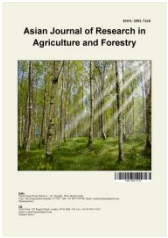

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Impact of Climate Change on the Environment: A Synthesis Study

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Climate change has a significant impact on both physical and social components of the environment. Every component of the environment has been suffering the impacts of climate change. All components of the environment are interrelated through the exchanging of energy and matter; hence they actively interact. Major components of the environment like the biosphere,

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lithosphere, atmosphere, and hydrosphere are open systems to impact climate change. This paper describes the major impacts of climate change on major components of the environment. This study investigated the current state, wide-range global research trends, and different concerns on the impacts of climate change on the sustainable tourism. Global climate change represents a grand challenge for society, one that is increasingly influencing tourism sector investment, planning, operations, and demand. This study synthesized a total of 36 studies on climate change by sourcing published material from the review that was performed in indexed databases namely Dimensions, Web Science, Elsevier Scopus, and Google Scholar. Therefore, the study found that human beings are the major contributors to climate change through anthropogenic greenhouse gas emissions that worsened during the Green Revolution. Climate change outcomes through the loss of valuable ecosystem goods and services, degrading the most of keystone species sites. In other ways, loss of biodiversity, changes in atmospheric composition, changes in chemical reactions in soil, changes in water quality, availability, and hydrologic cycles, and frequent occurrence of extreme weather conditions. Of course! The effects of climate change are wide-ranging and diverse, impacting many areas and facets of daily life. Therefore, this study recommends implementing carbon pricing mechanisms to internalize the costs of greenhouse gas emissions and enforcing stringent environmental regulations and standards to limit emissions and pollution. Support global efforts and agreements to combat climate change, such as the Paris Agreement.

Keywords: Climate change; carbon dioxide; environmental components; greenhouse gases.

1. INTRODUCTION

Climate change is defined as the average state of the weather conditions prevailing in a region over a long period. The Intergovernmental Panel on Climate Change (IPCC) refers to climate change as" the state of the climate that can be identified statistically by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer" [1]. "Climate change may also threaten key natural resources, affecting water and food security which can trigger conflict, mass migration, health impacts, death, and environmental stresses" [2]. "Climate change has significant and broad impacts on the environment; changes in climate cause increased temperature, sea level rise, change in precipitation, and more frequent or intense extreme events that in turn affect human needs such as food, water, shelter, and health" [3,4]. "Although climate change is an inherently global issue, the impact is not felt equally across the globe. Impacts are likely to differ in continents, countries, and regions. Some nations are experiencing more adverse effects than others" [5].

"Climate change poses a major and growing threat to global food security. The expected effects of climate change – higher temperatures, more frequent extreme weather events, water shortages, rising sea levels, ocean acidification, land degradation, the disruption of ecosystems, and the loss of biodiversity – could seriously compromise agriculture's ability to feed the most vulnerable, impeding progress towards the eradication of hunger, malnutrition, and poverty. Action is urgently needed, therefore, to prepare crop and livestock production, fisheries, and forestry for the prospect of rapidly changing environmental conditions and to reduce agriculture's contribution to the greenhouse gas (GHG) emissions responsible for global warming" (Fig. 1) [6].

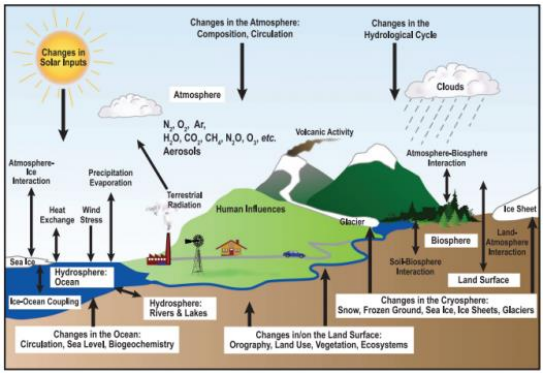

Fig. 1. Climate processes

"Through its impacts on agriculture, climate change will exacerbate the negative effects of all those trends and will make it even more difficult to meet the key Sustainable Development Goals of ending hunger, achieving year-round food security, and ensuring sustainable food production systems by 2030. In the longer term, the magnitude and speed of climate change, and the effectiveness of economy-wide mitigation

efforts and adaptation in agriculture, will be critical to the future of large segments of the world's population and, possibly, to humanity at large" [6].

"Global estimates predict major losses of biodiversity due to global climate change [7], which is generally higher than the current rate of loss and much higher than rates of species extinctions documented in fossil records" [8]. "One of the first global studies estimated that by 2050; 15-37% of species will undergo extinction under intermediate climate change, Malcom and colleagues stated in 2006 that the extinction rate of endemic species could reach up to 39-43% under worst case scenarios which represent a potential loss of 56000 endemic plant species and 3700 endemic vertebrate species" [9,8]. Therefore, this study highlights the impacts of climate change on the environment based on previous studies.

2. IMPACT OF CLIMATE CHANGE ON MAJOR ENVIRONMENTAL COMPONENTS

2.1 Impacts of Climate Change on Agriculture and Related Impacts on Human Beings

"Agriculture is a sector that has been facing impacts from climate change. Heat stress, drought, and flooding events may lead to a reduction in crop yields and livestock productivity. Agriculture is important for food security in two ways: first, it produces the food people eat; secondly, it provides the primary source of livelihood for 36% of the world's total workforce. In the heavily populated countries of Asia and the Pacific, this share ranges from 40-50%, and in sub-Saharan Africa; two-thirds of the working population still; make their living from agriculture" [10]. "If agricultural production in the low-income developing countries of Asia and Africa is adversely affected by climate change, the livelihood of a large number of the rural poor will be put at risk and their vulnerability to food insecurity can be increased. However, in many low-income countries with limited financial capacity to trade and high dependence on their production to cover food requirements, it may not be possible to offset declines in local supply without increasing reliance on food aid. Evidence indicates that more frequent and more intense extreme weather events (droughts, heat, cold waves, heavy storms, floods, rising sea levels, and increasing irregularities in seasonal rainfall patterns are having immediate impacts on food products and hurting human beings directly. Due to climate change an average of 500 weather-related disasters are now taking place each year compared with 120 in the 1980^{s}; the number of floods has increased sixfold over the same period" [4].

2.2 Impacts of Climate Change on Human Health

"The prevalence of some tropical diseases and other threats to human health depend largely on the local climate. According to the Intergovernmental Panel on Climate Change, extreme temperatures can lead directly to the loss of life, while climate-related disturbances in ecological systems can directly impact the incidence of infectious diseases such as water-borne and air-borne" [11]. "On the other hand, warm temperatures can increase air and water pollution, which in turn harm human health. Extreme weather events destroy shelter, contaminate water supplies, cripple crop and livestock production, and tear apart existing health and other service infrastructures. This will ultimately increase the existing burden of disease and other non-health needs of vulnerable human communities. The magnitude and nature of climate change's impact on human health depend on the relative vulnerability of population groups to the extent and duration of exposure to the climate itself and society's ability to adapt or cope with the change" [1]. The risk of emerging disease may increase due to changes and survival of pathogens in the environment, changes in migration pathways of carriers and vectors, and changes in the natural ecosystem. The increased frequency of drought and flooding is likely to increase the frequency and magnitude of epidemics or waterborne diseases as well as influence the incidence of vector-borne diseases.

"Climate-sensitive diseases, like vector-borne diseases, are sensitive to climate change because temperature and precipitation changes can alter vector development rates shift their geographical distribution, and alter transmission dynamics attributable to rising global temperatures" [12]. "Vector-borne and water-borne diseases are known to be climate-sensitive diseases. The IPCC has noted that the global population is at risk from vector-borne diseases will increase between 220 million to 400 million in the next century, this increase is predicted to occur in Africa" (Figure 2)[13]. "Climate change

directly affects disease transmission by shifting the vector's geographic range and increasing reproductive and biting rates by shortening the pathogen incubation period. Malaria is by far the most important vector-borne disease-causing high morbidity and mortality in Sub-Saharan Africa.

Fig. 2. Effect on soil and crops

However, due to changes in socio-economic, environmental, and vector-related factors, the disease is now common in previously malaria-free highland areas" [14]. According to a study conducted in Tanzania, modeling malaria endemicity using an outpatient case (2004-2008) about mean temperature and mean precipitation has shown that almost the whole of Tanzania is endemic for malaria. The disease is prevalent throughout the tropics and subtropics and is very important in highly urbanized communities with poorly managed water and solid waste systems.

Climate change effects on human health can be divided into primary, secondary, and tertiary. Primary effects are heat waves, fever, cold waves, injuries, floods, and fires, while secondary effects are infectious diseases, especially vector-borne, allergies, and air pollution. Tertiary effects are; famine, conflicts, population displacement, and refugees.

2.3 Impact of Climate Change on Biodiversity

"Indeed, the changing climate results in endangering and loss of biodiversity, especially in critical ecosystems of the world. One of the widely accepted definitions of biodiversity is the one put forward by the International Union for Conservation of Nature. Which states that biodiversity is the variability among living organisms from all sources including terrestrial, marine, and other aquatic ecosystems and ecological complexes of which they are part; this includes diversity within species and ecosystems" [15]. "Biodiversity is affected by climate change at different levels from low land to high mountains and from small rivers to deep seas. Extinction can disrupt the fundamental ecological processes" [16]. "In the case of the mountain environment, the effects of climate change can be observed through snow cover loss, melting permafrost, receding avalanches, and landslides. Similarly, the loss of biodiversity is one of the most significant aspects of global environmental changes, given the extent to which it undermines the global economy and human welfare" [17]. Although threatened and endangered species at vulnerable locations such as in polar regions and the high Mountains have uncertain life or existence, they play a major role in controlling the functioning of the ecosystems. Current climate projection indicates that more ecological change will occur in the coming decades. Species behaviors are altering and disrupting at an excessive role which has already been seen in the past and this process is continuing at present and may remain in the future. The earth's terrestrial system has been extensively altered by human activity significantly contributing to climate change. According to the report by Millennium Ecosystem Assessment, nearly 75% of the Mediterranean and Temperate forests have been adopted by human activity whereas five out of thirteen biomes analyzed showed 50% conversion on average among a few. Similarly, marine ecosystems experience adverse effects posed by the impacts of climate change. Marine ecosystems are of huge importance to the biology of the planet because they are among the largest of all the health of both marine and terrestrial environments. Coastal estuaries revealed that 80% of the largest vertebrates and blue whales, 90% of ouster, 65% of sea grass, and 67% of wetlands were lost due to the changes in climatic variation weather patterns.

"Freshwater ecosystems may well be the most endangered ecosystems in the world due to climate change. They are biologically rich and play major roles in providing ecosystem services to a greater magnitude" [18]. "Freshwaters are principally vulnerable to climate change because many species within these fragmented habitats have limited abilities to disperse as the

environment changes, water temperature and availability are climate dependent, and many systems are already exposed to various anthropogenic stressors such as contaminants and pollutants. Extinction rates and extirpations of freshwater species either match or exceed those suggested for better-known terrestrial taxa" [19]. The degree of alteration of river and lake systems by humans is clear. Humans have been exploiting freshwater systems for drinking water, transportation, irrigation, and power generation. However, proper attention has not been given to other ecosystem services that this system provides, such as temperature regulation, water purification, erosion and flood control, and cultural services.

2.4 Impact of Climate Change on the Atmosphere

"Anthropogenic leads to an increase in the concentrations of greenhouse gases and aerosols that perturb the Earth's energy amounts and cause a radiative forcing of the climate system. Collectively, greenhouse gases and aerosols can be considered radiative forcing agents, which lead to either increased (positive forcing) or decreased (negative forcing) global mean temperature, with associated changes in other aspects of climate such as precipitation and sea level rise. The concentrations of the major greenhouse gases carbon dioxide, methane, and nitrous oxide have increased due to human activities, and ice core data show that these gases have now reached concentrations not experienced on Earth in at least several thousand years" [20]. "The recent rates of increase in CO_2, CH_4, and N_2O are unprecedented in at least 20,000 years" (Joos & Spahni, 2008). Atmospheric CO_2 concentration has crossed from 280 to 400 ppm while Methane concentration increased from 800 to 1800 PPb and Nitrous oxide concentration increased from 270 to 320 PPb, IPCC 5th Assessment Report (2018).

"The abundances of CO_2, N_2O, and CH_4 are well-mixed over the globe, and hence their concentration changes radiative and the greenhouse effects. Tropospheric ozone has also increased largely as a result of emissions of antecedent from nitric oxide and organic molecules including volatile methane. The short atmospheric lifetimes of aerosols and tropospheric ozone lead to very large variations in their abundances depending upon proximity to local sources and transport, increasing the uncertainty in estimates of their global mean and forcing their spatial distribution. Shortwave-absorbing aerosols change the vertical distribution of solar absorption" [21], causing energy that would have been absorbed at the surface and communicated upward by convection to be directly absorbed in the atmosphere instead; this can potentially lead to changes in precipitation and atmospheric gas circulation even in the absence of warming.

2.5 Impact of Climate Change on the Lithosphere

"Chemical weathering of rocks by carbon dioxide dissolved in rainwater has never been taken into account in models of future climate change so far. However, researchers from the Laboratoire Géosciences Environnement Toulouse, in collaboration with the Laboratoire des Sciences du Climat et de l'Environnement and the University of Bergen (Norway), demonstrated its sensitivity; the higher the carbon dioxide levels in the atmosphere, the more powerful the carbon sink, which accelerates the dissolution of rocks" [22]. The carbon dioxide in the atmosphere dissolves in rainwater forming carbonic acid, which, once in contact with rocks, slowly dissolves them. A study conducted on one of the biggest arctic water sheds, the Mackenzie River basin located in northwest Canada shows that when the amount of atmospheric CO_2 rose from 355 PPmv (at the end of the twentieth century) to 560 PPmv (by 2100), the Mackenzie River basin responded by capturing 50% more atmospheric CO_2 through chemical weathering. From this increment 40% of this increase is directly linked to climate change, higher temperatures and rainfall accelerate mineral dissolution, while the remaining 60% is put down to changing vegetation activity. Higher atmospheric CO_2 levels reduce evapotranspiration in plants, which intensifies the circulation of water in soils.

"Soil is another important terrestrial component that can be influenced by climate change. Significant and abrupt changes in daily, seasonal, and inter-annual temperature; changes in the wet/dry cycles; intensive rainfall and heavy storms; extended periods of drought; extreme frost; heat waves and increased fire frequency, are expected to significantly impact terrestrial systems, soil properties, surface water and stream-flow" [6]. "The results from a 44-year field study show that weathering rates are already

increasing because of global warming" [23]. "However, the spatial patterns, temporal trends, and controlling factors of the processes and reactions and their effects on different scales, especially regional, continental, and global scales, are not fully understood at this time. In another way the dissolution of atmospheric CO_2 gas in soil water and the subsequent formation of carbonic acid followed by its dissociation causes a decrease in soil pore water pH as a result of aqueous phase proton enrichment through the following chemical reaction: $CO_2(g) + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3\text{-}(aq) + H+(aq)$. The organic matter content of soils is one of the most important soil properties that define soil fertility and, to a large extent, control the chemical and biological behavior of the soil system. Organic carbon incorporated into SOM may play a major role in controlling soil behavior as a sink or source of atmospheric CO_2, thus contributing significantly to the global carbon cycle". (Ghee et al., 2013) "The predicted climate change and the need for a more unified approach to mitigate greenhouse gas emissions, the soil's ability to sequester and release carbon into the atmosphere, and thus to act as a carbon sink or source for atmospheric CO_2, has received growing attention" [24]. For example, enhanced soil respiration in response to global warming may substantially increase atmospheric CO_2 concentrations above the anthropogenic contribution, depending on the mechanisms underlying the temperature sensitivity of soil respiration.

2.6 Impacts of Climate Change on Hydrosphere

"The water resource is a very important component of the environment that is vital for living things and the existence of balanced systems on the earth. The impacts of climate change on the hydrosphere can be seen from the quantity and quality of water that exists under the ground, on the surface, and in the atmosphere as well as changes in the water cycle" [25]. "In terms of water availability, projected effects include more seasonal and higher intensity rainfall; increasing seasonality of river flows; modification of groundwater recharge patterns; and risk of significant reduction in the volume of reliable surface water resources. Implications include reductions in the reliability of rainwater harvesting schemes; greater need for and reliance on both natural and man-made water storage; the potential breaching of damage to low-capacity sewage and drainage systems; and increased dependence on groundwater in Africa and South Asia to meet future water demand. The hydrologic cycle, often called the water cycle, is one of the main components of the planetary system regulating human, animal, and plant life. This cycle also forms the foundation of other cycles, such as carbon cycle, nitrogen cycle, etc. Therefore, the stability of the water cycle is critical for the sustainability of biological populations and ecosystems. The hydrologic or water cycle describes a natural set of continuous and dynamic processes through which water masses in the form of liquid, vapor, or solid, move, circulate, and are stored within the earth system" [26]. "This cycle controls the circulation and the state of moisture within the atmosphere, the biosphere transpiration, the cryosphere, the pedosphere, and the lithosphere. The movement of water is driven by different energy gradients, including gravity, pressure, and temperature as well as the difference of concentration e.g., stomatal conductance for plant transpiration. In sum, the water cycle embeds several terrestrial phenomena among which we can list evapotranspiration, surface water flow, groundwater flow, and water storage glaciers, ice covers, and aquifers. The changes may be examined by focusing on the main components of the water budget, namely precipitation, infiltration including groundwater flux and base-flow, runoff, and evapotranspiration" [25]. However, the disturbances caused by climate change are also sensed with different magnitudes, depending on the component targeted, the time, and the location. For instance, some regions of the globe experience a decreasing trend of precipitation amount. At the same time, several regions are reported with extraordinary peaks of precipitation, while others are still having stable precipitation patterns.

2.7 Impacts of Climate Change on the Global Economy

"The overall aggregate effect of climate change on economic growth will most likely be negative in the long run. Although there will be winners and losers from climate change at varying levels of warming, the impact of rising temperatures will be widespread, in part due to the financial, political, and economic integration of the world's economies" [27]. "Global warming will primarily influence economic growth through damage to property and infrastructure, lost productivity, mass migration, and security threats. For instance, Hurricane Sandy, which flooded much

of New York in 2012, are prime example of the economic damage such extreme weather events can cause. Rising sea levels will also likely harm economic output as businesses become impaired and people suffer damage to their homes" [28]. "While the initial economic response to recover this damage may be positive for GDP when it is possible to do so, once it is recognized that such events are a permanent feature of the environment, the world economy faces an extreme challenge. Many will find that it is not worth replacing capital stock unless measures can be taken to prevent future damage, or there is an opportunity to move the business to safer ground. At best, this could involve a short period of disruption as businesses relocate and; at worst, a permanent loss of capital stock and output. The biggest threat climate change poses to economic growth is from immediate, aggressive, and inefficient mitigation policies. Agricultural yields are sensitive to weather conditions and as our climate becomes ever more extreme, more frequent droughts may reduce crop yields in areas where food production is vital. We must acknowledge that these effects will be partially offset as other regions become suitable for crop production and new drought-resistant crops are developed. However, in aggregate, and as the level of warming becomes even greater, food price inflation should rise. Rising inflation may also materialize through reduced land availability" [29]. "The surge in global temperatures may eventually cause some areas of the world to become inhabitable and with this will come mass migration [30]. As our climate becomes more extreme, we are likely to demand greater energy to both cool our working and living environments during the summer and heat them when we experience harsher winters. Not only will energy demand change, but supply may shrink as the efficiency of existing power stations is compromised due to higher temperatures" [31].

2.8 Impacts of Climate Change on Sustainable Tourism

The intricate relationship between climate change and tourism is multifaceted and poses significant challenges to the industry's sustainability and competitiveness. Climate change is already reshaping tourism investments, planning processes, and operational strategies. The direct impacts of climate change, such as rising temperatures, changing precipitation patterns, and sea-level rise, directly affect tourist destinations and activities. Indirectly, extensive policy responses to climate change further influence tourism dynamics, altering the geographical distribution and attractiveness of destinations [32].

The repercussions of climate change extend beyond environmental aspects to economic, social, and cultural dimensions of tourism. Economic growth in many regions could be impeded, leading to increased water and food insecurity and displacement of populations. Ecosystems are under threat, impacting biodiversity and cultural heritage sites. Transportation costs may rise due to changing conditions, affecting travel patterns and accessibility. These challenges are compounded by interactions with other macro-scale drivers of tourism, such as globalization and technological advancements [33].

While climate change presents risks, it also creates opportunities for innovation and adaptation in tourism. Sustainable practices, eco-friendly tourism initiatives, and resilient infrastructure development are crucial responses to mitigate the adverse effects. However, the impacts of climate change on tourism will vary by market segment and geographic region. Addressing these challenges requires coordinated efforts among governments, tourism stakeholders, and communities to ensure the long-term viability and sustainability of the tourism sector in a changing climate [34].

Climate change poses significant challenges to sustainable tourism worldwide. Rising temperatures, sea-level rise, extreme weather events, and ecosystem disruptions threaten iconic tourist destinations. Coral reefs, glaciers, and coastal areas face degradation, impacting biodiversity and tourist experiences. Changes in precipitation patterns affect water availability for activities like skiing or rafting. Shifts in wildlife behavior and habitats can alter safari experiences. Sustainable tourism efforts must prioritize climate resilience, reducing carbon footprints, and conserving natural resources to mitigate these impacts and ensure long-term viability [35].

In Africa, climate change impacts on sustainable tourism are pronounced. Countries rely heavily on wildlife-based tourism, which is vulnerable to habitat loss and wildlife displacement due to climate shifts. Droughts and water scarcity affect iconic landscapes like savannahs and wetlands. Coastal erosion threatens beach resorts and

marine ecosystems. African nations are increasingly investing in climate adaptation strategies, such as eco-friendly accommodations and community-based tourism initiatives. Sustainable tourism in Africa requires integrated approaches that balance economic development with conservation and climate resilience [35].

In Uganda, climate change is impacting sustainable tourism, particularly its renowned national parks and wildlife reserves. Changing rainfall patterns and temperature variations affect vegetation, wildlife habitats, and water resources critical for tourism activities like gorilla trekking and safari tours. Deforestation and land degradation threaten biodiversity and ecosystem health. The government is implementing strategies to promote sustainable tourism, including community engagement and climate-resilient infrastructure. Conservation efforts are essential to safeguard Uganda's tourism sector from climate-related risks while ensuring long-term economic benefits and environmental sustainability [36].

3. CONCLUSION

Resilience to climate change needs to be strengthened across biophysical, economic, and social spheres, worldwide. To some degree, adaptation in agriculture will be a spontaneous response by farmers, fisherfolk, and foresters; however, many of them, especially small-scale producers, may face both a lack of feasible options and constraints to adopting appropriate solutions. An enabling environment that facilitates adaptation, therefore, is critical. In the short term, adaptation at the level of the production unit or farm household, where possible, may be sufficient. However, longer-term adaptation is necessary to cope with the changes already “locked in” by past and ongoing increases in the concentration of greenhouse gases in the atmosphere. That will require more systemic changes, such as major shifts in the loci of production of specific products and species, compensated by changes in both trading and consumption patterns. However, adaptation by itself is insufficient – mitigation is essential for ensuring the long-term food security of the world’s population. There is a fundamental difference between adaptation and mitigation and the incentives needed to promote them. Adaptation is something everyone will want to do in their interest. Mitigation is something that has to be done together, in the interests of everyone. It is a global public good and a social responsibility to which the agriculture sectors must also contribute. The recommendations that follow can be used to alleviate and lessen these effects:

Strategies for Mitigation: Encourage and assist the switch from fossil fuels to renewable energy sources, such as hydroelectric, solar, and wind power. Energy Efficiency: Encourage the use of energy-efficient practices and technologies in both homes and businesses. Reforestation and Afforestation: To remove carbon dioxide from the atmosphere, plant more trees and revitalise deteriorated forests. Deforestation Reduction: Put laws in place to stop deforestation, especially in important ecosystems like rainforests.

Adaptation Techniques: Invest in resilient infrastructure so that it can survive the effects of climate change, including storms, flooding, and sea level rise. Water Management: To deal with shifting patterns of precipitation and more water stress, enhance the management of water resources. Crop diversification: Motivate farmers to use climate-resilient agricultural techniques and a variety of crops. Ecosystem conservation refers to the preservation and restoration of natural buffers against the effects of climate change, such as mangroves and wetlands.

Governance and policy; carbon pricing: To internalise the costs associated with greenhouse gas emissions, implement carbon pricing mechanisms. Regulatory frameworks: Limit emissions and pollutants by enforcing strict environmental regulations and standards. International cooperation: Encourage international initiatives and accords, like the Paris Agreement, to tackle climate change. Inclusive Decision-making: Make sure that various stakeholders are included in inclusive and participatory governance processes that entail planning for climate action.

Awareness campaigns: Raise awareness among the general population about the effects of climate change and the significance of individual action.

Education in schools: To empower future generations, incorporate climate change education into school curricula. Building Capacity: Assist communities, corporations, and governments in becoming more resilient to

climate change and capable of adapting to it by offering training and tools.

Invest in climate research: Encourage studies aimed at gaining a deeper understanding of the local and global effects of climate change. Technological development: Promote innovation in climate adaptation strategies, sustainable agriculture, and clean technologies. Data sharing: To support evidence-based decision-making, and promote data sharing and cooperation between scientists, decision-makers, and practitioners.
Justice and equality: Taking Care of Vulnerable communities: Give special attention to the needs of vulnerable groups, such as marginalised areas that are disproportionately impacted by climate change, indigenous populations, and low-income communities. Just-transitions: Assist impacted workers and communities while guaranteeing justice and equity in the shift to a low-carbon economy.

These recommendations take a holistic approach to mitigating the effects of climate change, covering both adaptation (addressing current and future problems) and mitigation (cutting emissions). To achieve significant and long-lasting effects, governments, corporations, civil society organisations, and individuals must work together to implement these strategies.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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