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REVIEW ARTICLE

THE IMPACT OF CARBON SINKS AND EMISSIONS FROM VARIOUS SECTORS ON CLIMATE: A REVIEW OF HIGH HUMAN DEVELOPMENT INDEX (HDI) NATIONS

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Abstract: A major worldwide problem is carbon dioxide (CO_2) emissions from fossil fuel combustion and land use changes, as well as climate change. Emphasizing the necessity of marine strata and terrestrial ecosystems in absorbing too much CO_2 and reducing the impacts of climate change, this work investigates the fundamental processes governing the worldwide carbon cycle. Although natural carbon sinks consume a sizable share of emissions, continuous fossil fuel usage and deforestation threaten to increase atmospheric CO_2 levels to never-before-seen extremes, hence with rather severe climatic consequences. Moreover, the complex interaction of policy measures, technological innovation, and economic growth is investigated by combining current research on greenhouse gas emissions across key sectors, including energy, manufacturing, transportation, and land use. Given their past emissions and present trajectories, countries with a high Human Development Index (HDI) draw special interest. Emphasizing the great need for coordinated, science-based policies, the study combines sectoral trends, emission drivers, and mitigating technologies, including carbon capture technologies and renewable energy adoption. Effective climate action, tackling both environmental and moral needs of global CO_2 reduction, is sought, hence balancing economic expansion with sustainability. Knowing the interactions of carbon between the atmosphere, terrestrial ecosystems (the living and dead organic matter on land), and the seas first helps one to understand the broader dynamics of the global carbon cycle and its effect on climate change. Particularly, their middle layers at depths of 100 to 1000 meters, the oceans act as significant reserves that soak up heat and extra atmospheric carbon dioxide (CO_2), thereby helping to somewhat stop global warming.

Keywords: Carbon dioxide, Climate, Greenhouse gas emissions

INTRODUCTION

Identifying the main components of the carbon cycle is mostly based on basic observations from the Scientific Committee on Problems of the Environment (SCOPE) study by Bolin *et al.* (1979).

Atmospheric CO2 levels rose from roughly 314 parts per million (ppm) in 1958 to 334 ppm by 1979, an increase of 20 ppm, or roughly 42 billion tons of carbon. Over this period, though, human activity,

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mostly the burning of fossil fuels, freed around 78 billion tonnes of carbon. Going further back, it is believed that more than 150 billion tons of carbon have been released into the atmosphere since the mid-19th century, when pre-industrial CO_2 levels were probably about 290 ppm.

By around 30%, human activities have reduced the global forest present cover, thereby converting carbon held in trees and soils into CO_2 as they expanded agricultural areas to nearly 10%. Estimates of these land-use emissions vary widely from 40 to over 200 billion tons of carbon beginning early in the twentieth century, though the exact magnitude is unknown. It's rather amazing that not all released carbon stays in the atmosphere. Natural carbon sinks, absorbing between 50% and possibly more than 70%. The forests of the rest of the world could be using more carbon as greater growth caused by higher atmospheric CO_2 levels takes effect. Surface and intermediate ocean water above 1000 meters deep. Deep ocean water lies beneath 1000 meters.

Though the deep ocean's carbon sequestration is not yet completely understood, radiocarbon studies show it has only captured a small portion of the released carbon. Observations like the nuclear-test-derived radioactive marker penetrating these waters support recent studies demonstrating that the middle ocean layers may function as more efficient carbon sinks than hitherto understood. It is unknown whether increased CO2 has spurred the remaining forests to store more carbon. These knowledge gaps cause projecting future atmospheric CO_2 concentrations to become particularly difficult. Usually, it has been thought that about half of human-generated emissions linger in the atmosphere, but oceanic absorption processes could lower this share to roughly 40% or less. Rising atmospheric CO2 levels beyond current estimates might result from ongoing deforestation. Moreover, the ability of the ocean to absorb CO2 diminishes with rising levels because of the chemical buffering features of seawater.

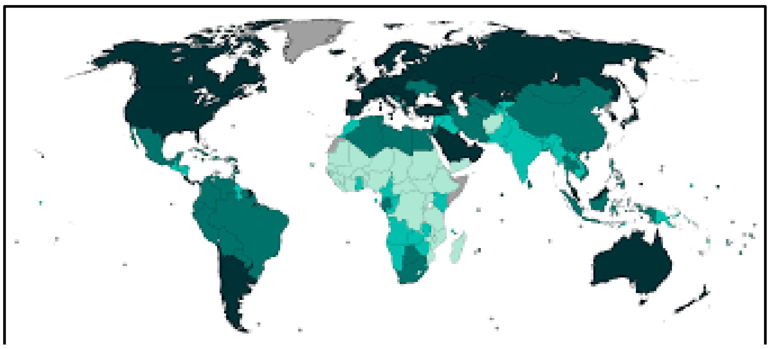
Looking ahead, if all known fossil fuel reserves estimated to contain at least 5000 billion tons of carbon were burned, atmospheric CO_2 levels could rise to between 1300 to 2000 ppm, roughly four to six times higher than present levels. While increasing terrestrial carbon storage is improbable to offset this substantially, land-based emissions from deforestation and land use change may add another 500 billion tons of carbon. Reductions in atmospheric CO_2 would need centuries because of the sluggish mixing and turnover of deep ocean water. Though not yet properly understood, the breakdown of calcium carbonate deposits on continental slopes may offer some buffering, therefore boosting oceanic CO_2 absorption over lengthy periods. If fossil fuel usage increases at 4% yearly, the rate observed until recently, a doubling of atmospheric CO_2 from pre-industrial levels could occur as early as 2030 based on present trends. While stabilizing fossil fuel consumption at present levels might delay doubling well into the 22nd century, slowing growth to 2% would postpone doubling by 15 to 20 years.

The doubts, especially about maritime carbon sinks, the results like ongoing fossil fuel burning will significantly increase atmospheric CO_2, hence preparing the ground for great climatic changes. Exploring the possible effects and reactions to worldwide climate change requires this knowledge.

Maintaining the surface temperature of the Earth higher than it would be without them, atmospheric gases known as greenhouse gases (GHGs) catch heat from the sun. Among the most common greenhouse gases are carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and fluorinated gases. Although the natural production of these gases is essential for maintaining a suitable environment, human actions, including industrial processes, burning of fossil fuels, and deforestation, have significantly raised their levels. The intensified greenhouse effect, which causes worldwide warming and climate change, leading to rising sea levels, extreme weather events, and environmental disruptions, is the primary driver.

Let's see what a carbon footprint involves. It covers every greenhouse gas emission, whether direct or indirect. Among greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons. CO_2, one of the greenhouse gases and a major problem in the present world, is the main focus here. Carbon dioxide's causes are: industrialization, fossil fuels, and deforestation. Global warming, climate change, ocean acidification, a rise in health concerns among the population, and economic effects of severe storms and environmental shifts are the major consequences of the rise in CO_2. One of the most important measures for reaching sustainability is reducing the carbon footprint. This might come from technology, law, or a change in someone's way of living.Net zero is the moment at which the amount of greenhouse gases released into the atmosphere equals the amount either absorbed or neutralized. To reach net zero, steps must be taken to absorb an equivalent amount of the CO_2 or other greenhouse gases generated by human activity, including tree planting, using carbon capture technology, or advocating for renewable energy. It means balancing the remaining emissions to stop additional contributions to global warming rather than removing all emissions; it also aims to reduce emissions wherever feasible. Achieving net zero, in accord with the Paris Agreement, is vital to maintain the rise in the global temperature to 1.5°C above pre-industrial levels. Many countries, cities, and companies have vowed to attain net-zero targets, usually by 2050 or sooner. This calls for major changes to our energy consumption and manufacturing, infrastructure expansion, land and resource management. It also calls for coordinated worldwide programs, creative thinking, and behavioural changes at every level of society.

Along with natural sinks and sector emissions, nations with high Human Development Index (HDI) play a vital part in advancing worldwide decarbonization through climate finance and technology transfer. Given their past emissions and economic potential, these nations have both the responsibility and the chance to spearhead the transition by backing sustainable land management practices, carbon capture technology, and renewable energy projects in developing nations. International climate finance mechanisms like the Green Climate Fund (GCF) are vital to allow low-income nations to meet their Nationally Determined Contributions (NDCs) and ensure a fairer worldwide response to climate change. Furthermore, significantly contributing to the worldwide carbon footprint are emissions resulting from consumption in HDI nations, especially those emanating from cities, transportation, and food systems. Urban areas, which are home to over half of the world's population and account for more than 70% of CO_2 emissions, require a comprehensive climate plan. Shifting toward public transportation, green structures, and small metropolitan design can help considerably reduce emissions. Likewise, dietary modifications toward less resource-intensive foods, especially a reduction in dairy and meat consumption, have been shown to offer great mitigating benefits.



Another little-understood field in climate mitigation is blue carbon, which describes the carbon absorbed by marine and coastal habitats, including tidal marshes, mangroves, and seagrasses. At rates far higher than those of land forests, these habitats store carbon; nevertheless, coastal growth and pollution are quickly eliminating them. Preservation and restoration of these ecosystems might enhance oceanic carbon storage as well as provide important co-benefits, including storm surge defence and biodiversity conservation. Concurrently, more emphasis has to be placed on the chance of climatic tipping points, which are thresholds in the systems of the Earth that, if crossed, could result in substantial and permanent environmental changes. Among several examples are the fading of the Amazon rainforest, the dissolving of Arctic permafrost, and the decline of Atlantic Ocean circulation. The urgency of reducing atmospheric CO2 before these critical thresholds are crossed is emphasized by the fact that these feedback loops could increase emissions and lower the efficiency of mitigation measures. Achieving net-zero targets finally calls for solid governance and policy integration.

HDI countries must adopt fair transition policies, phase out fossil fuel subsidies, and impose carbon pricing to ensure social inclusion of climate action. Stronger institutional alignment at the national and subnational levels, supported by science-based targets, will be crucial for combining economic development with climate resiliency. Getting citizens engaged in participatory budgeting, climate meetings, and education can help create public support for drastic changes.

REVIEW OF LITERATURE

Among the most pressing and serious problems now confronting humanity is climate change. Greenhouse gas (GHG) emissions, mainly carbon dioxide (CO_2) from fossil fuel combustion and land-use changes, have been steadily rising since the 19th century, peaking in the year 2019. This increase has greatly worsened the greenhouse effect, therefore contributing to global warming and its effects, including extreme weather events, loss of biodiversity, and interference with human and natural systems (Hao *et al.*, 2016; Liu *et al.*, 2019; Loucks, 2021).

Ambitious goals established by the 2015 Paris Agreement aim to restrict the worldwide temperature increase to 1.5 °C to 2°C above pre-industrial levels. With the time to change emission trends quickly closing (Höhne *et al.*, 2020), present emission paths, national commitments, and infrastructure projects, however, endanger these objectives more and more. The Intergovernmental Panel on Climate Change (IPCC) divides world GHG emissions into five main categories: energy systems, industry, buildings, and transportation. Agriculture, forestry, and other land uses (AFOLU) include land-based emissions and removals, energy supply, energy demand, and process-related emissions. Every industry presents its difficulties, and in Coal-powered generation from entrenched infrastructure (Jakob *et al.*, 2020) is critical for energy systems. Transport and construction use diffuse emissions related to urban design and behavioural elements (Creutzig et al., 2015). Difficult-to-decarbonize processes linked to metals, chemicals, and cement fall under industry (Davis *et al.*, 2018; Rissman et al., 2020). AFOLU emissions from opposing land-use needs vital for food, feed, and timber output complicate mitigation efforts (IPCC, 2019).

China has been the top CO_2 emitter worldwide since 2008, embodying the conflict between carbon reduction and economic development. China showed the possibility for decoupling emissions from economic growth via structural and technical developments between 1996 to 2010, reducing carbon intensity against quick industrialization (2012, 2010). Beyond CO_2, the ecological footprint measure offers a more general perspective of environmental effects, taking into consideration several resource needs. Research covering newly industrialized nations shows how rising energy use and economic growth cause environmental deterioration, hence stressing the necessity of specific mitigating measures (1998; 1977-2013) and Promising avenues to reduce industrial emissions are offered by technological advancements in carbon capture, use, and storage (CCUS). Though cost, recyclability, and industrial scalability remain hurdles, materials such as porous silicas and hydrogels have demonstrated very strong CO_2 capture capacity (2010-2024). Advancement of these solutions from laboratory to widespread deployment depends on continuing research, political backing, and the development of green materials.

Governments worldwide follow varied climate strategies, including renewable energy adoption, energy efficiency upgrades, and international cooperation frameworks like the Paris Agreement (Fekete *et al.*, 2021; Seo, 2017). Programs such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation) focus on forest preservation as a cost-effective emissions reduction tool (Rakatama *et al.*, 2017). A successful climate action depends on a sophisticated knowledge of emissions causes, both direct and indirect, including social behaviour, technical development, and economic policies (Jiang *et al.*, 2018; Wang *et al.*, 2023). This awareness is critical for developing particular policies, encouraging international cooperation, and guaranteeing resilience in climate change mitigation initiatives (Cai *et al.*, 2018; Li *et al.*, 2022).

Focusing on high Human Development Index (HDI) countries, whose economic growth trajectories have traditionally driven significant CO_2 emissions (Adekoya *et al.*, 2021; Hossain and Chen, 2021), the research examines these national leaders in technology and economic development, and their critical decisions that will affect global climate outcomes. Their industrial revolutions and consumption patterns have greatly shaped today's atmospheric composition, while their potential to pioneer innovative mitigation technologies positions them uniquely in the global effort (Ahmad and Zhang, 2020b; Mardani *et al*., 2020; Le Quéré *et al*., 2019). Thus, knowing the diversity of CO_2 emissions in highly HDI countries is both a moral obligation and an environmental need. The review's objective is to support informed policy design that may efficiently address climate change while balancing economic development and sustainability targets using in-depth data analysis and sector-specific decompositions created by the United Nations Development Programme (UNDP).

The Human Development Index (HDI) offers a complete picture of a nation's development by including three main elements: Health, represented by life expectancy at birth; Education, measured by mean years of schooling and predicted years of schooling.; Living Standards (Indicated by Gross National Income (GNI) per capita (PPP international dollars).

Focusing on high Human Development Index (HDI) nations, using a thorough examination of scientific papers, reports, and world data sources about carbon emissions, carbon sinks, and climate change. Primary investigations and international databases were combined to provide data on atmospheric CO_2 concentrations, fossil fuel consumption, land-use changes, and carbon capture by woodlands and oceans. To find major drivers and possibilities for reduction, sectoral emission patterns in energy, industry, transportation, and agriculture were examined. Radiocarbon and tracer evidence were used to determine the importance of natural carbon sinks, whereas future CO_2 scenarios were assessed under several trajectories of fossil fuel consumption. The research review highlights research needs and analyzes uncertainties in carbon cycle elements in order to guide successful climate policies.

DISCUSSION

Particularly in the intermediate deepwater bodies, analysis emphasizes the important roles of terrestrial ecosystems and oceanic layers as major carbon sinks absorbing a considerable share of anthropogenic emissions. Still, questions arise about the efficiency and long-term capacity of these natural sinks, particularly in view of continuous deforestation and possible saturation of maritime absorption. Observed rise in atmospheric CO_2 from pre-industrial levels near 290 ppm to possibly double or triple within this century if fossil fuel usage continues, which may raise serious issues about future climate stability. The complexity of the carbon budget is highlighted by the interplay between fossil fuel burning and land-use change emissions. Although remaining forests might counteract emissions via accelerated growth induced by high CO_2, deforestation patterns threaten to speed up atmospheric accumulation. Analysis of sectoral emissions highlights unique problems throughout agriculture, transportation, industry, and energy systems.

The delayed oceanic mixing and chemical buffering of seawater imply that even significant emission reductions will take decades to fully affect atmospheric CO2 levels, therefore underlining the necessity of early and continuing mitigation. Reaching targets for climate outlined in the Paris Agreement calls for global cooperation, strong policy frameworks, and socio-economic transformation. While technological breakthroughs and effective land-use policies like REDD+ (Reducing Emissions from Deforestation and Forest Degradation) provide helpful tools, their success depends on combining scientific knowledge of carbon cycle behaviour with practical implementation strategies. Furthermore, tackling indirect emissions and behavioural components will help to reduce the whole ecological footprint.

CONCLUSION

The study stresses the need to use a whole, multisectoral strategy to fight climate change, fuelled by a holistic grasp of the global carbon cycle. Countries with a high Human Development Index (HDI) have a unique opportunity and a great responsibility to lead efforts to reduce emissions and advance innovation, given their background in emissions and technological progress. Good climate action calls for well-coordinated policies combining economic growth with sustainability, the use of cutting-edge technologies, and global cooperation. Ultimately, postponing mitigation worsens the problems brought on by the slow responses inside the carbon cycle as well as the long atmospheric and marine lifespans of CO2. Fast, science-driven efforts are needed to control temperature rise, preserve ecosystem services, and guarantee a stable climate for future generations.

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