-evolutionary perspective," Philosophical Transactions of the Royal Society, 2024. royalsocietypublishing.org

15. J. M. Anderies, W. Barfuss, J. F. Donges, and others, "A modeling framework for World-Earth system resilience: exploring social inequality and Earth system tipping points," *Environmental Research Letters*, vol. 2023. iop.org

16. J. Fan, J. Meng, X. Chen, and H. J. Schellnhuber, "Complexity science meets Earth system," Science Bulletin, 2025. researchgate.net

17. D. A. Norman, "Design for a better world: Meaningful, sustainable, humanity centered," 2024. [HTML]

18. G. Thunberg, "The climate book: The facts and the solutions," 2024. [HTML]

19. S. Aheleroff, H. Huang, X. Xu, and R. Y. Zhong, "Toward sustainability and resilience with Industry 4.0 and Industry 5.0," *Frontiers in Manufacturing*, vol. 2022. frontiersin.org

20. M. P. Almeida, C. Gaylarde, F. C. Pompermayer, L. S. Lima, "The complex dynamics of microplastic migration through different aquatic environments: Subsidies for a better understanding of its environmental dispersion," Microplastics, 2023. mdpi.com

21. P. S. Roy, R. M. Ramachandran, O. Paul, and P. K. Thakur, "Anthropogenic land use and land cover changes-A review on its environmental consequences and climate change," *Journal of the Indian*, vol. 2022, Springer. researchgate.net

22. K. Sahil, P. Mehta, S. K. Bhardwaj, and L. K. Dhaliwal, "Development of mitigation strategies for the climate change using artificial intelligence to attain sustainability," in *… for climate change with …*, 2023, Elsevier. [HTML]

23. S. P. Raghuraman and D. Paynter, "Greenhouse gas forcing and climate feedback signatures identified in hyperspectral infrared satellite observations," Geophysical Research Letters, vol. 2023, Wiley Online Library. wiley.com

24. D. J. Soeder, "Greenhouse gas and climate change," in *… of fossil fuel, greenhouse gas, and climate change*, Springer, 2025. [HTML]

25. A. Barkhordarian, "Attribution of extremes to greenhouse gas-induced changes in regional climate variability, distinct from changes in mean climate," Environmental Research Letters, 2024. iop.org

26. W. Brutsaert, "Hydrology," 2023. [HTML]

27. S. Gnann, J. W. Baldwin, M. O. Cuthbert, "The influence of topography on the global terrestrial water cycle," *Reviews of...,* 2025. wiley.com

28. N. Yang and G. Wang, "Spatial variation of water stable isotopes of multiple rivers in southeastern Qaidam Basin, northeast Qinghai-Tibetan Plateau: Insights into hydrologic cycle," Journal of Hydrology, 2024. [HTML]

29. S. Okajima and H. Nakamura, "Midlatitude oceanic fronts strengthen the hydrological cycle between cyclones and anticyclones," Geophysical Research, vol. 2024, Wiley Online Library. wiley.com

30. Y. Lin, X. Zuo, A. Weng, M. M. Nizamani, and Y. Jin, "... the imbalance of forest cover change at county level in mainland China during 2000-2020: From the perspective of subdividing forest cover change into forest …," Journal of Cleaner Production, 2024. sciencedirect.com

31. S. Xiong and F. Yang, "Ecological resilience in water-land transition zones: A case study of the Dongting Lake region, China," Ecological Indicators, 2024. sciencedirect.com

32. M. R. Karim, S. A. Mukul, R. B. Zahir, S. R. Saimun, "The role of protected areas co-management in enhancing resistance and resilience of deciduous forest ecosystem to extreme climatic events in Bangladesh," Journal of …, vol. XX, no. YY, pp. ZZ-ZZ, 2023. researchgate.net

33. N. Osadolor and I. B. Chenge, "Impact of land use land cover change on the forest area of Okomu national park, Edo state, Nigeria," *Journal of Forest and Environmental Science*, vol. 2023. koreascience.kr

34. V. Dakos, C. A. Boulton, J. E. Buxton, *et al.*, "Tipping point detection and early warnings in climate, ecological, and human systems," Earth System Dynamics, vol. 2024. copernicus.org

35. M. Maslin, "The science of human-induced climate change," in *Purpose-Driven Organisation in Times of Climate Change*, 2025. [HTML]

36. S. Fang, Z. Wang, J. Kurths, and J. Fan, "Tipping Points and Cascading Transitions: Methods, Principles, and Evidences," arXiv preprint arXiv:2511.01168, 2025. [PDF]

37. V. Dakos, C. A. Boulton, J. E. Buxton, J. F. Abrams, *et al.*, "Tipping point detection and early-warnings in climate, ecological, and human systems," 2023. copernicus.org

38. A. K. Sagar, A. Chakraborty, and R. K. Srivastava, "Global Atmospheric Trends and Climate Change: A Comprehensive Analysis of Greenhouse Gases and Temperature (2003-2020)," Mitigation and Adaptation, 2025. [HTML]

39. P. J. Taylor, "Natural Drivers of Global Warming: Ocean Cycles, Anthropogenic Greenhouse Gases and the Question of Percentages," Journal of Environmental & Earth Sciences Volume, 2025. researchgate.net

40. Q. B. Lu, "Major contribution of halogenated greenhouse gases to global surface temperature change," Atmosphere, 2022. mdpi.com

41. J. A. Milam-Guerrero, B. Yang, D. T. To, and N. V. Myung, "Nitrous oxide is no laughing matter: a historical review of nitrous oxide gas-sensing capabilities highlighting the need for further exploration," ACS sensors, 2022. [HTML]

42. M. E. Malerba, B. Edwards, L. Schuster, O. Odebiri, *et al.*, "Pondi-a low-cost logger for long-term monitoring of methane, carbon dioxide, and nitrous oxide in aquatic and terrestrial systems," 2025. copernicus.org

43. L. Tyagi, R. Devi, S. Tyagi, and V. Kumar, "Environmental impacts and recent advancements in the sensing of methane: a review," *Environmental Science and Pollution Research*, vol. 2025, Taylor & Francis. [HTML]

44. N. Wunderling and A. S. von der Heydt, "Climate tipping point interactions and cascades: a review," Earth System Dynamics, vol. 2024. copernicus.org

45. T. POINT, "Tipping points: Climate surprises," Climate change, 2023. [HTML]

46. T. M. Lenton, M. Milkoreit, S. Willcock, J. F. Abrams, *et al.*, "Global tipping points report 2025," 2025. uu.nl

47. M. A. E. AbdelRahman, "An overview of land degradation, desertification and sustainable land management using GIS and

remote sensing applications," Rendiconti Lincei. Scienze Fisiche e Naturali, 2023. springer.com

48. M. B. Abdullahi, A. A. Elnaggar, M. M. Omar, "Land degradation, causes, implications and sustainable management in arid and semi arid regions: A case study of Egypt," *Journal of Soil*, vol. 2023. ekb.eg

49. P. K. Badapalli, R. B. Kottala, and P. S. Pujari, "Land degradation and desertification," in *Desertification: Disaster with Visual …*, 2023, Springer. [HTML]

50. R. Mahtta, M. Fragkias, B. Güneralp, A. Mahendra, "Urban land expansion: the role of population and economic growth for 300+ cities," Npj Urban, 2022. nature.com

51. W. Cao, Y. Zhou, B. Güneralp, X. Li, K. Zhao, "Increasing global urban exposure to flooding: An analysis of long-term annual dynamics," *Science of The Total Environment*, vol. 2022, Elsevier. osu.edu

52. O. Gershon, J. K. Asafo, A. Nyarko-Asomani, and others, "Investigating the nexus of energy consumption, economic growth and carbon emissions in selected African countries," *Energy Strategy Reviews*, vol. 2024, Elsevier. sciencedirect.com

53. C. Bertelsmeier, A. Bonnamour, J. R. Garnas, "Temporal dynamics and global flows of insect invasions in an era of globalization," Nature Reviews, 2025. unil.ch

54. V. D. Spanos, L. Sdrolias, and N. Kakkos, "The contribution of sea routes regarding the modern town of Preveza: Creating new space terms," researchgate.net, . researchgate.net

55. H. C. Le and T. H. Le, "Effects of economic, social, and political globalization on environmental quality: international evidence," Environment, . [HTML]

56. Z. Liang, "China's Stories and Innovation in Economic Theory," in *The Innovation of Economic Theory in China*, Springer, 2026. [HTML]

57. M. Kabir, U. Habiba, M. Z. Iqbal, and M. Shafiq, "Impacts of anthropogenic activities & climate change resulting from increasing concentration of Carbon dioxide on environment in 21st Century; A Critical Review," Earth and Environmental Science Series, vol. 2023. iop.org

58. M. Kabir, U. E. Habiba, W. Khan, A. Shah, S. Rahim, "Climate change due to increasing concentration of carbon dioxide and its impacts on environment in 21st century; a mini review," Journal of King Saud University, vol. XX, pp. XX-XX, 2023. sciencedirect.com

59. R. B. Jackson, M. Saunois, A. Martinez, *et al*., "Human activities now fuel two-thirds of global methane emissions," *Environmental*, 2024. hal.science

60. M. Li, G. Bekö, N. Zannoni, G. Pugliese, M. Carrito, *et al*., "Human metabolic emissions of carbon dioxide and methane and their implications for carbon emissions," *Science of the Total Environment*, vol. 2022, Elsevier. sciencedirect.com

61. A. Lamothe, P. D. Akers, S. Albertin, N. Caillon, S. Darfeuil, *et al*., "1000 years of Nitrogen Oxide Sources in Western Europe: Evidence from Nitrogen Stable Isotopes (δ15N) of Nitrate in a Mont Blanc Ice Core," 2025. hal.science

62. A. Lamothe, P. Akers, P. Ginot, S. Albertin, A. Eichler, "300-Year NH3 Inventory in Europe: Uncovering Combustion's Recent Share," hal.science, 2024. hal.science

63. S. Bansal, N. Raghuram, T. K. Adhya, and others, "Long-term trends of direct nitrous oxide emission from fuel combustion in South Asia," *Environmental Science: Processes & Impacts*, vol. 2022. iop.org

64. S. Fadnavis, Y. Elshorbany, J. Ziemke, and others, "Influence of nitrogen oxides and volatile organic compounds emission changes on tropospheric ozone variability, trends and radiative effect," 2024. copernicus.org

65. X. Bi, C. Wu, Y. Wang, J. Li, C. Wang, and A. Hahs, "Changes in the associations between heatwaves and human mortality

during two extreme hot summers in Shanghai, China," Sustainable Cities and Society, vol. 2023, Elsevier. [HTML]

66. S. A. M. Khatana, R. M. Werner, and P. W. Groeneveld, "Association of extreme heat and cardiovascular mortality in the United States: a county-level longitudinal analysis from 2008 to 2017," Circulation, 2022. ahajournals.org

67. Y. Wu, S. Li, Q. Zhao, B. Wen, A. Gasparrini, "Global, regional, and national burden of mortality associated with short-term temperature variability from 2000-19: a three-stage modelling study," *The Lancet Planetary Health*, vol. 6, no. 10, pp. e1072-e1084, 2022. thelancet.com

68. S. Khatana and R. M. Werner, "Association of extreme heat with all-cause mortality in the contiguous US, 2008-2017," JAMA Network Open, 2022. jamanetwork.com

69. K. S. Yun, A. Timmermann, S. S. Lee, M. Willeit, "A transient coupled general circulation model (CGCM) simulation of the past 3 million years," *Climate of the Past*, vol. 19, no. 1, pp. 1-20, 2023. copernicus.org

70. E. Ziegler, N. Weitzel, J. P. Baudouin, M. L. Kapsch, *et al*., "Patterns of changing surface climate variability from the Last Glacial Maximum to present in transient model simulations," *Climate of the Past*, vol. 2025. copernicus.org

71. M. Filonchyk, M. P. Peterson, and L. Zhang, "Greenhouse gases emissions and global climate change: Examining the influence of CO2, CH4, and N2O," The Total Environment, 2024. [HTML]

72. UA Bhatti, MA Bhatti, H Tang, MS Syam, "Global production patterns: Understanding the relationship between greenhouse gas emissions, agriculture greening and climate variability," Environmental ..., vol. 2024, Elsevier. [HTML]

73. P. Wang, Y. Yang, D. Xue, L. Ren, J. Tang, "Aerosols overtake greenhouse gases causing a warmer climate and more weather extremes toward carbon neutrality," *Nature*, 2023. nature.com

74. D. Hemathilake and D. Gunathilake, "Agricultural productivity and food supply to meet increased demands," Future foods, 2022. sciencedirect.com

75. A. Ali, T. Hussain, and A. Zahid, "Smart irrigation technologies and prospects for enhancing water use efficiency for sustainable agriculture," AgriEngineering, 2025. mdpi.com

76. L. Rosa, "Adapting agriculture to climate change via sustainable irrigation: biophysical potentials and feedbacks," Environmental Research Letters, 2022. iop.org

77. S. Alharbi, A. Felemban, A. Abdelrahim, and M. Al-Dakhil, "Agricultural and Technology-based strategies to improve water-use efficiency in Arid and Semiarid areas," Water, 2024. mdpi.com

78. S. Li, L. Yu, W. Jiang, H. Yu, and X. Wang, "The recent progress China has made in green mine construction, Part I: mining groundwater pollution and sustainable mining," *International Journal of …*, 2022. mdpi.com

79. G. Ravindiran, S. Rajamanickam, S. Sivarethinamohan, "A review of the status, effects, prevention, and remediation of groundwater contamination for sustainable environment," Water, vol. 2023. mdpi.com

80. F. Arthur-Holmes, K. A. Busia, N. Yakovleva, "Artisanal and small-scale mining methods and the Sustainable Development Goal 6: Perceived implications for clean water supply," *Science & Policy*, vol. 2022, Elsevier. port.ac.uk

81. S. Tomiyama and T. Igarashi, "The potential threat of mine drainage to groundwater resources," *Current Opinion in Environmental Science & Health*, vol. 2022, Elsevier. sciencedirect.com

82. S. D. Mohammed, "Strategies for Teaching the Hydrologic Cycle (Water Cycle)," South Eastern Journal of Research and …, 2025. sejrsd.org.ng

83. M. Manashree, "A Brief Discussion on Fresh water and Hydrologic cycle," Environment Science, . alexispress.in
84. R. Rosso, "The Water Cycle," in *Five Easy Pieces on Water: Essentials of Water …*, Springer, 2024. [HTML]
85. L. Ehtasham, S. H. Sherani, and F. Nawaz, "Acceleration of the hydrological cycle and its impact on water availability over land: an adverse effect of climate change," in *Hydrology and Water*, 2024. icm.edu.pl
86. K. Haustein and Q. Rayer, "Water cycle changes in a warming world: the scientific background," in *Water risk modeling: Developing risk-return …*, 2023, Springer. [HTML]
87. K. Nagata, I. Shoji, T. Arima, T. Otsuka, "Practicality of integrated water resources management (IWRM) in different contexts," *Journal of Water Resources*, vol. XX, no. XX, pp. XX-XX, 2022. tandfonline.com
88. B. K. Shukla, A. Tripathi, J. C. Nagavi, S. Prasad, "Integrated Water Resources Management (IWRM) in the Geospatial Epoch: An Ontological Dive into Sustainable Hydrological Governance," in *Technology*, vol. 2, 2024, Springer. researchgate.net
89. N. Kant and G. Wrat, "A review of integrated groundwater and surface water management for environmental sustainability," Acta Geochimica, 2025. cas.cn
90. AA Banso, JO Olurin, ES Okem, "Integrated water resource management in South West Nigeria: A comprehensive review of strategies and outcomes," International Journal of …, 2023. academia.edu
91. M. El-Rawy AKA Ahmed, "The impact of aquifer recharge on groundwater quality," in *Managed aquifer recharge in MENA countries*, 2024, Springer. [HTML]
92. S. Sloan, P. G. Cook, and I. Wallis, "Managed aquifer recharge in mining: A review," Groundwater, 2023. wiley.com
93. H. Gebreslassie, G. Berhane, T. Gebreyohannes, "Water Harvesting and Groundwater Recharge: A Comprehensive

Review and Synthesis of Current Practices," Water, vol. 2025. mdpi.com

94. X. Kuang, J. Liu, B. R. Scanlon, J. J. Jiao, and S. Jasechko, "The changing nature of groundwater in the global water cycle," *Science*, vol. 2024. science.org

95. H. Shemer, S. Wald, and R. Semiat, "Challenges and solutions for global water scarcity," Membranes, 2023. mdpi.com

96. C. Ingrao, R. Strippoli, G. Lagioia, and D. Huisingh, "Water scarcity in agriculture: An overview of causes, impacts and approaches for reducing the risks," Heliyon, 2023. cell.com

97. FA Padder and A Bashir, "Scarcity of water in the twenty-first century: Problems and potential remedies," MEDALION JOURNAL: Medical, 2023. medalionjournal.com

98. A. Panhwar, R. Abro, A. Kandhro, "Global water mapping, requirements, and concerns over water quality shortages," in *Water Quality-New Challenges and Opportunities*, 2022. intechopen.com

99. M. S. Islam and M. MG, "Impacts of climate change on global freshwater quality and availability: a comprehensive review," Journal of Water and Environment Technology, 2024. jst.go.jp

100. M. T. H. Van Vliet, J. Thorslund, M. Strokal, *et al.*, "Global river water quality under climate change and hydroclimatic extremes," *Earth & Environment*, 2023. [HTML]

101. M. B. Kayastha, X. Ye, C. Huang, and P. Xue, "Future rise of the Great Lakes water levels under climate change," Journal of Hydrology, 2022. sciencedirect.com

102. F. Liu, M. H. Conklin, and G. D. Shaw, "Elevational control of isotopic composition and application in understanding hydrologic processes in the mid Merced River catchment, Sierra Nevada …," Hydrology and Earth System, 2024. copernicus.org

103. I. Overland, J. Juraev, and R. Vakulchuk, "Are renewable energy sources more evenly distributed than fossil fuels?," Renewable Energy, 2022. sciencedirect.com

104. J. Wang and W. Azam, "Natural resource scarcity, fossil fuel energy consumption, and total greenhouse gas emissions in top emitting countries," Geoscience frontiers, 2024. sciencedirect.com

105. J. L. Holechek, H. M. E. Geli, M. N. Sawalhah, and R. Valdez, "A global assessment: can renewable energy replace fossil fuels by 2050?," Sustainability, 2022. mdpi.com

106. M. Zastempowski, "Analysis and modeling of innovation factors to replace fossil fuels with renewable energy sources-Evidence from European Union enterprises," Renewable and Sustainable Energy Reviews, 2023. [HTML]

107. M. M. Hasan, S. Hossain, M. Mofijur, Z. Kabir, I. A. Badruddin, "Harnessing solar power: a review of photovoltaic innovations, solar thermal systems, and the dawn of energy storage solutions," Energies, 2023. mdpi.com

108. JF Rosales-Pérez, A. Villarruel-Jaramillo, *et al.*, "Hybrid system of photovoltaic and solar thermal technologies for industrial process heat," Energies, 2023. mdpi.com

109. N. S. M. N. Izam, Z. Itam, W. L. Sing, and A. Syamsir, "Sustainable development perspectives of solar energy technologies with focus on solar Photovoltaic-A review," Energies, 2022. mdpi.com

110. C. P. Correia, V. Bernardo, "Comparative analysis between traditional and emerging technologies: economic and viability evaluation in a real case scenario," *Materials for Renewable*, vol. 2023, Springer. springer.com

111. C. F. Kutscher, J. B. Milford, and F. Kreith, "Principles of sustainable energy systems," 2025. [HTML]

112. W. Chen, M. Alharthi, J. Zhang, and I. Khan, "The need for energy efficiency and economic prosperity in a sustainable environment," Gondwana Research, 2024. [HTML]

113. C. Breyer, S. Khalili, D. Bogdanov, M. Ram, "On the history and future of 100% renewable energy systems research," in IEEE, 2022. ieee.org

114. H. Chen, Y. Shi, and X. Zhao, "Investment in renewable energy resources, sustainable financial inclusion and energy efficiency: A case of US economy," Resources Policy, 2022. [HTML]

115. J. Alzeer, "Beyond disorder: A new perspective on entropy in chemistry," Am J Med Chemos, 2024. swisssdc.ch

116. A. K. Yasuri, "Harnessing Entropy: Innovations in Energy Efficiency and Sustainability," Sustainable Futures, 2025. sciencedirect.com

117. D. K. Jha, "Entropy Driven Awareness: Consciousness in the Flow of Time," 2025. philarchive.org

118. Q. Guo, "Economic Entropy Increase: A Fundamental Principle of Economic Evolution," Available at SSRN 5272837, 2025. ssrn.com

119. P. Ezhilarasi, L. Ramesh, P. Sanjeevikumar, and B. Khan, "A cost-effective smart metering approach towards affordable deployment strategy," Scientific Reports, 2023. nature.com

120. M. Shafiullah, S. Rahman, B. Imteyaz, and M. K. Aroua, "Review of smart city energy modeling in Southeast Asia," *Smart Cities*, 2022. mdpi.com

121. L. Govindarajan, M. F. B. M. Batcha, and M. K. B. Abdullah, "Solar energy policies in southeast Asia towards low carbon emission: A review," Heliyon, 2023. cell.com

122. B. K. Dhar, M. M. Roshid, S. Dissanayake, and U. Chawla, "Leveraging FinTech and GreenTech for long-term sustainability in South Asia: Strategic pathways toward Agenda 2050," *Green Technologies and …*, 2025. sciencedirect.com

123. V. Veerasamy, L. P. M. I. Sampath, H. Qiu, H. Huang, Y. Li, "Grid infrastructure and renewables integration for singapore energy transition," Scientific Reports, 2025. nature.com

124. M. B. Hannouf, A. Padilla-Rivera, G. Assefa, "Social life cycle assessment (S-LCA) of technology systems at different stages of development," *Journal of Life Cycle Assessment*, 2025. [HTML]

125. D. Ott, S. Goyal, R. Reuss, and H. O. Gutzeit, "LCA as decision support tool in the food and feed sector: evidence from R&D case studies," Environment Systems and Decisions, vol. 2023, Springer. springer.com

126. A. K. Kamali, D. Lee, R. Futsch, E. Glogic, "Steering innovation toward sustainable electrochromic displays: a prospective life cycle assessment study," ACS Sustainable, vol. 2024, ACS Publications. hal. science

127. M. Požarnik, L. R. Mohar, and D. Kosi, "Evaluating environmental impacts with LCA to achieve carbon neutral societies," Journal of Human, . academia.edu

128. R. Gupta, "Mineralization of soil carbon, nitrogen, and phosphorus and role of nanofertilizers in soil fertility and plant growth," Structure and functions of pedosphere, 2022. researchgate.net

129. H. S. Wan, W. C. Zhang, W. Wu, and H. B. Liu, "Environmental factors affecting soil organic carbon, total nitrogen, total phosphorus under two cropping systems in the Three Gorges Reservoir area," Journal of Soils and Sediments, 2023. [HTML]

130. AJ Hussain and DKA Al-Taey, "Biochar Application Increases the Amount of Nitrogen, Phosphorus and Potassium in the Soil: a Review," IOP Conference Series, 2023. iop.org

131. M. A. Tahir, A. Hamza, S. Hussain, Z. Xie, and M. Brestic, "Carbon sequestrating fertilizers as a tool for carbon sequestration in agriculture under aridisols," *Carbon Letters*, vol. 2022, Springer, 2022. [HTML]

132. T. Daum, "Mechanization and sustainable agri-food system transformation in the Global South. A review," Agronomy for Sustainable Development, 2023. springer.com

133. M. Gautam, D. Laborde Debucquet, A. Mamun, W. Martin, "Repurposing agricultural policies and support: options to transform agriculture and food systems to better serve the health of people, economies, and the planet," 2022. cgiar.org

134. B. Davis, L. Lipper, and P. Winters, "Do not transform food systems on the backs of the rural poor," Food security, 2022. nih.gov

135. M. Zurek, A. Hebinck, and O. Selomane, "Climate change and the urgency to transform food systems," Science, 2022. science.org

136. F. Hailu, "Climate change as a trigger for desertification and possible alternatives to reduce biodiversity loss," Journal of the Selva Andina Biosphere, 2023. scielo.org.bo

137. Z. Ahmed, D. Gui, S. K. Abd- Elmabod, "An overview of global desertification control efforts: Key challenges and overarching solutions," Soil Use and Management, vol. 2024, Wiley Online Library. [HTML]

138. S. Jain, A. Srivastava, L. Khadke, U. Chatterjee, "Global-scale water security and desertification management amidst climate change," *Science and Pollution Research*, vol. 2024, Springer. [HTML]

139. A. K. Kulik and M. V. Vlasenko, "Global planning strategy for the restoration of degraded and desertified ecosystems," *Proceedings of Lower Volga Agro-University*, 2024. [HTML]

140. M. C. Lens, "Zoning, land use, and the reproduction of urban inequality," Annual Review of Sociology, 2022. nih.gov

141. A. Shamaei and K. Jafarpour Ghalehteimouri, "Evaluating the impact of Zanjan city's economic drivers on the quality of life in peri-urban villages: a case study of Do Asb and Payin Kouh villages," *Journal of Urban and Rural Planning*, 2024. springer.com

142. S. Mansour, N. Al Nasiri, A. Abulibdeh, "Spatial disparity patterns of green spaces and buildings in arid urban areas,"

Building and Environment, vol. XX, no. YY, pp. ZZ-ZZ, 2022. [HTML]

143. S. Leng, R. Sun, X. Yang, and L. Chen, "Global inequities in population exposure to urban greenspaces increased amidst tree and nontree vegetation cover expansion," Communications Earth & Environment, 2023. nature.com
144. R. Baldwin-Kordick, M. De, and M. D. Lopez, "Comprehensive impacts of diversified cropping on soil health and sustainability," *Food Systems*, vol. 2022, Taylor & Francis. tandfonline.com
145. B. Upadhaya, K. Kishor, V. Kumar, N. Kumar, S. Kumar, "Diversification of rice-based cropping system for improving system productivity and soil health in eastern gangetic plains of India," Agronomy, vol. 12, no. 5, 2022. mdpi.com
146. Z. Yan, J. Zhou, C. Liu, R. Jia, K. Z. Mganga, and L. Yang, "Legume-based crop diversification reinforces soil health and carbon storage driven by microbial biomass and aggregates," *Soil and Tillage Research*, vol. 202, 2023. uu.nl
147. R. Li, Z. He, P. He, R. Yang, D. Ma, Y. Li, Y. Xiang, "Crop diversification improves productivity and soil health by regulating fungal diversity," Soil and Tillage, 2025. [HTML]
148. P. Ekka, S. Patra, M. Upreti, G. Kumar, "Land degradation and its impacts on biodiversity and ecosystem services," *Environmental Science and Pollution Research*, vol. 2023, Wiley Online Library. [HTML]
149. A. S. Kolawole and A. O. Iyiola, "Environmental pollution: threats, impact on biodiversity, and protection strategies," in *… utilization and conservation of Africa's biological …*, 2023, Springer. academia.edu
150. S. V. Rathod, P. Saras, and S. M. Gondaliya, "Environmental pollution: Threats and challenges for management," Eco-restoration of polluted…, 2024. [HTML]

151. S. K. Chakraborty, P. Sanyal, and R. Ray, "Pollution, environmental perturbation and consequent loss of wetlands," in Eco-biological uniqueness of a Ramsar, 2023, Springer. [HTML]

152. M. E. Hardouin and A. L. Hargreaves, "Mapping nationally and globally at-risk species to identify hotspots for (and gaps in) conservation," *Proceedings of the …*, 2023. royalsocietypublishing.org

153. PY Huais, L. Osorio- Olvera, JM Cordier, *et al.*, "Rethinking global hotspots for threatened terrestrial vertebrates," Global Ecology and…, 2025. [HTML]

154. B. R. Shipley and J. L. McGuire, "Interpreting and integrating multiple endemism metrics to identify hotspots for conservation priorities," Biological Conservation, 2022. sciencedirect.com

155. AS Erst, S. Baasanmunkh, Z. Tsegmed, "Hotspot and conservation gap analysis of endemic vascular plants in the Altai Mountain Country based on a new global conservation assessment," *Global Ecology and Conservation*, vol. XX, pp. YY-ZZ, 2023. sciencedirect.com

156. M. Fortnam, T. Chaigneau, L. Evans, *et al.*, "Practitioner approaches to trade- off decision- making in marine conservation development," *People and Nature*, vol. 2023, Wiley Online Library. wiley.com

157. L. Ma, L. Hong, and X. Liang, "Integrating Ecological and Economic Approaches for Ecosystem Services and Biodiversity Conservation: Challenges and Opportunities," Ecologies, 2025. mdpi.com

158. S. M. Jalilov, Y. Rochmayanto, D. C. Hidayat, J. T. Raharjo, "Unveiling economic dimensions of peatland restoration in Indonesia: A systematic literature review," Ecosystem Services, 2025. sciencedirect.com

159. S. Neubert, J. McGowan, K. Metcalfe, J. O. Hanson, *et al.*, "Multiple-use spatial planning for sustainable development and conservation," Trends in Ecology & Evolution, vol. 40, no. 1, 2025. cell.com

160. G. Beaugrand, "Towards an understanding of large-scale biodiversity patterns on land and in the sea," Biology, 2023. mdpi.com

161. C. Román- Palacios and D. Moraga- López, "The origins of global biodiversity on land, sea and freshwater," Ecology Letters, vol. 25, no. 6, pp. 1469-1482, 2022. researchgate.net

162. J. R. Allan, H. P. Possingham, S. C. Atkinson, A. Waldron, *et al*., "The minimum land area requiring conservation attention to safeguard biodiversity," *Science*, 2022. science.org

163. B. Finand, T. Monnin, and N. Loeuille, "Evolution of dispersal and the maintenance of fragmented metapopulations," Oikos, 2024. wiley.com

164. J. Jacobs, Y. Salmaniw, K. Y. Lam, L. Zhai, *et al*., "Fundamental principles of the effect of habitat fragmentation on species with different movement rates," *Conservation*, 2025. nsf.gov

165. M. Jõks, A. Helm, L. Kasari-Toussaint, E. Kook, R. Lutter, *et al*., "A simulation model of functional habitat connectivity demonstrates the importance of species establishment in older forests," *Ecological...,* vol. 2023, Elsevier. [HTML]

166. C. J. Zabin, L. J. Jurgens, J. M. Bible, *et al*., "Increasing the resilience of ecological restoration to extreme climatic events," *… and the Environment*, 2022. wiley.com

167. T. T. Nguyen, U. Grote, F. Neubacher, and M. H. Do, "Security risks from climate change and environmental degradation: implications for sustainable land use transformation in the Global South," in Environmental ..., 2023. sciencedirect.com

168. D. Amoak, I. Luginaah, and G. McBean, "Climate change, food security, and health: Harnessing agroecology to build climate-resilient communities," Sustainability, 2022. mdpi.com

169. X. M. Chen, A. Sharma, and H. Liu, "The impact of climate change on environmental sustainability and human mortality," Environments, 2023. mdpi.com

170. A. Kassab, D. Al Nabhani, P. Mohanty, C. Pannier, "Advancing plastic recycling: Challenges and opportunities in the integration of 3D printing and distributed recycling for a circular economy," Polymers, 2023. mdpi.com

171. X. Chen, "Machine learning approach for a circular economy with waste recycling in smart cities," Energy Reports, 2022. sciencedirect.com

172. M. T. Islam and U. Iyer-Raniga, "Lithium-ion battery recycling in the circular economy: a review," Recycling, 2022. mdpi.com

173. A. Sarker, M. K. Ghosh, T. Islam, M. Bilal, R. Nandi, "Sustainable food waste recycling for the circular economy in developing countries, with special reference to Bangladesh," Sustainability, vol. 2022. mdpi.com

174. S. H. H. Al-Taai, "Air pollution: A study of its concept, causes, sources and effects," *... and Pollution*, 2022. academia.edu

175. D. A. Vallero, "Fundamentals of air pollution," 2025. [HTML]

176. H. D. Hesketh, "Air pollution control: traditional hazardous pollutants," 2023. [HTML]

177. G. E. Halkos and P. S. C. Aslanidis, "How waste crisis altered the common understanding: from fordism to circular economy and sustainable development," Circular Economy and Sustainability, 2024. [HTML]

178. M. Ram and E. Bracci, "Waste management, waste indicators and the relationship with sustainable development goals (SDGs): a systematic literature review," Sustainability, 2024. mdpi.com

179. M. D. Vaverková, "Will We or Will We not Be on Track with Sustainable Development Goals in Waste Management-That is the Question?," in *Emerging Trends in Sustainable Geotechnics: Keynote …*, Springer, 2025. [HTML]

180. P. H. Nguyen, T. N. Le, M. T. Pham, and M. Q. Trinh, "Circular economy, economic growth, and e-waste generation in EU27 countries: Further evidence from the novel circular economy

index and threshold effect," *Environmental Science and …*, 2024. [HTML]

181. K. K. Gopalakrishnan, R. Sivakumar, and D. Kashian, "The microplastics cycle: an in-depth look at a complex topic," Applied Sciences, 2023. mdpi.com

182. T. Xayachak, N. Haque, D. Lau, and B. K. Pramanik, "The missing link: A systematic review of microplastics and its neglected role in life-cycle assessment," *Science of the Total Environment*, vol. 2024, Elsevier. sciencedirect.com

183. M. Shen, B. Song, C. Zhou, E. Almatrafi, T. Hu, "Recent advances in impacts of microplastics on nitrogen cycling in the environment: a review," *Journal of the Total Environment*, vol. 2022, Elsevier. [HTML]

184. Y. Gao, K. Fan, Z. Lai, C. Wang, H. Li, and Q. Liu, "A comprehensive review of the circulation of microplastics in aquatic ecosystem using scientometric method," Environmental Science and …, vol. 2022, Springer. researchgate.net

185. NSA Yaro, MH Sutanto, L Baloo, NZ Habib, A Usman, "A comprehensive overview of the utilization of recycled waste materials and technologies in asphalt pavements: towards environmental and sustainable low …," Processes, 2023. mdpi.com

186. G. Bartariya, S. Rathore, and M. Sharma, "Waste to Resource for Achieving Environmental Safety," in *Management of Waste to Control …*, Springer, 2025. [HTML]

187. P. Rawat and S. Mohanty, "From waste to resource: Engineering advancements for municipal solid waste fine fraction utilization-A review," Waste Management & Research, 2025. [HTML]

188. T. W. Davis, R. Mahmud, S. McNaul, M. Jamieson *et al.*, "A Comparative Analysis of Waste-as-a-Feedstock Accounting Methods in Life Cycle Assessments," Hydrogen, 2025. mdpi.com

189. J. Guo, Y. Zhang, J. Fang, Z. Ma, C. Li, M. Yan, and N. Qiao, "Reduction and reuse of forestry and agricultural bio-waste

through innovative green utilization approaches: A review," Forests, vol. 2024. mdpi.com

190. S. Beluhan, K. Mihajlovski, B. Šantek, and M. Ivančić Šantek, "The production of bioethanol from lignocellulosic biomass: Pretreatment methods, fermentation, and downstream processing," Energies, 2023. mdpi.com
191. M. Broda, D. J. Yelle, and K. Serwańska, "Bioethanol production from lignocellulosic biomass-challenges and solutions," Molecules, 2022. mdpi.com
192. A. Devi, S. Bajar, H. Kour, R. Kothari *et al.*, "Lignocellulosic biomass valorization for bioethanol production: a circular bioeconomy approach," Bioenergy Research, 2022. springer.com
193. A. Bikis, "Urban air pollution and greenness in relation to public health," Journal of environmental and public health, 2023. wiley.com
194. X. Wang, F. Dong, Y. Pan, and Y. Liu, "Transport infrastructure, high-quality development and industrial pollution: fresh evidence from China," *International Journal of Environmental*, vol. 2022. mdpi.com
195. Y. Guo, Q. Lu, S. Wang, and Q. Wang, "Analysis of air quality spatial spillover effect caused by transportation infrastructure," *Transportation Research Part D: Transport and Environment*, vol. 102, pp. 103-115, 2022. [HTML]
196. V. Saxena, "Water quality, air pollution, and climate change: investigating the environmental impacts of industrialization and urbanization," Water, . [HTML]
197. P. Mishra and G. Singh, "Energy management systems in sustainable smart cities based on the internet of energy: A technical review," Energies, 2023. mdpi.com
198. S. Rathi and V. K. Gola, "Innovative components of smart cities with a special focus of water distribution systems challenges and opportunities: A review," in *Earth and Environmental Conference Series*, 2024. iop.org

199. M. G. M. Almihat, M. T. E. Kahn, K. Aboalez, and A. M. Almaktoof, "Energy and sustainable development in smart cities: An overview," Smart Cities, 2022. mdpi.com

200. I. Sosunova and J. Porras, "IoT-enabled smart waste management systems for smart cities: A systematic review," Ieee Access, 2022. ieee.org

201. G. Li, C. Fang, Y. Li, Z. Wang, S. Sun, S. He, W. Qi, *et al*., "Global impacts of future urban expansion on terrestrial vertebrate diversity," *Nature*, vol. 2022. nature.com

202. M. Lowe, D. Adlakha, J. F. Sallis, D. Salvo, *et al*., "City planning policies to support health and sustainability: an international comparison of policy indicators for 25 cities," *The Lancet Global Health*, vol. XX, no. YY, pp. ZZ-ZZ, 2022. thelancet.com

203. Z. Allam, M. Nieuwenhuijsen, D. Chabaud, *et al*., "The 15-minute city offers a new framework for sustainability, liveability, and health," *The Lancet Planetary Health*, vol. 6, no. 4, pp. e400-e402, 2022. thelancet.com

204. J. Nkiriki, P. Jaramillo, N. Williams, A. Davis, "Estimating global demand for land-based transportation services using the shared socioeconomic pathways scenario framework," *Environmental Research*, vol. 2022. iop.org

205. S. Kraus, S. Ishmam, T. Grube, J. Linßen, J. May, "Model-based analysis of future global transport demand," Transportation Research, vol. 2024, Elsevier. sciencedirect.com

206. A. Köves and Z. Bajmócy, "The end of business-as-usual?-A critical review of the air transport industry's climate strategy for 2050 from the perspectives of Degrowth," Sustainable Production and Consumption, 2022. sciencedirect.com

207. S. Hofbauer, "Scenarios in urban public transport 2050: accommodating for passenger's basic needs in the design of vehicles," 2022. tuwien.at

208. A. M. M. Irfeey, H. W. Chau, M. M. F. Sumaiya, C. Y. Wai, and N. Muttil, "Sustainable mitigation strategies for urban heat island effects in urban areas," Sustainability, vol. 2023. mdpi.com
209. HK Jabbar and MN Hamoodi, "Urban heat islands: a review of contributing factors, effects and data," IOP Conference Series, 2023. iop.org
210. X. Yao, K. Yu, X. Zeng, Y. Lin, B. Ye, and X. Shen, "How can urban parks be planned to mitigate urban heat island effect in 'Furnace cities'? An accumulation perspective," *Journal of Cleaner Production*, vol. 2022, Elsevier. [HTML]
211. Q. Lu, A. Sha, Y. Chen, Z. Liu, Z. Feng, and Z. Li, "Development of high absorbency and lightweight water-retentive semi-flexible pavement for urban heat island mitigation," *Construction and Building Materials*, vol. 2025, Elsevier. [HTML]
212. [212, 1] U. K. Ashinze, B. A. Edeigba, A. A. Umoh, "Urban green infrastructure and its role in sustainable cities: A comprehensive review," World Journal of ..., 2024. semanticscholar.org
213. J. Kaur, "Towards a sustainable Triad: Uniting energy management systems, smart cities, and green healthcare for a greener future," in *Materials, Technologies, and Solutions for Energy*, 2024. researchgate.net
214. P. O. Okedele, O. R. Aziza, P. Oduro, and A. O. Ishola, "Transnational environmental law and the challenge of regulating cross-border pollution in an interconnected world," Iconic Res Eng J, 2024. researchgate.net
215. T. A. Tran and C. Tortajada, "Responding to transboundary water challenges in the Vietnamese Mekong Delta: In search of institutional fit," Environmental Policy and Governance, 2022. wiley.com
216. G. O. Antai, P. A. Aidonojie, J. E. Ashibi, "Examination of the Efficacy of International Law in Combatting Trans-Border Environmental Crimes," NIU Journal of Legal, 2025. niujournals.ac.ug

217. T. Lappe- Osthege, "The ripple effects of compliance: reconfiguring EU policy effectiveness in transboundary environmental governance," JCMS: Journal of Common Market Studies, 2024. wiley.com

218. Y. Steinebach, "Instrument choice, implementation structures, and the effectiveness of environmental policies: A cross- national analysis," Regulation & Governance, 2022. wiley.com

219. UM Adanma and EO Ogunbiyi, "A comparative review of global environmental policies for promoting sustainable development and economic growth," International Journal of Applied …, 2024. researchgate.net

220. J. Evans and C. Thomas, "Environmental governance," 2023. [HTML]

221. X. Ji, G. Wu, J. Lin, J. Zhang *et al*., "Reconsider policy allocation strategies: A review of environmental policy instruments and application of the CGE model," Journal of Environmental Management, 2022. [HTML]

222. O. I. Sharno, "Environmental impact assessment and Environmental expertise as tools to prevent Environmental Damage: Some Opinions …," of Management, . paradigmy34.ru

223. C. Obudulu, M. I. Ikeh, and O. A. Okeke, "Environmental impact assessment a key to sustainable development," *African Journal on*, 2024. unizik.edu.ng

224. P. Maurya and A. Akarsh, "Environmental Impact Assessments: Ensuring Sustainability," bioticapublications.com, . bioticapublications.com

225. J. Awewomom, F. Dzeble, Y. D. Takyi, W. B. Ashie, "Addressing global environmental pollution using environmental control techniques: a focus on environmental policy and preventive environmental management," *Journal of Environmental Management*, vol. 2024, Springer. springer.com

226. K. Emerson, E. Baldwin, T. A. Scott, J. R. Pidot, "Toward NEPA performance: A framework for assessing EIAs," Environmental

Impact Assessment Review, vol. 2022, Elsevier. sciencedirect.com

227. R. Vishwakarma, P. Singh, and Y. Singh, "Methods and Applications of Environmental Impact Assessments," *Energy, Ecology, and …*, 2025. researchgate.net

228. T. Kamijo, "How to enhance EIA systems in developing countries: a quantitative literature review," Environment, . [HTML]

229. A. Fonseca, "Introduction to the handbook of environmental impact assessment," Handbook of environmental impact assessment, 2022. [HTML]

230. R. Hasan, "Enhancing stakeholder engagement in project management through ai-driven predictive modeling," 2024. harrisburgu.edu

231. [231, 1] D. H. Daudelin, "Stakeholder engagement in predictive model development for clinical decision support," in *Broadly Engaged Team Science in Clinical and …*, Springer, 2022. [HTML]

232. M. Abdeldayem, A. Baqi, and S. Aldulaimi, "Empowering stakeholder engagement and decision-making in future nuclear organisations: a multilevel research framework for challenges and opportunities," *International Journal of …*, 2025. researchgate.net

233. S. Yan and R. B. Ibrahim, "Exploring the Factors That Influence Stakeholder Participation in Decision- Making for the Moat System Restoration Project in Tianchang City, China," The Scientific World Journal, 2023. wiley.com

234. A. Breusova, "Green Economy and Sustainable Development: A New Paradigm for Traditional Business Models," Reliability: Theory & Applications, 2024. cyberleninka.ru

235. S. Khalid, I. Stecenko, Z. Kadirova, A. Nurieva, "Sustainable development goals through the triad of green economy, growth, and deal," in *Proceedings of the …*, 2023. scitepress.org

236. L. C. King, I. Savin, and S. Drews, "Shades of green growth scepticism among climate policy researchers," Nature Sustainability, 2023. ssrn.com

237. L. Susskind and A. Kim, "Building local capacity to adapt to climate change," Climate Policy, 2022. [HTML]

238. E. Carmen, I. Fazey, H. Ross, M. Bedinger, F. M. Smith, "Building community resilience in a context of climate change: The role of social capital," Ambio, vol. 51, no. 1, pp. 1-12, 2022. springer.com

239. R. Steiger, N. Knowles, K. Pöll, and M. Rutty, "Impacts of climate change on mountain tourism: A review," *Journal of Sustainable …*, 2024. tandfonline.com

240. B. S. Ngcamu, "Climate change effects on vulnerable populations in the Global South: a systematic review," Natural Hazards, 2023. springer.com

241. B. Wisner, "Assessment of capability and vulnerability," in *Reflecting on Ben Wisner's Contributions to …*, 2025. [HTML]

242. J. Lanlan, M. N. I. Sarker, I. Ali, R. B. R. Firdaus, and others, "Vulnerability and resilience in the context of natural hazards: a critical conceptual analysis," Environment, vol. 2024, Springer. researchgate.net

243. J. X. Kasperson, R. E. Kasperson, B. L. Turner, *et al.*, "Vulnerability to global environmental change," in *Social contours of …*, 2022. [HTML]

244. HA Mirdda, S. Bera, and R. Chatterjee, "Vulnerability assessment of mountainous households to landslides: A multidimensional study in the rural Himalayas," *International Journal of Disaster Risk*, vol. 2022, Elsevier. [HTML]

245. B. Sowińska-Świerkosz and J. García, "What are Nature-based solutions (NBS)? Setting core ideas for concept clarification," Nature-Based Solutions, 2022. sciencedirect.com

246. A. Scolobig, J. A. Rodriguez, J. Martin, and J. Linnerooth-Bayer, "Governance innovation for the design, financing and

implementation of NBS, and their application to the concept and demonstration projects," 2023. iiasa.ac.at

247. J. Bello, P. Adetoro, I. Mogaji, *et al*., "Exploring the feasibility and benefits of integrating nature-based solutions in stealth construction practices," *Intelligent Buildings*, 2024. researchgate.net

248. S. E. Debele, L. S. Leo, P. Kumar, J. Sahani, *et al*., "Nature-based solutions can help reduce the impact of natural hazards: A global analysis of NBS case studies," *Science of the Total Environment*, vol. 2023, Elsevier. sciencedirect.com

249. Y. Beco, "Mainstreaming Institutional Policy and Frameworks of Disaster Risk Management in Ethiopia: Challenges and Prospects," 2024. ethernet.edu.et

250. G. Sisay, A. Sefene, A. Kassaw, D. Getachew *et al*., "Sendai framework for disaster risk management: practices and challenges against the targets in Ethiopia," Natural Hazards, 2025. [HTML]

251. K. Jacobsen, J. B. Hollander, S. R. Sternlieb, "Urban policy responses to climate hazards in Addis Ababa, Ethiopia," City and Environment, vol. 2024, Elsevier. sciencedirect.com

252. T. L. Addis, B. S. Birhanu, and T. Z. Italemahu, "Effectiveness of urban climate change governance in Addis Ababa City, Ethiopia," Urban Science, 2022. mdpi.com

253. M. De Sisto, C. Shearing, T. Heffernan, "Reshaping disaster management: An integrated community- led approach," Public Administration, 2024. wiley.com

254. D. Sanderson, T. Heffernan, M. DeSisto, and C. Shearing, "Community- centred disaster recovery: A call to change the narrative," Disasters, 2025. wiley.com

255. D. Josè Moisès, N. Kgabi, and O. Kunguma, "Integrating “top-down” and “community-centric” approaches for community-based flood early warning systems in Namibia," Challenges, 2023. mdpi.com

256. D. Sanderson, T. Heffernan, M. DeSisto, "Community-centred disaster recovery," 2025. anu.edu.au

257. J. Jiang, J. Zhang, P. Cui, and X. Luo, "Influence Mechanism of Land Use/Cover Change on Surface Urban Heat Islands and Urban Energy Consumption in Severely Cold Regions," Land, 2025. mdpi.com

258. M. D. Biru, "Impact analysis of forest and peatland landscape change: Socio-economic and environmental implications," Jurnal Bisnis Kehutanan dan Lingkungan, 2025. journal-iasssf.com

259. T. Niskanen, M. Pitkänen, A. Puscasu, A. Saraman, and A. Xu, "Living Corridors: Reclaiming the Landscape of Kumasi, Ghana," 2025. aalto.fi

260. K. E. Clark, V. D. Bravo, S. N. Giddings, K. A. Davis, "Land use and land cover shape river water quality at a continental caribbean land-ocean interface," *Frontiers in …*, 2022. frontiersin.org

261. F. Farida, "Supply Chain Management Strategy to Increase Product Availability," Jurnal Info Sains: Informatika Dan Sains, 2023. seaninstitute.or.id

262. R. L. Rajani, G. S. Heggde, and R. Kumar, "Demand management approaches in services sector and influence on company performance," *Management*, vol. 2023, 2023. researchgate.net

263. H. Kamyab, T. Khademi, S. Chelliapan, *et al*., "The latest innovative avenues for the utilization of artificial Intelligence and big data analytics in water resource management," *Results in Engineering*, vol. XX, pp. YY-ZZ, 2023. sciencedirect.com

264. M. S. Bakare, A. Abdulkarim, M. Zeeshan, and A. N. Shuaibu, "A comprehensive overview on demand side energy management towards smart grids: challenges, solutions, and future direction," Energy Informatics, 2023. springer.com

265. P. K. Ozili, "Sustainability and sustainable development research around the world," Managing Global Transitions, 2022. upr.si

266. F. Hermundsdottir and A. Aspelund, "Competitive sustainable manufacturing-Sustainability strategies, environmental and social

innovations, and their effects on firm performance," Journal of Cleaner Production, 2022. sciencedirect.com

267. F. Biermann, T. Hickmann, C. A. Sénit, M. Beisheim, *et al.*, "Scientific evidence on the political impact of the Sustainable Development Goals," *Sustainability*, 2022. nature.com

268. C. Free, S. Jones, and M. S. Tremblay, "Greenwashing and sustainability assurance: a review and call for future research," Journal of Accounting Literature, 2025. researchgate.net

269. R. P. Espíndola and N. F. F. Ebecken, "Advances in remote sensing for sustainable forest management: monitoring and protecting natural resources," Revista Caribeña de Ciencias, 2023. revistacaribena.com

270. A. Raj, M. K. Jhariya, A. Banerjee, B. Lal, "Forest for sustainable development," *Management*, vol. 2023, Wiley Online Library. [HTML]

271. P. C. Pandey and M. Pandey, "Highlighting the role of agriculture and geospatial technology in food security and sustainable development goals," Sustainable Development, 2023. [HTML]

272. E. Korol and S. Korol, "Ai-augmented commons governance: Ethical rulemaking and enforcement for sustainable resource management in rural areas," Journal of Business and Management, 2025. al-kindipublishers.org

273. S. W. J. Canty and J. L. Deichmann, "Do small- scale fisheries have the capacity to provide food security to coastal populations?," Fish and Fisheries, 2022. [HTML]

274. M. Alsaleh, "The role of the fishery industry in the shift towards sustainable food security: a critical study of blue food," Environmental Science and Pollution Research, 2023. [HTML]

275. A. N. Tidd, Y. Rousseau, E. Ojea, R. A. Watson, "Food security challenged by declining efficiencies of artisanal fishing fleets: A global country-level analysis," *Food Security*, vol. 2022, Elsevier. sciencedirect.com

276. J. Virdin, X. Basurto, G. Nico, S. Harper, *et al.*, "Fishing for subsistence constitutes a livelihood safety net for populations dependent on aquatic foods around the world," Nature Food, 2023. nature.com

277. N. Wang, N. Cui, J. Hao, and Y. Chai, "The Role of Government Procurement in Sustainable Industry Development-The Trends and Research Agenda," Sustainability, 2025. mdpi.com

278. H. T. Benchekroun, Z. Benmamoun, and H. Hachimi, "Sustainable public procurement for supply chain resilience and competitive advantage," Acta Logistica, 2024. actalogistica.eu

279. O. Manta, M. Panait, E. Hysa, E. Rusu *et al.*, "Public procurement, a tool for achieving the goals of sustainable development," Amfiteatru Economic, 2022. econstor.eu

280. P. F. Johnson and R. D. Klassen, "New directions for research in green public procurement: The challenge of inter-stakeholder tensions," Cleaner Logistics and Supply Chain, 2022. sciencedirect.com

281. K. Zhou, F. Kong, H. Yin, and G. Destouni, "Urban flood risk management needs nature-based solutions: a coupled social-ecological system perspective," *Urban Sustainability*, 2024. nature.com

282. B. Li, "The role of financial markets in the energy transition: An analysis of investment trends and opportunities in renewable energy and clean technology," Environmental Science and Pollution Research, 2023. [HTML]

283. A. Raihan, "A review of the global climate change impacts, adaptation strategies, and mitigation options in the socio-economic and environmental sectors," Journal of Environmental Science and Economics, 2023. academia.edu

284. A. Dilanchiev, F. Nuta, I. Khan, and H. Khan, "Urbanization, renewable energy production, and carbon dioxide emission in BSEC member states: implications for climate change mitigation and energy markets," *Environmental Science and …*, vol. XX, no. XX, pp. XX-XX, 2023. nih.gov

285. R. Wang, Y. Sun, J. Zong, Y. Wang, X. Cao, and Y. Wang, "Remote sensing application in ecological restoration monitoring: A systematic review," Remote Sensing, 2024. mdpi.com

286. L. Liu, M. Chen, P. Luo, W. Duan *et al.*, "Quantitative model construction for sustainable security patterns in social-ecological links using remote sensing and machine learning," Remote Sensing, 2023. mdpi.com

287. AB Ahmadi, M Mohammadi, "Unveiling the complexity of Earth's dynamic ecosystems: harnessing the power of remote sensing for environmental analysis," Journal of Earth, 2023. [HTML]

288. D. Yu and C. Fang, "Urban remote sensing with spatial big data: A review and renewed perspective of urban studies in recent decades," Remote Sensing, 2023. mdpi.com

289. M. M. Nizamani, Q. Zhang, G. Muhae-Ud-Din, "Application of GIS and remote-sensing technology in ecosystem services and biodiversity conservation," in *Deep learning for …*, 2024. researchgate.net

290. B. Calka and M. Szostak, "GIS-Based Environmental Monitoring and Analysis," Applied Sciences, 2025. mdpi.com

291. L. Parra, "Remote sensing and GIS in environmental monitoring," Applied Sciences, 2022. mdpi.com

292. M. Shaikh and F. Birajdar, "Advancements in remote sensing and GIS for sustainable groundwater monitoring: applications, challenges, and future directions," *International Journal of Research in …*, 2024. researchgate.net

293. X. Liu, D. Lu, A. Zhang, Q. Liu, and G. Jiang, "Data-driven machine learning in environmental pollution: gains and problems," *Environmental Science & Technology*, vol. 2022, pp. 1-10. [HTML]

294. W. W. Hsieh, "Evolution of machine learning in environmental science-A perspective," Environmental Data Science, 2022. cambridge.org

295. TNN Chowdhury, AY Battamo, R Nag, "Impacts of climate change on groundwater quality: a systematic literature review of analytical models and machine learning techniques," Environmental..., 2025. iop.org

296. H. Zhang, H. Li, X. Xu, X. Lv, J. Peng, and Q. Weng, "Comprehensive assessment of the water environment carrying capacity based on machine learning," *Journal of Cleaner Production*, vol. 2024, Elsevier. [HTML]

297. L. Wang, J. Zhang, H. Yang, Z. Y. Chen, and J. Tang, "User behavior simulation with large language model-based agents," ACM Transactions on ..., 2025. acm.org

298. W. Hua, L. Fan, L. Li, K. Mei, J. Ji, Y. Ge, and L. Hemphill, "War and peace (waragent): Large language model-based multi-agent simulation of world wars," arXiv preprint arXiv:XXXX.XXXX, 2023. [PDF]

299. J. Tang, H. Gao, X. Pan, L. Wang, H. Tan, "Gensim: A general social simulation platform with large language model based agents," in *Proceedings of the …*, 2025. aclanthology.org

300. I. M. Hernández-Ochoa, T. Gaiser, K. C. Kersebaum, "Model-based design of crop diversification through new field arrangements in spatially heterogeneous landscapes. A review: Model-based design of crop …," Agronomy for Sustainable Development, vol. 42, no. 1, 2022. springer.com

301. K. U. Ehigiamusoe, M. T. Majeed, and E. Dogan, "The nexus between poverty, inequality and environmental pollution: evidence across different income groups of countries," Journal of Cleaner Production, 2022. [HTML]

302. A. Amin, Z. Wang, A. H. Shah, and A. A. Chandio, "Exploring the dynamic nexus between renewable energy, poverty alleviation, and environmental pollution: fresh evidence from E-9 countries," *Environmental Science and …*, vol. 2023, Springer. [HTML]

303. S. D. Ssekibaala and T. A. Kasule, "Examination of the poverty-environmental degradation nexus in Sub-Saharan Africa," Regional Sustainability, 2023. sciencedirect.com

304. A. Awad and M. H. Warsame, "The poverty-environment nexus in developing countries: Evidence from heterogeneous panel causality methods, robust to cross-sectional dependence," Journal of Cleaner Production, 2022. [HTML]

305. Y. O. Nesterov, "Green Economy in the Paradigm of Sustainable Development," in *Economics, Sustainability, Leadership and Innovation*, 2022. besli.org

306. N. Trushkina, "Green economy in the conditions of modern challenges: conceptual frameworks," Science Journal of Management, Economics & …, 2022. isg-journal.com

307. M. Adamowicz, "Green deal, green growth and green economy as a means of support for attaining the sustainable development goals," Sustainability, 2022. mdpi.com

308. N. Houssam, D. M. Ibrahiem, S. Sucharita, and K. M. El-Aasar, "Assessing the role of green economy on sustainable development in developing countries," Heliyon, 2023. cell.com

309. C. Batcup, M. Breth-Petersen, T. Dakin, A. Barratt, *et al.*, "Behavioural change interventions encouraging clinicians to reduce carbon emissions in clinical activity: a systematic review," BMC Health Services Research, vol. 23, 2023. springer.com

310. A. M. van Valkengoed, W. Abrahamse, and L. Steg, "To select effective interventions for pro-environmental behaviour change, we need to consider determinants of behaviour," Nature human behaviour, 2022. rug.nl

311. T. Ercan, N. C. Onat, N. Keya, O. Tatari, and N. Eluru, "Autonomous electric vehicles can reduce carbon emissions and air pollution in cities," *Transportation Research Part D: Transport and Environment*, vol. 2022, Elsevier. qu.edu.qa

312. A. Altassan, "Sustainable integration of solar energy, behavior change, and recycling practices in educational institutions: a

holistic framework for environmental …," Sustainability, 2023. mdpi.com

313. S. Chandeliya, "Transition of India's Early Childhood Care and Education System Compared to Emerging Nations," Available at SSRN 5467396, 2025. ssrn.com

314. S. Ahn, J. Zhou, D. Jiang, S. Kerr, Y. Zhu, "WHO global research priorities for traditional, complementary, and integrative (TCI) medicine: an international consensus and comparisons with LLMs," Journal of Global ..., 2025. nih.gov

315. NTT Mai, IF Wilderspin, and DTT Hong, "Creating Sustainable and Friendly Urban Spaces in Viet Nam Through Effective Stakeholder Engagement," in *Conference series on …*, 2024, Springer. [HTML]

316. R. Nyonje and H. Kidombo, "Kenya Country Report," 2024. adeanet.org