Role Of Co₂ In Climate Change and Its Mitigation to Make the World a Better Place

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***Abstract*—Human being generated, anthropogenic CO_2 is the most important cause of Green House Gas (GHG) emissions, this gas is the main reasons of global warming. In post combustion carbon capture process, there is inherent advantage of absorbing CO_2 from the point source, as the concentration of CO_2 is highest over there. This point source is the location where the CO_2, which is the product of combustion of fossil fuel is getting formed. After the release of CO_2 in the atmosphere due to dilution effect, caused due to mixing of CO_2 with air it's concentration becomes less, chemical absorption of CO_2 with base chemical solvents like MEA becomes difficult. Due to modernization there is continuous rise in levels of CO_2 in the atmosphere beyond acceptable limits, it's mitigation is the important ecological challenge to be addressed by the environmentalist as it leads to climate change. This write up delves into the onus of liability of CO_2 in global climate change and deliberates on various mitigation strategies aimed at achieving a sustainable low carbon future. This paper analyses the cause and effects of GHG production, its mitigation strategies and growing effect on climate change. The countries round the globe have mutually accepted the Paris Agreement for keeping the world carbon neutral. As per records kept by major scientific organizations like NOAA and WMO, the CO_2 concentration has increased to 420 parts per million(ppm) from 280 ppm since beginning of Industrial revolutions. The CO_2 concentration in atmosphere is constantly increasing due to rapid combustion of fossil fuel, to fulfill the growing Industrial need of energy in the manufacturing units. This rapid increase of CO_2 has detrimental environmental effect like rising of sea levels, severe weather events, melting of ice caps and ecological disturbances. Insights in this paper integrates the technical knowledge of GHGs, it's advancements in carbon capture, renewable energy, and acceptance of mutually agreeable policies such as the Paris Agreement. This paper brings out the liability of CO_2 in climate change, by examining sources of emissions and checking on universal trends. This study brings out the mitigation strategies, high-tech solutions, such as chemical absorption of CO_2 using advanced solvents in CCUS, the renewable energy changeovers and approaches affecting nature like afforestation and soil carbon sequestration. The Policy charters as contained in Paris Agreement and carbon pricing methods are pondered in this paper. This report undertakes to bring out joint responsibility of organizations, businesses, and people to achieve a low-carbon future and pledge planetary good fortune for future.**

***Key Words*—WMO-World Meteorological Organization; CC-Climate Change; GW-Global Warming; CCS-Carbon Capture and Storage; GHG-Greenhouse Gas; RE-Renewable Energy; SD-Sustainable Development; CO_2-Carbon Dioxide; NBS-Nature-Based Solutions; CCUS-Carbon Capture Utilization and Storage; LCF-Low-Carbon Future; IPCC-Intergovernmental Panel on Climate Change; NOAA- National Oceanic and Atmospheric Administration, USA.**

I. INTRODUCTION

Carbon dioxide (CO_2) is chemically stable, hard to reduce and is having long shelf life, this greenhouse gas, is well known for contributing significantly to global warming. The atmospheric concentration of CO2 is constantly increasing from 280 parts per million(ppm) to more than 420 ppm at present. The combustion of fossil fuels to produce electricity to run large scale manufacturing unit, growth in population, rapid urbanization leading to growth of towns and cities and reduction in size of agricultural lands have led poor land use are the main reasons of this rise in concentrations of CO_2 directly or indirectly. The change in weather is induced by increasing levels of CO_2 in the atmosphere which has direct impacts on patterns of weather, ecosystems, and human livelihoods. Thus the awareness of CO_2's presence and its adverse effects on human health and climate change is therefore essential to formulate mitigation strategies to combat growth of CO_2 in the atmosphere.

Rapid industrialization has led to excessive use of fossil fuels. The carbon rich fossil fuels combustion has increased the concentration of GHGs in the atmosphere, these gases envelop the earth surface resulting in climate change, which is most challenging global aspect of this century. This rapid increase of CO_2 in the atmosphere has altered the natural carbon cycle, and has increased the global mean surface temperature by roughly 1.1°C above the pre-industrial levels, as per reports published in IPCC 2023.The effects of global warming are perceptible in the form of ocean acidification, intense and erratic rainfall and heatwaves configurations, glacier melting and retreat, biodiversity loss. The aim of this presentation is to study the impact of CO_2 increase in climate change and its mitigation techniques, both technical and natural process. The technological approaches comprise of CCS, adoption of renewable energy and efficiency improvement techniques. Next strategy of mitigation of CO_2 is by adoption of natural process route of increasing forest concentration by planting more number of trees through afforestation and soil carbon management to have a carbon neutral word. By implementing effective mitigation strategies, this study highlights the need of an integrated global response. By adopting synchronized scientific and technological policy for CO_2 mitigation we can make the world a better place for future generations.

II. THE LIABILITY OF CO_2 IN CLIMATE CHANGE

The CO_2 is a major GHG (Green House Gas) the presence of which influences Earth's energy balance through the greenhouse effect, in a complex chemical reaction CO_2 along with other industrial and vehicular pollutants, like NOx in presence of sunlight and moisture reacts and forms a layer which envelops earth surface and does not allow infrared radiation emitted from the earth's surface to escape. Heat is absorbed and re-emitted by atmospheric gases, trapping heat within the troposphere. This radiative effect which is a driving force, is a measure of this energy imbalance, which has increased significantly by approximately 2 W/m² since pre-industrial times (ref report of IPCC, 2021). It has been observed that temperature globally has risen by approximately 1.1°C above pre-industrial levels, which has led to appreciable fast melting of glaciers, changes and increased intensification of extreme weather conditions, changes in duration and timings of rain and snowfall. The role of CO_2 in Climate Change are given below: -

(a) The Greenhouse Effect- The Earth's atmosphere acts as a natural insulating layer that regulates the planet's temperature through the greenhouse effect. Certain gases, primarily water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), trap a portion of the infrared radiation emitted from the earth's surface, preventing it from escaping into space. While water vapor (H_2O) is the most abundant GHG, carbon dioxide (CO_2) plays a more critical role because it remains in the atmosphere for centuries and acts as a thermostat regulating long term climate stability. The carbon cycle maintains a balance between CO_2 emission and absorption through processes such as respiration, photosynthesis, and oceanic exchange under normal conditions. The Combined effects of deforestation and burning of fossil fuels in all forms i.e. solid coal, liquid fuel Diesel, petrol and kerosene and in gaseous form of LPG & CNG. Solid fuel in the form of coal is used for thermal power generation in thermal power plants, all types of liquid and gaseous fuels are used in IC (Internal combustion) Engines for propulsion and for providing heat by direct burning in the form of oil cookers in large kitchens. That means the fossil fuel is convenient to use and will remain in operations for long time to come due to it's abundance and inherent advantages. Ease of availability, transportation, handling and storage, having high calorific value (CV) compatibility etc. etc. will keep fossil fuel in use for long time to come. Since the rate of usage or consumption of fossil fuel is higher than the rate of formation of fossil fuel, this leads to an imbalance in natural carbon cycle, resulting into constantly increase in carbon footprints in the form of raised concentration of CO_2 or GHG, responsible for global warming and climate change. This CO_2 is called anthropogenic carbon dioxide or man-made CO_2 produced due to combustion of Carbon rich fossil fuel. This CO_2 envelops the earth surface and creates disproportionate heating due to the radiative forcing effects. Trapping of infrared radiation by GHG envelop causes global warming as IR radiations are reflected back to earth surface increasing earth surface heat.

(b) Radiative Forcing and Climate Sensitivity Radiative forcing means the change in the balance between incoming solar energy and outgoing infrared radiation due to changes in atmospheric composition. When CO_2 concentrations increase, more infrared radiation is absorbed and reflected back to earth's surface, resulting in net warming effect. Due to doubling of atmospheric CO_2 intensity from pre-industrial levels of around 280 ppm to 560 ppm is predicted to produce a radiative forcing of approximately 3.7 W/m², causing global mean temperature upsurge of about 1.5°C to 4.5°C as per IPCC, 2023. Feedback processes intensify or reduce this warming. For instance, melting polar ice reduces surface albedo (it is the measure of how much sunlight a surface reflects, ranging from 0, a surface that absorbs all light to 1, a surface that reflects all light. It is calculated as the ratio of reflected solar radiation to the total solar radiation that hits the surface. Surfaces with high albedo, like snow and ice, reflect more sunlight, while surfaces with low albedo, such as forests and oceans, absorb more) increasing solar absorption (a positive feedback), while enhanced plant growth due to higher levels can slightly offset atmospheric concentrations (a negative feedback). Nonetheless, the net effect remains a substantial warming of the Earth's climate system.

(c) Contributors and Patterns of CO_2 Emissions. CO_2 emissions starts off from both natural and anthropogenic sources. The natural emissions, CO_2 arise from respiration, volcanic activity, and ocean and atmospheric exchanges, but these are largely balanced by natural sinks such as oceans and vegetation. The current imbalance and the resulting atmospheric CO_2 buildup is propelled by human-induced emissions, primarily from combustion of fossil fuels (coal, oil, and natural gas) for electricity, heat, and transport. Owing to deforestation, excessive modernization and land use methods, lessens the carbon sequestration capacity of earth surface. Modernization and industrial revolution have increased dependence on fossil fuels for energy. Products of combustion of fossil fuel have considerably increased CO_2 levels in the atmosphere. Data from, NOAA, 2024 show a steady increase in CO_2 from 315 ppm in 1958 to over 420 ppm in 2024. This is 33% rise in just over six-decade span is the fastest rate of increase in last 800,000 years, as confirmed by ice core data. Universal CO_2 emissions reached approximately 36.8 billion tons (Gt CO_2) in 2023 (Global Carbon Project, 2024), individual country wise share as China (30%), the United States (14%), the European Union (7%), and India (7%).

(d) Long shelf life and Persistence. CO_2 has adverse effect in climate change since it stays in the atmosphere for a long life time and has got large shelf lifetime for degradation, it is estimated to range from hundreds to thousands of years. Unlike short-lived gases such as methane, CO_2 accumulates in the atmosphere, making its effects long lasting even if emissions were reduced immediately. Its Global Warming Potential (GWP) is defined relative to that of CO_2 over a 100-year period is 1, but this serves as the baseline against which other gases are compared. Due to its cumulative nature, stabilizing global temperatures requires not just slowing emissions but achieving net-zero CO_2 emissions, where anthropogenic sources are balanced by removals through natural or engineered sinks.

III. IMPACTS OF ELEVATED CO_2

Modernization and rapid industrial progress have increased the concentrations of CO_2 beyond acceptable limits impacting natural habitat and human beings globally leading to dangerous meteorological conditions like frequent heatwaves. Floods and draught like conditions are the after effects of global warming. In case there is no change in present policies, by mid-century the global average temperature will rise by 1.5°C to 2° C. Ocean chemistry and sea level are also fluctuating approximately 30% of emitted CO_2 is absorbed by oceans, forming carbonic acid and lowering pH levels by the process known as ocean acidification. Thermal expansion and melting ice contribute to rising sea levels. Agriculture and food systems are getting affected due to changing climate patterns disrupting crop yields, water availability, and pest dynamics. Staple crops such as wheat and maize are projected to decline in tropical regions. Ecosystems and biodiversity are getting affected CO_2 induced warming leads to habitat loss, species migration, and coral bleaching. Human health and socioeconomic systems are getting damaged due to poor air quality, vector borne diseases (illnesses caused by pathogens like viruses, bacteria, or parasites transmitted to humans or animals by vectors, which are living organisms that act as carriers) are increasing, and economic losses from extreme events emphasize the human dimension of CO_2 impacts.

Reports of World Meteorological Organization (WMO, 2024) states that climate related disasters have more than tripled since the 1970s, crucial contributor being CO_2 driven warming which has increased in last few decades, the last decade (2014–2023) being the warmest on record (NASA, 2024). This accelerating temperatures have led to increased frequency and intensity of extreme weather few examples of recent times are heat waves across Europe, North America, and South Asia, high intensity tropical cyclones and hurricanes, fueled by warmer ocean surfaces, prolonged droughts and wildfires, in Mediterranean and Australian regions. India is experiencing frequent and intense heatwaves and high temperatures in both day and night, Delhi has broken temperature records. Extreme Rainfall and Flooding due to increased atmospheric moisture one such example is 2005 Mumbai floods, untimely September 2025 Kolkata Cloud bust at the same time other areas face reduced moderate rainfall in India. Drought are there in some regions of Vidarbha in Maharashtra due to water shortages drought prone areas are expanding. Due to melting of glaciers in the Himalayan region perennial rivers are changing it's course, threatening water supply, hydroelectricity generation, and causing floods Agriculture yields in India are getting impacted due to extreme weather, live examples are significant damage to crop yields for staples like tomatoes, onions, and potatoes, leading to price spikes.

IV. MITIGATION STRATEGIES

The approaches for CO_2 emissions mitigation and reduction includes technological, nature-based, and policy-driven approaches. The use of portfolio approaches along with technological innovations like Carbon Capture, Utilization, and Storage (CCUS), renewable energy systems, and use of energy efficient devices together play key role in CO_2 alleviation. Natural solutions, like afforestation, soil carbon enhancement, and blue carbon ecosystem restoration offers additional sequestration potential. Global frameworks such as the Paris Agreement and carbon pricing mechanisms create policy incentives for de-carbonization. In this section key strategies under three broad categories, technological, natural, and policy driven approaches are drawn, let's discuss them in brief one by one.

(i) Technological Approaches. The various scientific moderation strategies emphases on reducing CO_2 emissions at their point source or removing them directly from the atmosphere through engineering solutions. This expertise is key to industrial de-carbonization and the changeover from non-renewable sources of energy to a viable energy system.

(ii) Carbon Capture, Utilization, and Storage (CCUS). The CCUS encompasses capturing CO_2 discharges from the point source of generations, of large industrial installations, power plants, cement plants or factories or warehouses, thereafter compressing CO_2 and storing it in underground in saline formations, depleted oil reservoirs in order to extract more oil. Thereby enhancing oil and gas extractions from the deep natural depleted geological sites. Three basic approaches for capturing CO_2 are Post-combustion capture which uses chemical solvents like amines to absorb CO_2 from flue gases. Pre-combustion means CO_2 removal before air enters the combustion process and oxy-fuel combustion methods enhance capture efficiency. Captured CO_2 can also be utilized to produce chemicals, fuels, or building materials, turning waste into value. As per the reports published in the International Energy Agency (IEA, 2024), the large-scale deployment of CCUS could mitigate 15–20% of global CO_2 emissions by 2050 if governments support the policy and suitable investment frameworks are made available.

(iii) Renewable and Low-Carbon Energy Systems. Switching over from fossil fuels to renewable energy source is one of the most dynamic CO_2 mitigation strategies. By adopting portfolio approaches means using all renewable sources of energy i.e. solar, wind, hydropower, geothermal, and bioenergy along with CCS technologies to generate electricity without releasing CO_2. Use of solar photovoltaics and wind power now share 80% of all new renewable capacity additions globally. Fossil Fuels and green hydrogen, produced via electrolysis using renewable electricity, offers potential for decarbonizing heavy industries and transportation network. Nuclear power and advanced fission/fusion technologies are also part of the low-carbon mix in several countries. By accelerating renewable utilization, along with modern grid management and use of thermal energy storage(TES), is crucial for displacing carbon intensive energy sources.

(iv) Energy Efficiency and Industrial Innovation. Improving energy efficiency reduces demand and emissions simultaneously, examples of energy efficient and innovative industrial applications, retrofitting buildings with efficient insulation, lighting, and use of heating ventilation and air conditioning(HVAC) systems can reduce energy use by up to 40%. Use of electrically driven vehicles for transportation, supported by cleaner grids, decreases direct combustion emissions because of non-use of fossil fuels. Adopting to carbon-neutral manufacturing and process optimization by using electrified furnaces, using low-carbon cement, and green steel are critical pathways for reduction of overall carbon footprints. By use of artificial intelligence (AI) and Internet of Things (IoT) further augment monitoring and optimization, assisting industries to track and cut carbon footprints digitally.

(v) Carbon Dioxide Removal (CDR) Technologies. Over and above reducing carbon emissions, the negative emissions technologies (NETs) aim to briskly eliminate CO_2 from the air. The Direct Air Capture (DAC), pulls CO_2 directly from the atmosphere and chemically remove CO_2 from ambient air for storage or reprocessing.

(vi) Nature-Based Solutions are those solutions to remove CO_2 from ambient air by using natural system of photosynthesis. biomass accumulations and soil carbon storage of CO_2. Restoring and protecting ecosystems has co-benefits for biodiversity and local populaces. It has many nature centric solutions like planting of new trees and creating jungles (afforestation) and restoring degraded ones (reforestation) to enhance CO_2 uptake from the atmosphere. Trees absorb CO_2 during photosynthesis and store it as biomass. Universal reforestation initiatives, such as the Bonn Challenge and Trillion Tree Campaign, aims to restore 350 million hectares of forest by 2030, the success of such programs depends on long-term protection. Soil Carbon Sequestration and sustainable agriculture practices aims to have healthy soils, which are major carbon reservoirs. The time tested practices of no-till farming (is an agricultural technique that involves planting seeds directly into the soil without plowing or disturbing its structure. Instead of tilling, residue from previous crops is left on the soil surface, and specialized machinery plants seeds into the undisturbed ground, which helps retain moisture, nutrients, and soil health. This method is a key part of reformative agriculture and helps in reducing soil erosion, grow water infiltration crop rotation, cover cropping (Cover cropping is the practice of planting crops like legumes, grasses, or brassicas to protect and improve the soil rather than for harvest. These crops are typically grown during the off-season to prevent soil erosion, enhance fertility by adding organic matter and nitrogen, manage weeds, and improve soil structure and moisture retention. After they fulfill their role, they are usually plowed back into the soil or left to decompose, a process known as "green manure) and organic amendments is known to increase soil organic carbon content this concept has to explained to the agriculturists. By following regenerative agriculture techniques not only soil carbon storage is enriched but also increases soil fertility and water retention, creating a resilient farming systems.

(vii) Net-Zero Commitments via Paris agreement this was adopted in 2015 to bind global temperature upsurge to well below 2°C, preferably 1.5°C above pre-industrial levels. The commitment requires the countries to submit Nationally Determined Contributions (NDCs) charting out emission reduction plans. As of 2025, over 140 countries have announced net-zero targets, representing more than 90% of global GDP.

(viii) Carbon Pricing and Market Mechanisms it is a strategy that allows emitters to pay for their CO2 emissions, thereby inspiring them to cut down CO2 and invest in cleaner energy. Carbon pricing internalizes the social cost of emissions by allocating cost/monetary value (Rs/Tons of CO_2) to each tonne of CO_2 released. Thereby shifting the financial burden from the public to the source of the emissions. Through market mechanism the government sets an overall limit on total emissions permitted for a group of industries. This cap is divided into licenses, which are distributed or sold to companies. Companies that emit less than their allowance can sell their excess permits to those that surpass their limits, there by generating a financial encouragement to reduce emissions. The cap is tightened over time, making permits scarcer and costlier, which drives novelty in cleaner technology. For example, the Indian Carbon Credits Trading Scheme (CCTS) and the European Union's ETS.

(ix) Green Finance and Indian Sovereign Green Bond- Green Finance bring up the financial investments rolling into feasible and environmentally friendly projects and initiative that encourages the development of a low-carbon and climate friendly economy through green bonds, carbon pricing mechanisms, green loans, renewable energy funds, and climate risk insurance. Green Bonds are bonds issued by the World Bank and EIB in billions to fund clean energy and climate adaptation projects. Green Climate Fund (GCF), has been established under the UNFCCC to marshal up $100 billion per year from developed to developing nations for mitigation/adaptation. Green Finance and International Cooperation are enablers of carbon mitigation. They do not directly reduce CO_2 themselves, but they mobilize capital toward low-carbon solutions to enable technology sharing. Green finance creates pathways for public and private financing towards low-carbon technologies, renewable energy projects, and sustainable infrastructure. International cooperation complements this process through frameworks like the Paris Agreement.

(x) Features of India's Sovereign Green Bonds (SGrBs) Sovereign Green Bonds were launched in 2023 by Government of India through the Reserve Bank of India (RBI) with the objective to finance or refinance projects that cut down carbon emissions and promote a low-carbon, climate buoyant economy. It has been issued in ₹10,000 face value for a period of 5 and 10 years. Funds under this head are assigned to projects in renewable energy, clean transportation, energy efficiency, sustainable water and waste management, climate change adaptation, biodiversity conservation, and green buildings. The fund utilization excludes usage in nuclear power, large hydropower (>25 MW), fossil-fuel-based energy projects, and land acquisition projects for new plantations. The investments are open to both domestic and foreign institutional investors they offer a risk-free return, supported by sovereign guarantee. Initially ₹16,000 crores were allocated in 2023 which was fully subscribed. The fund has been reviewed by CICERO Shades of Green, which rated it as Medium Green with Good Governance. The bond has significance of promoting climate-aligned public investment and strengthens. India's position in global sustainable finance markets, encourages private sector participation in green finance and demonstrates India's commitment to carbon mitigation and sustainable progress. The fund can be used to finance solar parks, electric mobility, and energy-efficient infrastructure. Under Paris Agreement India has committed itself to achieve Net Zero by 2070.

V. CARBON PRICING.

It is an economic policy tool that allocates a monetary value to greenhouse gas (GHG) emissions, principally carbon dioxide (CO_2).

It's objective is to compel emitters pay for the green cost of their releases, creating a financial incentive to reduce them. There are two key methodologies for carbon pricing, first is Carbon Tax and second is Emissions Trading System (ETS) or Cap and Trade. Carbon tax works on the mechanism of fixed price per tonne of CO_2 emitted. In Sweden, Canada, Singapore, South Africa and Japan the government sets a tax rate (e.g., \$30/tonne CO_2). Emitters pay this tax based on their emissions. Simplicity is its main advantage. Emissions Trading System is a market-based system with a limit on total emissions, followed in European Union (EU ETS), China (national ETS), California and South Korea. In this system Government sets a total emissions limit and issues permits/allowances. Companies can buy/sell allowances in the market. The permit price reflects supply and demand. Carbon pricing matters for mitigation since it internalizes the cost of pollution, "polluter pays principle," it encourages innovation in low-carbon technologies, generates government revenue that can fund renewable energy, climate adaptation or compensate vulnerable sectors and provides flexibility to emitters who can choose to reduce or pay.

VI. EXAMPLES OF CARBON TAX CALCULATION

(a) Example1-If a power plant emits 200,000 tons of CO_2 per year, and the carbon tax rate is ₹2,000/tonne, then: Tax payable = 200,000 × ₹2,000 = ₹400 crore/year. This motivates the plant to switch to renewable energy or improve efficiency to reduce costs.

(b) Example 2-For some emission source: Total CO_2 emitted (kg CO_2) = Activity Data × Emission Factor; Conversion to tons: Emissions (tCO_2) = Emissions (kg CO_2) ÷ 1,000; Activity Data = Fuel consumed (L, kg), electricity (kWh), distance travelled (km), tons of material processed, etc. Emission Factor (EF) = kg CO_2 per unit of activity (from IPCC, GHG Protocol, national inventories, or supplier-specific factors). Common emission factors and sources; Combustion fuels: use IPCC or national EF (e.g., diesel -2.68 kg CO_2 / L; coal and natural gas have specific EF per mass or energy); Electricity: use grid emission factor (kg CO_2 / kWh) country or regional grid operator data is best; if procuring renewable power, use supplier/attribute data (I-RECs, Guarantees of Origin). Transport: EF per vehicle-km or per liter; Process & fugitive: use specialized factors (IPCC or industry manuals).

(c) Example 3 Let's assume diesel generator is consuming 10,000 L of diesel per year. Calculate the carbon footprints in cost terms.

Solution-Activity data: 10,000 L diesel per year. Emission factor (EF): 2.68 kg CO_2 per liter (typical diesel EF) Carbon Emitted per year =Activity × EF i.e. 10,000 × 2.68 = 26,800 kg CO_2 or 26,800 ÷ 1,000 = 26.8 tCO_2

(d) Example 4 Calculate the Carbon footprints generated because of 5000,00 kWh of Electricity generated per year Grid Emission Factor (EF) is 0.70 kg CO_2 / kWh.

Solution-Activity data: 500,000 kWh per year. Grid EF: 0.70 kg CO_2 / kWh. CO_2 emitted=500,000 × 0.70 =350,000 kg CO_2. or 350,000 ÷ 1,000 = 350 tCO_2. If Penalty is Rs2000/t Penalty=2000x350= Rs7000,00/- (Rs 7Lakhs). This gives incentives to switch the plant to a renewable energy or upgrade the plant to reduce carbon footprints by using energy efficient devices.

VII. INCENTIVE DECISION BY CARBON ABATEMENT

Establish baseline emissions (current year or multi-year average).

(a) Establish baseline emissions (current year or multi-year average).
(b) Estimate abatement from proposed measure (e.g., solar PV reduces grid consumption by X kWh → convert to tCO_2 saved).
(c) Calculate cost per tCO_2 abated: (Project net cost ÷ expected annual tCO_2 abated) or levelized cost across project lifetime.
(d) Compare to carbon price / incentive threshold: if cost per tCO_2 ≤ offered incentive (or social cost of carbon), project is attractive.
(e) Consider lifetime, additionally, permanence (especially for offsets)

VIII. FUTURE OUTLOOK AND PATHWAYS TO A SUSTAINABLE LOW-CARBON FUTURE

It indicates shifting of economy from high carbon fossil fuel based energy intensive system to an efficient, effective, cyclic and regenerative mode by allowing use of renewable source of energy. Modern economy is to be built on a sustainable, low carbon system having a transformative approach to balance between economic advancement and energy security. Indian government has committed itself of net zero emissions by 2070, by employing compact green energy devices like green hydrogen, employing energy storage device like batteries, nuclear power plant based power grid system where grid can easily switch in and cut out individual renewable sources of energy producing devices. Modernizing electricity grid and distribution network by reducing both technical and commercial losses. Employing advanced renewable technology and carbon recycling method is an effective carbon mitigation technic. It is well known futuristic approach to achieve net zero carbon by 2070 by recycling captured CO_2 into useful products instead of releasing captured CO_2 directly into atmosphere. Thus carbon recycling method is a main pillar of circular carbon economy (CCE) which helps to reduce net GHG emissions.

IX. CONCLUSION

The concept of carbon recycling implies capturing CO2 from industrial emissions, biomass and from air and converting into valuable products. Rather than considering CO2 as a waste gas it can be considered a resource if it is used in industrial applications, for strengthening of concrete by injecting captured CO2 where it gets mineralized and stored permanently. In transport and industrial sectors, with the help of green hydrogen it can be converted into e-fuels or synthetic methanol, Algae bioreactors as a biological system, also recycle CO2 by converting it into biomass for bio fuels, animal feed or bioplastics. This approach plays a significant role in mitigating CO2. All these illustrations convey how carbon recycling can change discharges into economic value while contributing to global emissions reduction targets. Not only CO2 lies at the heart of climate challenge but also at the center of potential solution.

DECLARATIONS

Availability of Data and Materials

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing Interests
The authors declare that they have no competing interests.
Funding
The authors received no specific funding for this work.

Authors' Contributions
Lt Col Prabhat K Prasad (Retd), PhD Scholar, perceived the study, designed the methodology, carried out the analysis, and drafted the manuscript. Dr Manish Gangil, Guide, supervised the research, provided expert review, and contributed to refinement of the final manuscript. Both authors approved the final version of the paper.

Acknowledgements
The authors express their sincere gratitude to the Journal of Engineering and Applied Science editorial team for their support during the submission process.

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