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A Review Study on Carbon Sinks: A Natural Remedy for Anthropogenic.

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Abstract

Anthropogenic greenhouse gas emissions, primarily carbon dioxide (CO_2), are the leading cause of global climate change, necessitating urgent mitigation strategies. Carbon sinks—natural and artificial systems that absorb and store CO_2 offer a promising remedy to offset emissions. This article examines the various types, mechanisms, and effectiveness of carbon sinks, including forests, oceans, soils, and advanced technologies such as carbon capture and storage (CCS). We evaluate their potential to achieve net-zero emissions. By integrating carbon sinks with emission reduction strategies, global efforts to combat climate change can be significantly enhanced. This paper discusses natural carbon sinks, which are also called Ecological carbon sinks. These carbon sinks absorb carbon dioxide from the atmosphere and store it as plant tissues and organic matter. Ecological carbon sinks are highly complex and interconnected, reflecting the myriad processes that occur within ecosystems. For instance, the carbon sequestration process is connected to water, nutrient cycles, biodiversity, and climatic factors. The interconnectivity between different carbon sinks, like forests, soil, and oceans, also adds another layer of complexity. Indian scenarios on climate change control have been appreciative as India is the only G20 nation in line with the 2 degrees centigrade warming and achieves the CCS target of reducing emission intensity 11 years in advance of the target of 2030. The responsibility for protecting and enhancing such carbon sinks in favour of humankind is crucial at this hour. Except for the large time scale required for forests and oceans to fix carbon, the rest is cost-effective.

Keywords: Anthropogenic activity, Carbon sinks, Carbon stock, Carbon sequestration, Global warming, Greenhouse gas emissions.

The rapid rise in anthropogenic greenhouse gas emissions, driven by fossil fuel combustion, deforestation, and industrial activities, has accelerated global warming, with profound environmental and societal consequences. In 2023, global CO_2 emissions reached approximately 37.4 billion metric tons, underscoring the need for effective mitigation strategies (IEA, 2024).

A carbon sink is a natural or artificial reservoir that absorbs and stores carbon from the atmosphere through physical and biological mechanisms. This is increasingly recognized as a critical tool for mitigating climate change. The process where carbon is captured or trapped and stored in a stable form is called Carbon sequestration. As the Carbon sink can be both naturally occurring and artificial, even the carbon sequestration process can be artificially regulated. With ever-increasing global temperatures, the world is facing the urgent tasks of increasing net carbon sequestration and reducing carbon emissions. It is estimated that CO_2, CH_4, and N_2O together contribute (80%) of the total greenhouse gas (GHG) emissions, with CO_2 alone accounting for (56%) (Zhang et al., 2019).

Nature auto-regulates itself with the carbon cycle. Anthropogenic emissions stem from human activities, in India significantly contribute to greenhouse gas (GHG) emissions, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases, these are critical drivers of climate change, trapping heat in the Earth's atmosphere and contributing to global warming. Activities like Fossil fuel combustion, power generation, urbanization, agriculture, and industry account (65%) of global CO_2 emissions (IPCC, 2022). The deforestation and land-use change contribute (10–15%) by releasing stored carbon and reducing sink capacity (FAO, 2023). These emissions have driven a global temperature increase of 1.1°C since pre-industrial times, with projections indicating 2.4–3.5°C by 2100 under current trends (IPCC, 2022). According to the Global Carbon Budget 2022, of the annual anthropogenic carbon emissions globally, approximately (48%) ultimately enter the atmosphere, with 5.2 ± 0.02 Gt C yr-1 growth during 2012–2021. India's share of global greenhouse gas emissions reached 7.8% in 2024, the highest since 1970. The rate of emissions growth increased by nearly 1 percentage point between 2020 and 2023. (SER, 2025). The degree of climate warming is determined by the radiative forcing and feedback processes in the climate system. This paper discusses about importance of carbon sinks and their capability of carbon sequestration, comprehensively gathering all the data which are availed from various reports, statistics, and studies.

What are Carbon Sinks? And the role of these carbon sinks in sequestration.

Carbon sinks are a vital part of the carbon cycle as they regulate the carbon in the atmosphere via processes like photosynthesis or absorption through pressure differences. Carbon sinks possess dual attributes, acting both as carbon sources and sinks, as they can release carbon through natural processes or absorb carbon through photosynthesis.

1. **Forests** are India's primary carbon sink, encompassing tropical, temperate, and subtropical ecosystems, including the Western Ghats, Northeast, and Himalayan regions. They sequester CO_2 through photosynthesis and store carbon in biomass, soil, litter, and deadwood. Globally, forests span approximately 4.06 billion hectares, representing (31%) of the Earth's land area, and hold an estimated 296 gigatonnes (Gt) of carbon, equivalent to 1,085 Gt CO_2, according to the **FAO Global Forest Resources Assessment (FRA) 2025**. They sequester roughly 7.6 Gt CO_2 annually, offsetting approximately 30% of global anthropogenic emissions (15–20 Gt CO_2 yr^{-1}), as reported by the **Global Carbon Budget 2024**. However, global forest sinks face significant threats from deforestation, with an annual loss of 10 million hectares, primarily in tropical regions, and climate-induced stressors such as rising temperatures and drought, which reduce carbon uptake by up to (10%) in tropical forests, According to **IPCC Sixth Assessment Report (AR6) Synthesis Report (2023)** "Climate change is reducing the carbon sequestration capacity of forests through increased frequency of wildfires, droughts, and pest outbreaks." Indian forests span over 71.37 million hectares, which is (21.76%) of the nation's land area, and hold 7.285 billion tonnes of carbon, equivalent to 26.74 Gt CO_2, as of 2023, reflecting an 81.5 million tonne increase since 2021[ISFR 2023]. This carbon storage can be allocated across biomass (45%), soil (55%), litter, and deadwood, underpinning India's Paris Agreement Nationally Determined Contribution (NDC) goal of achieving an additional 2.5–3 billion tonnes CO_2e sink by 2030. To align with the Paris agreement of 2015, to limit global warming below 2.0 degrees Celsius, and to achieve Net-zero emissions by 2070, India committed to increasing forest cover and creating an additional carbon sink of 2.5–3 billion tonnes CO_2 equivalent by 2030. But the **Climate Action Tracker (2023)** rates India's current policies as "Insufficient" for 1.5°C pathways, projecting a trajectory toward 2.4–2.6°C warming without enhanced mitigation and sink restoration.

2. **Water Bodies (Oceans, Wetlands, Mangroves, and Seagrasses)**

Oceans, mangroves, wetlands, seagrasses, and other water bodies serve as vital carbon sinks, absorbing and storing significant amounts of carbon dioxide (CO_2) from the atmosphere. These are collectively known as Blue Carbon Ecosystems. According Ramsar Convention on Wetlands 1971, these are considered highly efficient carbon sinks.

Wetlands are transitional ecosystems where land is saturated or inundated with water, either permanently or seasonally, supporting unique vegetation and wildlife. They include marshes, swamps, bogs, fens, and floodplains, often characterized by hydric soils and hydrophytic plants. Mangroves are coastal forests found in intertidal zones, typically in saline or brackish water, with specialized trees. They are a subset of wetlands but are often classified separately due to their unique coastal ecology. Seagrasses are submerged marine angiosperms that grow in shallow coastal waters, typically in saline or brackish environments, rooted in sediment with grass-like leaves.

Globally, oceans cover approximately (71%) of the Earth's surface (361 million km^2) and absorb about (25–30%) of anthropogenic CO_2 emissions, equivalent to 2.5–3 Gt C yr^{-1} (9.2–11 Gt CO2e yr^{-1}), as reported by the **Global Carbon Budget 2024**. This sequestration occurs via the physical pump (CO_2 dissolution in seawater forming carbonic acid) and the biological pump (phytoplankton photosynthesis storing carbon in biomass and deep-sea sediments), with ocean carbon stocks estimated at **38,000 Gt C**, per the IPCC Sixth Assessment Report (AR6) (2023). Mangroves, spanning 14.8 Mha globally, store 4 Gt C, while seagrasses, covering 10–30 Mha, hold 2–4 Gt C, and wetlands, including inland marshes and peatlands, store 700 Gt C, despite a (35%) area loss since 1970 (IPCC AR6 2023; UNEP 2025). Mangroves cover 14.8 Mha and store 4 Gt C, with sequestration rates of 2–4 t C $ha^{-1}yr^{-1}$ (7.34–14.68 t CO_2 $ha^{-1}yr^{-1}$), per UNEP (2025). They are 2–3 times more efficient than terrestrial forests per hectare. Mangroves in India, particularly in the Sundarbans, are highly efficient carbon sinks, storing 702.42 million tonnes CO2 equivalent with potential to reach 748.17 Mt by 2030" (ISFR 2023). Seagrasses sequester 1–2 t C $ha^{1}yr^{1}$ (3.67–7.34 t CO2 $ha^{-1}yr^{-1}$).

3. **Soil (Grassland and Agroforestry)**

Soils store carbon as organic matter, particularly in forest, agricultural, and grassland soils. Practices like biochar and conservation tillage enhance sequestration. Forest soils hold 3.96 Gt C (55% of forest carbon stock), while agricultural soils sequester 0.5–2 t

CO2 ha^{1}yr^{1}, with biochar boosting carbon by (41.28). Grasslands store carbon in roots and soils, with lower sequestration rates than forests, but significant potential in arid and semi-arid regions. Grasslands (e.g., in Rajasthan, Deccan Plateau) have lower sequestration rates (~0.5–1 t CO2 ha^{-1}yr^{-1}) compared to mangroves (2–5 t CO2 ha^{-1}yr^{-1}) but cover larger areas.

Agroforestry integrates trees with crops or livestock, while TOF includes urban trees, roadside plantations, and scattered trees, storing carbon in biomass and soils. Agroforestry sequesters ~78 Mt C yr^{1} under demand-driven scenarios, offsetting (50%) of 1990 deforestation emissions, with TOF contributing to the national 149 Mt CO2 yr^{1} (Ravindranath et al.; ISFR 2023). Rates range from 1–10 t CO2 ha^{1}yr^{1}. Agroforestry systems globally sequester 1–2 Gt CO2 yr^{1} (FAO, 2025).

Role of Carbon Sinks in Mitigating Anthropogenic Emissions

Carbon sinks, both natural and artificial, are essential for mitigating anthropogenic emissions and achieving net-zero emissions. Sinks contribute to net-zero by offsetting residual emissions from hard-to-abate sectors like aviation and cement, which account for (15%) of global emissions, enhancing ecosystem resilience and biodiversity, and supporting long-term climate stabilization through permanent storage in soils and sediments.

Artificial carbon sinks, encompassing technologies like Carbon Capture and Storage (CCS), Bioenergy with Carbon Capture and Storage (BECCS), and Direct Air Capture (DAC), are emerging as critical tools for mitigating anthropogenic CO2 emissions. CCS captures CO2 from industrial sources (e.g., power plants, cement factories) and stores it in geological formations, with global capacity reaching 40 Mt CO_2 yr^{1} in 2023, though this offsets only 0.1% of global emissions (40.6 Gt CO2e, Global CCS Institute 2024; Global Carbon Budget 2024). BECCS combines biomass energy production with CO_2 capture, offering negative emissions potential by sequestering carbon from bioenergy processes; for instance, pilot projects in India's bioenergy sector could sequester 1–2 Mt CO_2 yr^{1} if scaled. DAC, which extracts CO2 directly from the atmosphere, is exemplified by the Orca plant in Iceland, capturing 4,000 t CO_2 yr^{1}, yet its energy intensity and high costs (up to $1,000/t CO_2) hinder widespread adoption (Climeworks 2024).

In this era of Anthropocene, the Earth's natural ecosystem is threatened in a greater way. The witness to this is seen over the decades in the form of catastrophes, devastation, natural calamities, and unprecedented weather patterns, heatwaves, flash flooding, and cloudbursts. Extreme weather occurred on 88% of days in 2024 (255 out of 274 days in the first nine months), up significantly from 2022(SER, 2025). The atmosphere is filled with more toxic gases than ever from the time of humans started using fossil fuels. The emissions are so high that achieving carbon carbon-neutral environment is a tough road ahead. To face and regulate further global warming, governments, international institutions should strategically implement carbon sequestration techniques and mitigate further emissions. To an extent, several carbon credit programs and the carbon credit market are yielding results. To achieve these goals, efforts need to be made in multiple aspects, including decarbonization of the power sector, electrification of end-use sectors, and greening of other industries.

Abbreviations

CCS: Carbon Capture and Storage
G20: Group of 20 is an Intergovernmental forum comprising 19 sovereign countries, the European Union (EU), and the African Union (AU).
IEA: International Energy Agency
FAO: Food and Agriculture Association
CO2e: Carbon Dioxide equivalent
Gt C yr-1: Gigatonnes carbon per year
IPCC: Intergovernmental Panel on Climate Change
Mha: Million per hectare
Mt CO_2 yr^1: Metric tonnes carbon dioxide per year
ha^1yr^1: per hectare per year
SER: State of Environment Report, 2025

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