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ARTICLE

Combating Climate Change and Global Warming for a Sustainable Living in Harmony with Nature

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ABSTRACT

As humanity has been polluting the atmosphere with greenhouse gases, the planet is getting warmed up which is triggering the frequency and the intensity of extreme events like heat waves, dry conditions, wildfires, cyclones, tornadoes, lightning, and massive flooding all over the planet Earth. There is considerable evidence that the concentration of greenhouse gases, especially that of CO_2 has steadily increased in the atmosphere as a result of the indiscriminate use of fossil fuels around the world particularly during the last 70 years. The glaciers in the high mountain and polar regions are diminishing fast, sea levels are rising, and food production is being affected severely in certain parts of the world. In fact, the changing climate has currently become one of the major threats to the survival of civilization. The world scientific communities are warning of a climate emergency and requesting the decision makers to promptly respond and act to sustain life on planet Earth. To deliver net zero emissions by the year 2050, the whole world must phase out the technologies such as coal-powered thermal plants and diesel/petrol/gasoline-powered vehicles which release abundant amounts of CO_2 and other greenhouse gases into the atmosphere and invest in the development of clean energies such as hydel, wind, solar, space-solar, and nuclear energies. This transition to a low-carbon economy with the help of these technologies together with other technologies such as hydrogen fuel, fuel cells, electric vehicles, and massive plantations is expected to take our planet Earth to a safe zone in the coming 20-30 years.

Keywords: Greenhouse gases; Ocean acidification; Diminishing of glaciers; Sea level rise; Carbon capture; Direct air capture; Critical minerals in deep-sea

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1. Introduction

Our planet is very complex and delicate in several ways, without taking proper steps to preserve its ecosystem related to life on Earth would not sustain itself. Currently, global warming is one of the biggest threats to the survival of the natural environment and humans with disastrous consequences such as long-term shifts in global weather patterns and temperatures (https://news.un.org/en/story/2022/05/1117842). In fact, the whole world is waging a war against nature for which man himself is responsible. Ever since the industrial revolution started about 150 years back, human activities especially related to power generation and various other industries, transportation, and agriculture have indiscriminately released huge amounts of major greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) into the environment disrupting the natural phenomenon and the delicate ecosystem of the planet (https://www.epa.gov/ghgemissions/overview-greenhouse-gases). Concentrations of these GHGs are currently more abundant in the earth's atmosphere than at any time in the last 800,000 years. In 2021 our planet Earth reached a dark milestone of hitting over 150% of CO_2 value in the atmosphere compared to that of the pre-industrial times (https://www.noaa.gov/news-release/carbon-dioxide-now-more-than-50-higher-than-pre-industrial-levels). According to the National Oceanic and Atmospheric Administration (NOAA), the average surface temperature across land and ocean in 2021 was 0.86 °C warmer than the twentieth-century average of 13.9 °C, and 1.06 °C warmer than the pre-industrial period (https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature). In fact, the experiments conducted by the scientific community even in the 1800s gave hints of human-induced climate change as CO_2 and other gases are capable of altering the earth's climate. But by the 1950s, the subsequently generated data supported the global warming theory [1].

Carbon dioxide and other GHGs were found to be responsible for the increase in the average temperatures of the surface of the earth as well as oceans and their projected continuation due to the greenhouse effect. Further deeper studies indicated that the other general processes such as variations in solar radiation, deviations in the Earth's orbit, volcanic eruptions, mountain-building and continental drift, and changes in GHG concentrations are responsible for changes in the Earth's climate (https://www.bgs.ac.uk/discovering-geology/climate-change/what-causes-the-earths-climate-to-change/). On the other hand, the increased water stress, a rise in the frequency of extreme events such as heatwaves, floods, cyclones, snowstorms, poor agricultural productivity, drought conditions, extinction of different forms of fauna and flora, spreading of new diseases, etc., are the key indicators of climate change (https://climate.ec.europa.eu/climate-change/consequences-climate-change_en). Climate-related studies indicated that increased GHGs concentrations, land and ocean surface temperatures, sea level rise, and ocean acidification are the key indicators of climate change during the past few decades (**Figure 1**). The Intergovernmental Panel on Climate Change (IPCC) is a United Nations body set up in 1988 to assess the science around climate change, and to provide governments with scientific information which can be used to develop policies on reducing global warming. IPCC's 6th Assessment Report (AR6), which details the devastating consequences of GHG emissions around the world, was released in March 2023. It also identifies available, and cost-effective solutions to reduce GHG emissions to secure a safe, liveable future. The average increase in global temperatures is now about 1.1 °C above pre-industrial levels according to the IPCC (2023). To safeguard the Paris Agreement, there is a need to limit global warming to well below 2 °C, and if necessary drastic actions are required to pursue efforts to limit it to 1.5 °C. For example, the Himalayan ecosystem is very delicate and even the slightest changes in the climate can have long-lasting effects on such vulnerable regions [2]. The average global temperature across the year was around 14.9 °C, putting it around 1.2 °C rise above the average (**Figure 2**). The planet Earth

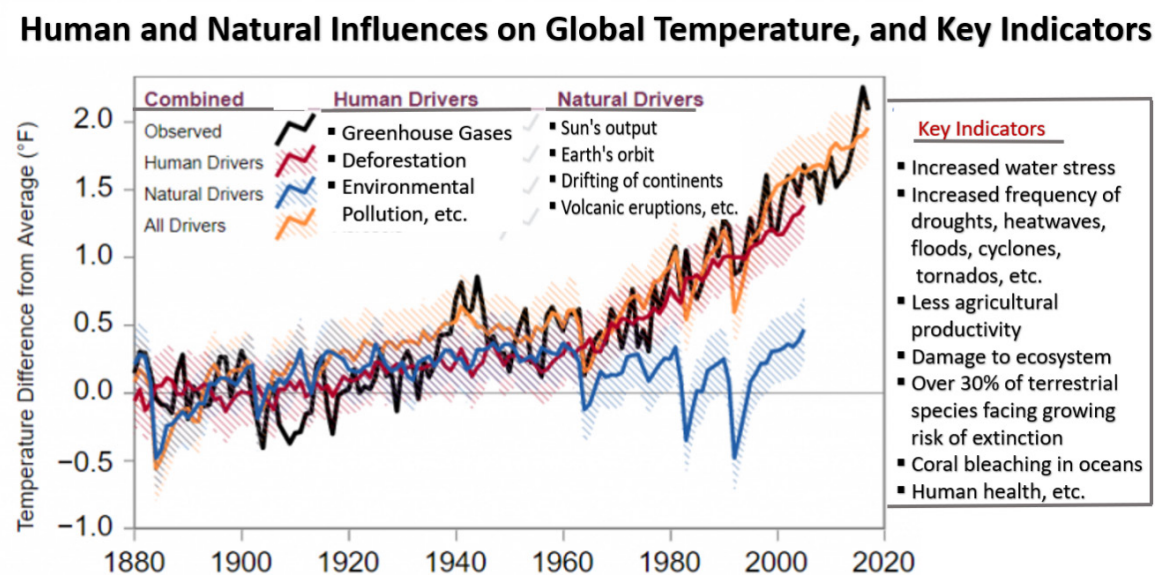

Figure 1. Natural and human factors are responsible for the earth's climate, and key indicators.

Source: Modified after U.S. Global Change Research Program, Fourth National Climate Assessment, Chapter 2: Our Changing Climate, 2017.

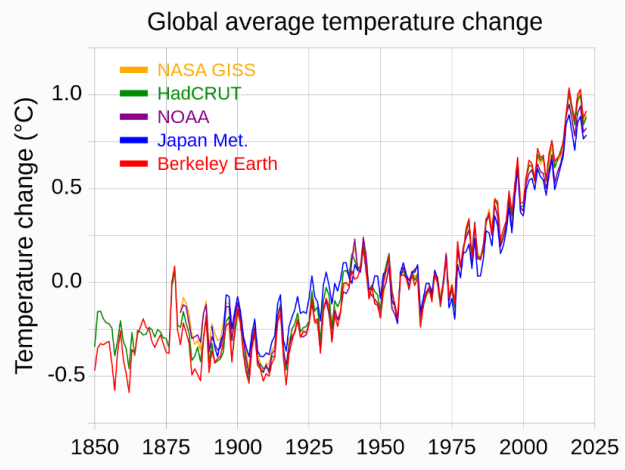

Figure 2. The increase in Earth's average surface temperature with time (from Wikipedia, 2023).

is neither too close nor too far away from the Sun and lies in a "Goldilocks zone" which is just right to support life—not too hot, not too cold with the planet's average surface temperature at 14.9 °C [3]. But currently, with remarkable changes in our climate, a lot of questions are arising. A recent study on a 300-foot-long core of mud from a lakebed high in the Peruvian Andes was found to preserve the history of the deformation and flow of glaciers for more than 700,000 years. This is one of the longest records of historical climate revealing the variations in temperature and precipitation based on geochemical and magnetic studies of the sediment [4]. Human activities such as industries, electric power generation by coal, agriculture, and transportation are the four top sources of GHGs which are responsible for almost all of the increase in greenhouse gases in the atmosphere over the last 150 years [5]. More pieces of evidence are seen in recent times about human-induced climate change [6]. Deforestation, agriculture, and the use of fossil fuels are the primary sources of CO_2. China, India, the US, Russia, and Japan are the biggest emitters of CO_2 in the world today.

2. Greenhouse effect

Between the year 1870 (the first industrial revolution) and today, the increase in global temperature is due to more fossil fuel burning (petroleum oil, natural gas, coal), which also increased the CO_2 levels from 280 ppm in preindustrial time to 423.46 ppm in June 2023 (NOAA, 2023 & https://www.co2.earth/daily-co2). The burning of fossil fuels and indiscriminate cutting of forests increases CO_2 in the atmosphere (15-35 km above the Earth's surface), and the increase in CO_2 causes more heat to be trapped in the Earth's atmosphere as CO_2 has the ability to absorb infrared radiation. As a result, global temperatures are rising. The Earth receives radiation during the

daytime from the Sun which is a flow of infrared radiation. Part of this is reflected back into space by the atmosphere, while the rest warms the planet during the day and is radiated back into space at night (https://earthobservatory.nasa.gov/features/EnergyBalance). During this delicate balance that prevailed in preindustrial times, the incoming heat was exactly offset by the amount lost to space, ensuring average global temperatures remained constant. But unfortunately, today, due to the drastic increase in GHGs, this balance is lost because some of the heat that should be radiated back into space gets trapped inside the atmosphere. Thus, the temperature is constantly rising as the concentrations of CO_2 which has about 82% share among greenhouse gases, along with other greenhouse gases such as CH_4, N_2O, and O_3, increase in the atmosphere. This is known as the greenhouse effect and these gases are trapping the infrared radiation and making the Earth warmer which is also called global warming [7]. In order to combat this phenomenon and to prevent the worst effects of climate change, humans must reduce the release of CO_2 and other GHGs into the atmosphere and this is the only option available for humanity. The rising temperatures could have catastrophic effects on ecosystems if these trends continue to persist. The rapid increase in temperature would wipe out species not able to adapt quickly enough to this warming environment which is already visible all across the planet. Polar ice caps could melt raising the sea levels and causing flooding of coastal cities. A number of pieces of evidence are being gathered on how human interference in the Earth's climate continues to impact global warming. Europe, the western US, and Canada lived through the warmest summer temperature records during the last 3-4 years due to extreme wildfires which burnt several towns to the ground and killed hundreds (https://climate.ec.europa.eu/climate-change/consequences-climate-change_en). In 2023 some of the European countries like Spain recorded the highest temperature of the season (https://www.worldweatherattribution.org/extreme-april-heat-in-spain-portugal-morocco-algeria-almost-impossible-without-climate-change/).

3. Rise in methane gas in the environment

The latest report from the IPCC leaves no doubt about the rising levels of CO_2 and the powerful link between methane (CH_4) and climate change has also been established already. Methane with more heat absorbing capacity has more warming potential and is 84 times stronger than CO_2 on a 20-year horizon [8]. Emissions of heat-trapping methane are rising all over the world, mostly due to agriculture, and intense fossil fuel use [9,10], with the current concentration of methane reporting at 1909 ppb against a pre-industrial time concentration of 722 ppb. The IPCC also highlighted the problem posed by methane, which has contributed as much as 0.5 °C of warming since preindustrial times, second only to CO_2 [11]. Last year, about 111 countries that were responsible for nearly half of the methane emissions promised to cut down methane emissions by 2030 at COP26 in 2021 (https://www.iea.org/reports/global-methane-tracker-2022/the-global-methane-pledge). Methane usually leaks from oil and gas pipelines during maintenance operations which is evidenced by the huge methane plumes from oil and gas seen on satellite maps. It is also produced by landfill, agriculture, and in coal production. Zhou et al. [12] evaluated the scale of methane emissions from the U.S. ammonia fertilizer industry and found that the majority of methane gets into the atmosphere through leakage only. At the same time, the methane emissions from the industrial sector have been vastly underestimated and are significantly higher. Recently Lauvaux et al. [13] focused their studies on detecting oil and gas leaks that can be plugged if companies want to invest in prevention. In addition, about 2% of the atmospheric methane is from the seafloor methane seepage due to the gas hydrate dissociation activity contributed by climate change [14,15]. Despite these recent studies, an appropriate understanding of the interplay between methane sources and sinks is not completely known.

4. Where from GHGs come and where do they go?

GHGs including CO_2 come from almost every human activity such as the burning of fossil fuels for transportation, electricity generation and running several industries, agriculture, land-use, and residential and commercial activities. In 2014, the top CO_2 emitters were China, the United States, the European Union, India, the Russian Federation, and Japan (https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data). Apart from coal-powered thermal power stations, transport, and several other industries, volcanic eruptions all over the world are some of the major sources of CO_2 (https://www.climate.gov/news-features/climate-qa/which-emits-more-carbon-dioxide-volcanoes-or-human-activities). Over the geological times, before the pre-industrial times, variations in atmospheric CO_2 depended mainly on volcanic emissions, which were difficult to estimate. For example, the Etna volcano in Italy releases an exceptional amount of CO_2 (9083 t/day) and contributes to 10% of global volcanic emissions [16]. But CH_4 and N_2O, mostly come from agriculture, and waste, and also from industries. For example, adipic acid is used in the production of industrial products such as nylon and polyurethanes and it is one of the largest sources of N_2O emissions [17]. China alone accounts for 94% of global annual N_2O emissions. Major contributors to GHG emissions in the USA in 2019 are shown in **Figure 3**. Only about 50% of the CO_2 from industrial emissions remains in the atmosphere. The remainder is approximately equally divided between uptake into the land biosphere and into the ocean. Most of the CO_2 is absorbed by the plants, trees, minerals, and microbes in the soils on the land, and oceans absorb a major portion, and the rest remains in the atmosphere (https://www.energy.gov/science/doe-explains-the-carbon-cycle).

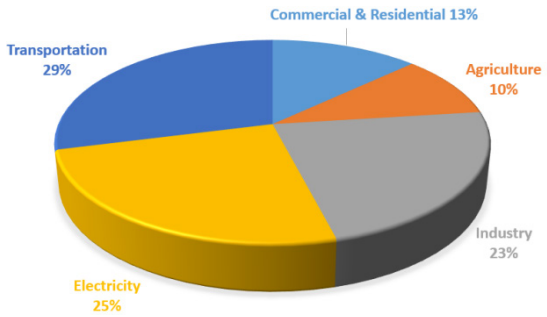

Figure 3. Approximate global GHG emissions from different sources in the US. Total emissions are 6,558 million metric tons of CO_2 equivalent.

Source: Modified after US EPA, 2019.

5. Increase in the frequency of extreme events

The devastating effects of climate change and nature's fury are visible in many forms such as higher average temperatures especially in colder regions, hotter summers even in regions such as Siberia, melting sea ice in places like Arctic and Antarctic regions, severe droughts, more wildfires, more powerful hurricanes, and stronger winter storms. These frequent and more intense extreme events are already signaling our planet's uncertain future. As a result, currently, millions of lives, and homes are destroyed in droughts and floods, and millions of people are dislocated and facing hunger in certain parts of the world as more than 3 billion people are living in highly vulnerable areas. These developments warrant more serious investigations. New data show, that the number of flooding and other hydrological events all over the world has quadrupled since 1980 and doubled since 2004 the world over [18]. Goswami et al. [19] reported that there is a significant rise in the trend of extreme rain events and extreme heat waves all over India in a warming environment. Extreme heat waves and wildfires are wreaking havoc around the globe every year, and these wildfires usually send plumes of smoke into the higher reaches of our atmosphere, where smoke particles interact with ozone. There is growing evidence that bushfire smoke reduces the concentration of ozone in the stratosphere (20-25 km from the Earth's surface), as the tiny carbon particles originating from these fires carry some chemical compounds containing chlorine which react with ozone, depleting its concentration [20]. Ozone is highly effective at blocking

damaging ultraviolet rays from the sun. Without this layer, many plants would die, while humans and other animals would be afflicted with skin cancers [21]. But it also contributes to the trapping of heat in the troposphere. The drought-hit countries like Kenya, Somalia, and Ethiopia in Africa have seen thousands of families being displaced from their homes whilst livestock losses have been huge. A small shift in the center means that more of the curve touches the extremes (**Figure 4**) and so heatwaves become more frequent and extreme as experienced, for example, in western Canada and the US in 2021. In recent years, the world has witnessed numerous wildfires in countries such as Turkey, Greece, Italy, Spain, Portugal, and France. The UK recorded over 40 ºC for the first time in history in 2022. In the usual weather cycle, hot weather creates more moisture and the water vapor in the air turns into droplets to create rain. The warmer it becomes, however, the more vapor there is in the atmosphere, resulting in more droplets and heavier rainfall, sometimes in a shorter space of time and over smaller areas such as experienced by the historic flooding in certain parts of China, Germany, Belgium, and the Netherlands in 2021, and Pakistan in 2022. Cyclones in ice-covered areas such as Greenland and Russia in the Arctic which can destroy sea ice and threaten people living in these regions are becoming more intense and frequent [22]. In fact, the polar regions and countries such as Britain, Spain, and Italy in Europe were hit hardest by global warming in 2022. Apart from Europe, there were significant heat record events in the Middle East, Central Asia, China, Pakistan, and parts of India. A comprehensive worldwide assessment of heatwaves down to regional levels has revealed that heatwaves have been increasing in frequency and duration since the 1950s in nearly every part of the world [23]. The extreme meteorological surface air temperatures recorded to date are –89.2 ºC in Antarctica, and 56.7 ºC in Death Valley, California [24]. Australia recorded the hottest day in 62 years as the temperature rose to 50.7 ºC in the coastal town of Onslow Western Australia in January 2022. Churu in Rajasthan, India recorded the highest temperature in the country in 2019 at 50.8 ºC, nine degrees above normal. In addition, the number of extremely hot days every year when the temperature reaches 50 ºC has doubled since the 1980s. India recorded its highest temperature in February in 2023 with an average maximum temperature was 29.54 ºC since recording began in 1901. Several other countries particularly in Asia and Europe are currently experiencing very high temperatures and severe dry conditions as rivers and freshwater lakes are getting dried up affecting their hydropower generation and agriculture leading to severe drought and global food crisis. Millions of fish are dying in some rivers in Europe and Australia due to ongoing heatwaves in addition to toxic algal blooms. Hotter temperatures are speeding up evaporation leading to increased salt levels in the surface water. Warmer water holds less oxygen than cold water leading to hypoxia conditions as fish require more oxygen in warmer conditions for their survival [25]. Sometimes the countries which are facing water stress are often accompanied by additional exposure to flooding (like India, and Pakistan) which have witnessed devastating rains and flooding with one-third of Pakistan under water in 2022 [26]. IPCC (2023) report says that the frequency and the intensity of those extreme events being witnessed these days are a result of global warming which will become more frequent and severe in the future as the planet continues to warm.

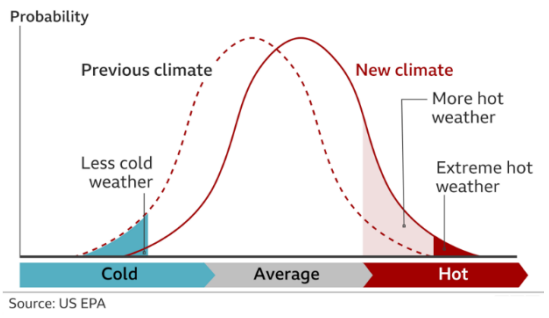

Figure 4. A small shift in climate can make a big difference in the weather conditions (US EPA).

6. Glaciers are shrinking and vanishing

Northern Alaska, Canada, Northern Europe, Northern Russia, Himalayas are melting faster at

the glacier bottom, shortening the glacier and reducing its mass, and the melt line moves upwards. A team of researchers [27] extracted ice cores from the glaciers on Mt. Hunter, in Alaska, and showed that the amount of water that melts currently is 60 times greater than it was prior to 1850. These studies are revealing that global temperatures are rising and in places like Greenland, the ice is vanishing and the destruction of coral reefs and other climate-related damages are hitting the world at an unprecedented rate. Satellite monitoring studies revealed that the overall rate of ice loss from Western Antarctica has increased five-fold over a 25-year period. It is interesting to note that Northern Hemisphere lost more ice (58%) in the past compared to that (42%) of the Southern Hemisphere [28]. Relatively a smaller number of studies were carried out on Himalayan glaciers due to problems with accessing remote and high-elevation glaciers, in politically unstable regions such as Nepal, Pakistan, China, and India, making these mountains difficult places to work especially for foreign scientists. In fact, Himalayan glaciers, are also showing increasing extreme temperatures and precipitation events, accelerating glacier-ice mass loss, permafrost degradation, frequent landslides, and a substantial shift in the seasonal riverine water supply. Terrestrial water storage and glacier show decreasing trends in most mountain regions across the planet and will have a greater influence on glaciers, groundwater, soil water, reservoirs, and lakes [29]. In addition, glacial lake outburst floods represent a major hazard in countries such as India, Pakistan, Peru and China where over 15 million people live in high mountain areas and are exposed to these risks [30]. Shukla and Sen [31], recommend satellite-based, real-time monitoring to develop a strong network of early flood warning systems in the Himalayas in order to check the devastating flash floods which are occurring in higher regions of the Himalayan mountains more frequently in recent times.

7. Sea levels rise and their impact on coastal zones

Climate-induced sea-level rises recorded along entire coastlines in different parts of the world have been a primary scientific focus in climate change studies for the past two decades as sea level rise is one of the primary indicators. The melting of global ice sheets is one of the primary causes of sea level rise, which has accelerated over recent decades. Since 1993, the global sea level has risen 4.3 cm (1.7 inches), 60% coming from the expansion of ocean water as its temperature rise, and 40% from melting glaciers. In coastal areas where 40% of the world's population lives, rising sea levels can increase the risk of flooding and endanger water sources. Pacific Island nations are already facing this threat, where people are being continuously displaced from their homes. Parts of cities such as Shanghai and Mumbai which are located in coastal areas are already experiencing flooding due to global warming, and the rise in sea levels along the coast (https://climate-adapt.eea.europa.eu/en/metadata/publications/ranking-of-the-worlds-cities-to-coastal-flooding/11240357). According to some studies, the global sea level is not rising steadily, rather it is getting faster every year. The global-mean sea level reconstruction shows a trend of 1.5 ± 0.2 mm/year from 1958 to 2014 [32]. Globally, the sea level has risen about eight inches (20 cm) since the beginning of the 20th century and more than two inches (5 cm) in the last 20 years alone. IPCC projections for 2100 range from 9 to 88 cm. Antarctica is covered by an up to 4 km thick ice layer and contains about 90% of fresh water on the surface of the Earth. This ice sheet in Antarctica is even shrinking in response to climate change and has lost over 3,000 billion tons of ice over 25 years [33]. Global sea level rise is 3 mm per year which is quite significant [34]. The rise in sea level not only encroaches on territories of coastal communities but also contributes to seawater intrusion on freshwater systems in coastal areas. Coastal wetlands are critical to Earth's ecosystem which is becoming increasingly vulnerable in the face of rising sea levels [6]. Recently, at the COP26 meeting in Glasgow, representatives of some 1.2 billion people, from the Climate Vulnerable Forum (CVF) consisting of countries from Latin America, Africa, Asia, the Caribbean, and the Pacific

were pushing the rest of the world to accept the idea of keeping the rise in global temperatures to under 1.5 ºC. Currently, the world's ocean surface heat is at record-breaking levels and its impacts are potentially catastrophic [35]. The vast amount of Arctic ice helps to cool the planet by reflecting the majority of the Sun's radiation back into space. But unfortunately, since the mid-1990s, there has been a marked decrease in sea ice cover in the Arctic Ocean [36] and there is a fear among the scientific communities that most of it could be gone in the coming 30 years [37]. According to some estimates, rising seas could submerge Jakarta (by 2100), Rio, and low-lying islands like those of the Maldives, where half a million people live barely a meter above the Indian Ocean, are under threat of rising sea levels driven by global warming. As a result, Indonesia is currently shifting its capital from Jakarta to the island of Borneo. The Mediterranean Sea level rise by 2100 will lead to a potential loss of about 192 km^2 of land along a coastline length of about 400 km of locations of tourist resorts, railways, airports, and heritage sites belonging to France, Spain, Tunisia, and Cyprus [38]. Coming to the Indian Ocean, the sea level rise is seen along the entire Indian coast and is rising faster than the global average [39,40].

8. Ocean acidification

Oceans cover over 70% of the Earth's surface and play a crucial role in sequestering significant quantities of CO_2 from the atmosphere. The free-floating algae called phytoplankton and tiny planktonic animals called zooplankton in oceans play a major role in the absorption of CO_2 and transfer of it to the ocean floor. The rise in CO_2 levels has led to more absorption and thereby more acidification of the oceans, leading to the weakening of the shells and skeletons of animals living in the sea. Concentrations of elements such as Mo, B, V, Cr, U, and Se and their isotopes in seawater and marine animals allow an understanding of ancient ocean chemistry and the ocean acidification process [41]. The replenishment of fish populations is threatened by ocean acidification caused by the uptake of additional CO_2 at the ocean surface which affects the marine ecosystem [42]. Ocean water's acidity level becomes higher when more CO_2 dissolves in the water, although some CO_2 returns to the atmosphere from the oceans and land reservoirs due to the outgassing effect. This makes it difficult for corals to build their skeleton [43] and coral reefs are under constant threat as the atmospheric CO_2 increases. In fact, both ocean warming and acidification are two of the greatest global threats to the persistence of coral reefs [44]. In addition, if the International Seabed Authority (ISA) gives permission to the mining of the seafloor for critical mineral resources, the disturbance to the ocean's ecosystems can also reduce their ability to absorb carbon to keep climate change under check [45].

9. Water scarcity

Groundwater has been extensively exploited worldwide during the last several decades. As a result, problems such as groundwater decline, and contamination are being currently confronted, and there is a definite threat to its sustainable use as a clean water source in the coming future unless proper early actions are taken. In addition, safeguarding groundwater quality is an essential part of sustainable water management and taking care of human health [25,46]. This deficiency of water is prevailing currently in several countries such as Madagascar, Yemen, India, and China, and in many European countries for several years across the globe. This situation has posed more serious questions about the disparity of rainfall caused by climate change and global warming, and over 4 billion people in the world are currently facing water scarcity [47]. At present, the whole world is suffering from the spread of new viral diseases such as COVID-19 and its several variants, monkeypox, and tomato flu, threatening the health of people the world over. According to Lim et al. [48], there is a threat of increased infectious disease risk likely in the future.

10. Effect on food production

As the global land surface temperature is on the

rise, our key food and fuel cropping systems are expected to affect our food production. In general, the increase in CO_2 concentrations together with the increase in global temperatures theoretically produces greater yields in crops. However, the majority of studies have shown that crop yields are downward trending due to the increase in the frequency of extreme weather events [49]. At temperatures above 40 °C, the photosynthesis rate slows down because the enzymes involved in the chemical reactions of photosynthesis are temperature sensitive and get destroyed at greater warming conditions. Excessive heat also can reduce the efficiency of enzymes that drive photosynthesis and can hinder plants' ability to regulate CO_2 uptake and water loss [50]. Hence with more and more global warming in the future, there is a definite threat to food production worldwide.

11. The sixth mass extinction?

There have been five mass biodiversity extinction events in the 4.54 billion years of the history of the Earth, all caused by dramatic and extreme natural phenomena such as prolonged ice age, sea-level changes, asteroid impacts, and voluminous volcanic eruptions in certain parts of the world. The massive volcanic eruptions leading to the formation of the Siberian Traps, and the enormous amounts of CO_2 led to the wiping out of 90% of all marine life during the largest extinction event (Permian-Triassic) in Earth's history [51]. Today, there is mounting evidence that the Earth is at the start of, or perhaps in the midst of the sixth mass extinction crisis which is underway with 7.5%-13% of species lost over the last 500 years, entirely caused by human activities [52]. Even if such an eventuality is unavoidable, some countries can most likely survive a global societal collapse and maintain their complex way of life according to a study by King and Jones [53]. For this study, five island nations, including Ireland and New Zealand were chosen as they could remain habitable through agriculture because of their vast land area for a small group of people they have, relatively cool temperatures, low weather variability, and other factors that make them more resistant to climate change. With favorable conditions such as a low population, large amounts of good quality agricultural land, and reliable domestic energy, New Zealand is expected to hold up the best, compared to others. So, even if climate change triggers a catastrophic global civilization collapse, humans will likely be able to keep going, at least, in some parts of the world. Coming to animals, polar bears are some of the largest terrestrial carnivores on Earth, but their fate is intimately tied to what happens to the Arctic's sea ice. Most polar bears are expected to struggle to survive in the Arctic by 2100 as the Arctic is continuously losing its ice. Standing almost four feet tall and weighing around 40 kg, emperor penguins in Antarctica are the world's largest penguins which need sea ice for their survival. A recent study estimates that 98% of colonies will be quasi-extinct by 2100 unless the world drastically reduces its greenhouse gas emissions [54]. Bumble bees which depend on wildflowers for their survival can also be affected as extremely high temperatures have negatively impacted most species of them over the past 120 years [55]. If greenhouse gas emissions and warmer temperatures are not controlled, some researchers estimate that life in oceans could be depleted severely within the coming 150 years [56]. The risk of species loss depends on how far global temperatures rise in the future.

12. Current, and upcoming technologies to limit warming, and steps to net zero

Cutting down CO_2 emissions to control climate change and reach net zero by 2050 is possible but not easy. So far, we have failed to reverse the 150-year trend of rising greenhouse gas emissions even after repeated warnings by the scientific communities for more than 30 years (IPCC, 2023). The UN secretary general is calling for countries to bring forward their plans for the effective reduction of GHG emissions for net zero by a decade or at least as close as possible to 2040. Innovative technologies such as solar-driven hydrogen production and fuel cell technologies [57,58], and space-solar power are likely to help to achieve sustainable goals and

for environmental planning by fulfilling the requirement of energy if they are technically feasible [59]. NASA and European Space Agency (ESA) are of the opinion that space-based solar power technology has the ability to increase energy independence and reduce greenhouse gas emissions. In addition, several countries have recognized the potential of wave power that could tackle the global energy crisis, support economic growth, and provide green energy [60]. Several studies are also currently focused on more efficient solar panels reaching efficiency levels nearing 50%. Four pioneering scientists who built more efficient electricity-generating silicon solar cells (from around 16-18% efficiency to about 25%) have won Queen Elizabeth Prize for Engineering in 2023. This is an example of the intensive efforts towards the development of technologies for tackling climate change, and the recognition and encouragement of the technologists and scientists who achieve stunning successes in this direction. The estimates of some scientists suggest that by the 2030s, solar will have more installed capacity than coal, oil, gas, nuclear, and hydro put together. Switching over to battery-powered electric vehicles or vehicles based on hydrogen fuel or using hydrogen fuel cells in the coming years will certainly help to reduce CO_2 and tackle climate change, despite the fact that there are also large uncertainties around the emissions associated with electric vehicle battery production. However, according to Plötz [61], fuel-cell electric vehicle technology will not play a major role in sustainable road transport in the future. The CO_2 concentration of about 425 ppm poses a difficult situation for high CO_2 capture capacities using sorption-desorption processes [62]. The magnitude of this crisis is gigantic, with about 40 gigatons/year of global CO_2 emission with no signs of shrinking [63]. Out of several technologies, technologies like direct air capture (DAC) which uses a 10% solution of KOH to capture CO_2 from the atmosphere, and carbon capture and storage (CCS) have emerged as indispensable tools in combating climate change and reaching their goal of net zero emissions. A lot of meetings and summits are being organized to discuss the latest developments by different international firms during the last couple of years. Unfortunately, the implementation of these and a few other critical and proven technologies has been very slow and inadequate [64]. Geological CCS technology involves the injection of CO_2 underground for long-term geological storage. It can help fight climate change by lowering industrial emissions [65]. Carbon dioxide would be injected into the ground for sequestration and geological medium like igneous and metamorphic rocks through a process known as carbon mineralization are needed for keeping the CO_2 underground [66] (**Figure 5**). In this context, olivine mineral is found to be very efficient in absorbing CO_2 and this process is also up-scalable [67].

Figure 5. Concept of carbon capture and storage.

Source: Modified after Schiermeier et al. [68].

Net zero emissions target means reducing carbon emissions to the greatest extent possible, by phasing out coal-powered thermal stations, switching over to alternate renewable energies such as hydro, solar, nuclear, hydrogen, and wave, and removing the remaining unavoidable emissions via removal technologies. Planting more and more trees is seen as a good option to tackle climate change. Replacing conventional fossil fuel vehicles with electric

vehicles which run on batteries would also significantly reduce CO_2 in the atmosphere improving air quality and human health [69]. Every nation on Earth understood the science behind climate change and the catastrophic consequences the people have to face if man does not act promptly to keep the rise in global temperatures well below 2 ºC by the end of this century and pursue efforts to keep it under 1.5 ºC. Several countries in Europe including the UK have already cut down the use of coal. India has set a target to ensure that 50% of its energy will be from renewable energy sources by 2030 and also to achieve net zero emissions latest by 2070 as per the declaration at the COP26 summit in Glasgow last year. In the meantime, a lot of studies are going on with regard to the reduction of CO_2 and converting it into useful products such as fuels, and chemicals which also contribute to the reduction of CO_2 levels and avoid catastrophic temperature rises across the world [70]. The easiest way to cut down the release of carbon is by using alternative ways to generate electricity such as the use of hydropower, nuclear fission, fusion (future), biomass, wind, geothermal, solar, hydrogen, and ocean energy [69,71]. Already some countries such as the UK are producing more electricity for the first time by using renewable sources such as wind power. At present, energy-efficient lighting is saving up to 75% of the energy currently used to light our homes, thanks to the invention of LED bulbs. In 2022, net fusion power was achieved for the first time, and some countries like the US, EU, UK, and Japan are heavily investing in nuclear-fusion power which is clean power and a breakthrough can be expected at any time in the near future [72].

Supply of critical metals required for green technology applications

For the whole world to deliver net zero by 2050, large-scale mining is more critical for metals such as Li, Cu, Ni, Co, Pt, Pd, REE, Ga, W, Te, and In, as these metals are essential for green technology applications such as making wind turbines, solar panels, fuel-cells, electric vehicles, and data storage systems required to transition to a low-carbon economy and for a sustainable energy future. Since land-based mineral deposits are dwindling fast, sea-bed resources are seen as a new resource frontier for mineral exploration and extraction [73-75]. As the land ore deposits are becoming scarce for some of these critical metals, there is an urgent need to look for alternative resources [76]. As vast mineral wealth is available in the seabed, the demand for exploiting critical minerals in the deep sea is rising in recent times. But what about the ecological and environmental consequences of mining the ocean which covers 71% of the planet's surface, and in turn is the habitat of the vast majority (97%) of living organisms? [45,77]. The oceans are an essential part of the biosphere, influencing several areas such as climate, food, health, and overall well-being.

13. United and rigorous global efforts only can resolve this crisis!

Many nations are not able to achieve their sustainable development goals such as poverty alleviation, quality healthcare, and economic growth due to climate change-driven lethal heatwaves and other climate change-driven extreme events [78]. Unfortunately, each country takes a different track toward the efforts for the mitigation of climate change. The big oil companies obtain approvals and licenses with the promise that they store huge amounts of CO_2 underground by CCS technology but fail to reach the promised storage goals. The EU targets to cut down all greenhouse gases by 2050. China's net-zero plan focuses on balancing CO_2 emissions by 2060. The UK announced that it would reach net zero greenhouse-gas emissions by 2050. Top oil exporter Saudi Arabia targets net zero by 2060, and Australia pledges to reach net zero emissions by 2050. But without more clear strategies by different countries behind achieving net zero targets, it's very difficult to evaluate the impact. However, according to Rogelj et al. [11] the current pledges and actions by different governments together with technological advancements, the world will be able to witness the decline of GHG only after 2050 through united and rigorous global efforts (**Figure 6**).

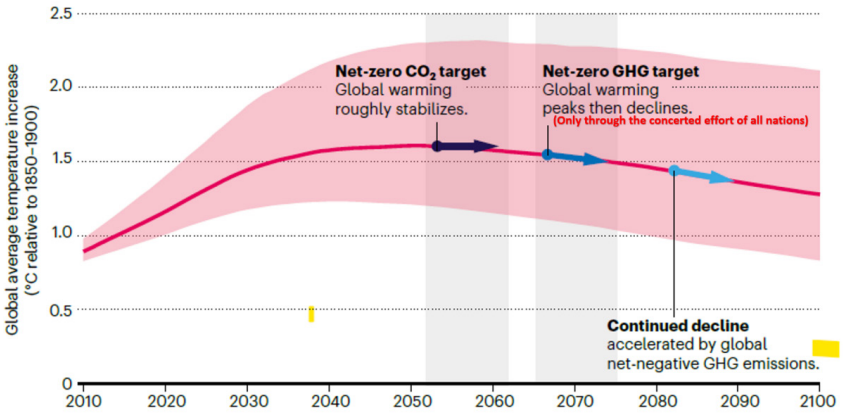

Figure 6. Estimated global temperature peaks (in pink) and declines (arrows) under net-zero GHG emissions.

Source: Modified after [11].

14. Conclusions and future

At the recent 26th United Nations Climate Change Conference of the Parties (COP26), over 127 countries committed to net zero targets which will limit global warming to 1.5 ºC above pre-industrial levels. Several scientists believe that the Paris Climate Agreement's goal to limit global warming in this century to 2 ºC is certainly within reach. All governmental bodies are making climate emergency declarations. It is possible to reach net zero carbon emissions, but it is not going to be easy and there is a long road ahead to net zero. With available emission budgets defined by the 2 ºC target itself looked challenging, the goal of achieving 1.5 ºC looks certainly harder unless united and rigorous global efforts are made. A coordinated effort of all nations is required to switch over from fossil fuels to renewable energy systems such as solar, wind, and nuclear for electricity generation (**Figure 6**). The necessary technologies have to be developed to remove excess CO_2 and other GHGs, and particulate pollution from the atmosphere, and limit CO_2 emissions by planting more and more trees. Every individual must understand the severity of this situation and contribute toward tackling climate change. Children should be taught the cause, effects, and how to combat climate change in depth even from high school. Any further delay in concerted global action will miss a brief and rapidly closing window to secure a liveable future. In fact, all of us can be very optimistic about the restoration of the natural climatic conditions as targeted, just as the notable recovery of the protective ozone layer in the upper stratosphere has been observed in recent times due to the complete ban on ozone-depleting substances. The UN Secretary-General António Guterres also said that the restoration of the ozone layer was "an encouraging example of what the world can achieve when we work together".

Conflict of Interest

There is no conflict of interest.

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