Carbon Emissions for Sustainable Soil Health

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ABSTRACT:
This article presents an innovative blockchain-based system that integrates carbon emission management with sustainable agricultural practices. The approach focuses on capturing industrial CO_2 emissions, filtering them using amine scrubbers, and storing the purified CO_2 in pressurized tanks. The stored CO_2 is then transported and precisely injected into agricultural soil using a surface infrastructure equipped with pressure control mechanisms, flow meters, and injection nozzles, ensuring no leakage into the atmosphere. The proposed system addresses the limitations of current carbon capture technologies, which often neglect agricultural integration and are cost-prohibitive. By leveraging blockchain, the platform securely validates and matches farmers soil carbon requirements with industrial CO_2 availability. Smart contracts automate the process, enabling transparent transactions between industries and farmers. Farmers receive financial incentives, while industries gain a cost-effective solution for managing emissions, reducing compliance costs, and enhancing their environmental footprint. The paper highlights the significance of this system in advancing sustainable development by offering a dual benefit: improving soil health through carbon sequestration and mitigating greenhouse gas emissions. This novel framework bridges the gap between industrial emission reduction and agricultural sustainability, contributing to global climate goals.

***Keywords**: Blockchain validation, smart contract execution, CO_2 filtration, transportation infrastructure, and advanced soil injection mechanisms.*

I.INTRODUCTION

Climate change and soil degradation are two interconnected environmental challenges that urgently require innovative and multidisciplinary solutions. Industrial CO_2 emissions, contributing nearly 40% of global emissions are a major driver of global warming, while the depletion of organic carbon in agricultural soils poses a severe threat to global food security. Unsustainable agricultural practices have led to declining soil fertility and productivity, exacerbating the pressure on farmers and ecosystems alike. Current technologies like Carbon Capture and Storage (CCS) focus primarily on capturing and sequestering CO_2 in geological formations. However, these approaches often lack scalability, involve high costs, and fail to deliver additional benefits such as addressing soil health. This dual crisis necessitates a novel approach that integrates emissions reduction with sustainable agricultural practices.

The CarbonConnection paper proposes a transformative solution that repurposes industrial CO_2 emissions to enrich agricultural soils, tackling both challenges simultaneously. The process begins with the capture of CO_2 from industrial flue gases using advanced technologies such as amine scrubbing, which efficiently filters and compresses CO_2 for transport. The captured CO_2 is then transported through pipelines or storage cylinders to farmlands, where it is injected into the soil using specialized subsurface systems. This soil injection process enhances soil organic carbon (SOC) levels, improves microbial activity, and boosts soil fertility, leading to increased agricultural productivity. A blockchain-powered platform underpins this system, ensuring transparency, accountability, and secure transactions. The platform incentivizes industries with carbon rewards for reducing their emissions, while farmers gain financial benefits and improved soil health through carbon-enriched practices.

CarbonConnection is more than just a technological innovation it establishes a collaborative framework between industries and farmers, creating a system where one sector's waste becomes another's resource. By reducing atmospheric CO_2 levels and promoting sustainable farming, the project offers dual environmental and economic benefits. Industries can offset their emissions, meet regulatory requirements, and earn financial incentives, while farmers benefit from improved crop yields, reduced dependence on chemical fertilizers, and additional revenue streams. With its scalable and transparent model, CarbonConnection aligns with global climate goals, including the Paris Agreement, and sets a benchmark for integrating blockchain, carbon capture, and agricultural sustainability. This research explores the feasibility, scalability, and impact of CarbonConnection, showcasing its potential to address climate challenges while fostering resilience in agriculture and industry.

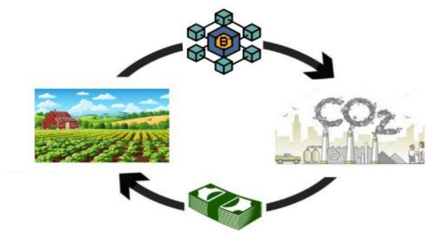

Fig1: Industry emitted carbon dioxide utilization for soil enrichment through Blockchain

a.Problem statement:
Carbon capture technologies such as Carbon Capture and Storage(CCS) and Direct Air Capture(DAC) are designed to mitigate CO_2 emissions but face challenges including high costs, energy demands, and limited scalability. CCS focuses on geological storage with risks like leakage and geographical constraints, while DAC systems are cost-prohibitive and lack integration with practical applications such as agriculture. These systems prioritize storage over utilization, missing the potential for enhancing soil organic carbon (SOC) through repurposed CO_2. A scalable, cost-effective solution is needed to bridge carbon capture with sustainable agricultural practices, addressing both emissions reduction and soil health improvement.

b. RESEARCH GAP :

- Current research focuses majorly on energy optimization, integration, and storage of carbon capture technologies.
- The reason of repurposing captured CO_2 for agricultural applications, for soil enrichment, is largely overlooked.
- Limited attention is given to enhancing soil fertility while reducing dependence on chemical fertilizers using CO_2.
- Integrating industrial CO_2 capture with agricultural repurposing remains an underexplored solution for dual environmental and agricultural benefits.
- There are no any innovative frameworks supported by blockchain for transparency.

ii. Literature Review:

LIXIA WANG, et al., (2024), propose a synergistic operation mode integrating Power-to-Gas (P2G) with Carbon Capture and Storage (CCS) to enhance the economic and low-carbon performance of Integrated Energy Systems (IES). The paper introduces an extended carbon emission flow model that incorporates electric energy storage devices, optimizing the "generation-capture-utilization" pathway of CO_2 emissions. By utilizing a parallel multi-dimensional approximate dynamic programming algorithm.

ZHAOPENG LIU, et.al., (2023), in their article, propose an optimal capacity configuration methodology for a Low-Carbon Energy System (LCES**),** integrating advanced technologies like oxygen-enriched combustion capture and high-temperature solid oxide electrolysis cells (SOECs). Their work introduces a multi-operational scenario extraction model using a multi-stage data processing algorithm and employs Conditional Value at Risk (CVaR) to address risks and uncertainties.

Gunawan,et.al.,(2023) developed an optimized methodology for CO_2 capture, transport, and storage systems, emphasizing the economic and environmental feasibility of industrial hubs in Louisiana. Their findings highlight the significant reduction in pipeline length and transport costs with shared infrastructure, while also addressing social and environmental justice considerations. This comprehensive study provides valuable insights for designing cost-effective CCTS networks tailored to regional needs.

Friedel Pretorius,et.al.,(2022) methodology outlines the specific measurement and reporting methodology for the capture component of a capture-transport-storage project and is intended to be used alongside a transportation and in-situ carbon storage methodology to create a complete methodology for the capture transport-storage project. The Transport and Storage methodologies/y are to be used to provide technology specific quantification of the emissions and monitoring of transported and injected and released/escaped CO2.

Rajesh Govindhan,et.al.,(2021) introduced an innovative BECCS/U system that integrates bioenergy carbon capture with agricultural greenhouse CO_2 enrichment. Their study demonstrated enhanced crop yields (13.8%) and reduced water requirements (28%) within the energy-water-food nexus. This comprehensive techno-economic and environmental assessment highlights BECCS/U's potential to achieve negative emissions and optimize resource management for sustainable agriculture.

Xiaoxin Zhou,et.al.,(2021) paper has proposed the concept of the integrated energy production unit (IEPU), combining the conventional coal fired generation unit with biomass co-combustion and CO2 capture, PV, hydrogen production through water electrolysis and methanol/methane. Efficient solution for the low-carbon/zero-carbon transformation of the coal-fired power plant and to support the safe and stable operation of power systems with high penetration of non-hydro renewable energy.

Noelia Faginas-Lago ,et.al.,(2020) has been studied Bilayer graphtriyne as a material for CO2 capture and gas separation, showing high CO2 uptake, selectivity, and permeability. Computational simulations and advanced molecular dynamics (MD) modeling have provided insights into its performance under various conditions. While selectivity for CO2/H2O systems is limited, bilayer graphtriyne remains a promising option for efficient gas separation in post-combustion processes.

Xin zaho,et.al.,(2020) paper introduces the dynamic parameters by treating the three parameters related with the enterprises and banks as decision variables .Especially under the back ground of electricity market reform, introducing the dynamic parameter of low-carbon subsidies, we can develop a more realistic game model of the cooperation of low-carbon power grid technology innovation. This model can be used to study the low-carbon development of Chinas power grid market under the policies of phasing out subsidies, and obtain more accurate simulation results.

S.No	Year	Author's	Article Title	Key Findings
1	2024	LIXIA WANG,et.,al,	Low-Carbon Economic Dispatch of Integrated Energy System Considering Expanding Carbon Emission Flows	• Integration of Carbon Capture and Storage (CCS) with Power-to-Gas (P2G) • Introduced the concept of Electricity-Carbon Ratio
2	2024	ZHAOPENG LIU,et.,al	Optimal Capacity Configuration of a Low-Carbon Energy System Considering Carbon Capture Technology and Hydrogen-Diversified Utilization Under Multiple Operational Scenarios.	• Enhanced Low-Carbon Energy System (LCES) Design • The research underscores the importance of integrating advanced carbon capture and hydrogen utilization technologies in optimizing energy systems for low-carbon objectives.
3	2023	Srinu Nagireddi,et.,al	Carbon Dioxide Capture, Utilization, and Sequestration: Current Status, Challenges, and Future Prospects for Global Decarbonization	• Significant GHG Emission Reduction • CO2 can be converted into fuels, chemicals, minerals, or used in biological processes, offering diverse avenues for its productive use.
4	2023	Tubagus Aryandi Gunawan,et.,al.	Design Insights for Industrial CO_2 Capture, Transport, and Storage Systems	• CO_2 Capture Potential • Identified Storage Sites
5	2022	Friedel Pretorius	Carbon Dioxide Removal by Direct Air Capture	• Injection Wellhead as Measurement Point • Monitoring and Data Management Requirements • Modular Framework for Transport and

				Storage
6	2022	Atanu Mukherjee, Saurav Chatterjee	Carbon Capture, Utilization and Storage (CCUS)	• Decarbonization Commitments and Challenges • Potential of Direct Air Capture (DAC • Intermittency of Renewable Energy
7	2021	Xiaoxin Zhou,et.,al	Integrated Energy Production Unit: An Innovative Concept and Design for Energy Transition Toward Low-carbon Development	• Integrated Energy Production Unit (IEPU) integrates multiple energy technologies • System Stability with High Renewable Energy Penetration.
8	2021	Ikhlas Ghiat,et.,al.	A novel 'plant to plant' approach driven by bioenergy with carbon capture systems within the energy, water and food Nexus	• Integration of BECCS/U within the Energy-Water-Food Nexus • CO_2 Enrichment Benefits for Agriculture This work underscores the dual benefits of BECCS/U pathways—enhancing food production systems while achieving substantial CO_2 emission reductions, thus aligning with global sustainability and climate goals.
9	2020	XIN ZHAO,et.,al.	Tripartite Evolutionary Game Theory Approach for Low-Carbon Power Grid Technology Cooperation With Government Intervention	• Development of a Tripartite Evolutionary Game Model. • emphasizes the feasibility of fostering low-carbon technology innovation in the power grid through market-driven mechanisms and collaborative efforts between grid enterprises, banks, and governments, with minimal reliance on subsidies
10	2020	Noelia Faginas-Lago,et.,al.	Carbon Capture and Separation from CO2/N2/H2O Gaseous Mixtures in Bilayer Graphtriyne: A Molecular Dynamics Study	• Bilayer Graphtriyne as a CO2 Capture Material • High CO2 and H2O Permeability • Bilayer graphtriyne shows potential as an efficient material for CO2 capture and separation from gaseous mixtures, particularly due to its high CO2 and H2O permeability and selectivity.

iii.METHODOLGY

The Carbon Emission for Sustainable Soil Health paper integrates advanced carbon capture technologies with blockchain-based systems to repurpose industrial CO_2 emissions for agricultural soil enrichment. This multidisciplinary approach consists of the following key phases:

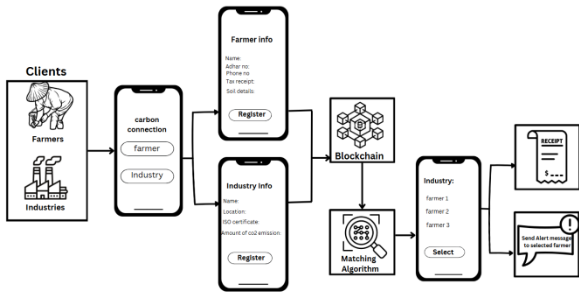

Fig2: Process Flow of Carbon Emission for Sustainable Soil Health

CO_2 Capture

- Technology Used: CO_2 is captured directly at industrial sources using amine scrubbing technology, which efficiently absorbs and separates CO_2 from other gases. After filtration, the CO_2 is stored in specially designed pressurized tanks to ensure safe handling and prevent expansion.

- Leak Prevention Measures: Rubber seals are employed at all connection points, and venture scrubbers are installed to capture any potential CO_2 leaks during the capture and storage processes.

- Output: The filtered CO_2 is compressed into a liquid or gaseous state for transportation.

CO_2 Transportation

- Transport Method: Pressurized tanks filled with compressed CO_2 are loaded onto specialized vehicles designed for safe and efficient transport to agricultural fields.

- Safety Protocols: Tanks are equipped with safety valves, pressure regulators, and monitoring systems to ensure stability and minimize risks during transit.

- Scalability: This approach allows for flexible delivery to distant and scattered farmlands, making the system accessible to diverse agricultural regions.

Soil Injection

- Subsurface Injection Technology: CO_2 is injected into agricultural soils using specialized injection systems that target depths of 30–50 cm. This method enhances soil organic carbon (SOC) levels and improves microbial activity, leading to greater soil fertility and crop productivity.

- Surface Infrastructure: Pressure maintenance systems and flow meters ensure precise control over the injection process, while injection nozzles and rubber seals prevent leaks during application.

Blockchain Integration

- Platform Design: A blockchain-based platform underpins the system to ensure transparency and security in all transactions.

- Smart Contracts: Automate transactions between industries and farmers, ensuring fair distribution of rewards and accountability.

- Data Logging: Tracks CO_2 volumes captured, transported, and injected, creating a tamper-proof ledger for monitoring and verification.

Incentive Mechanism

- Industries: Earn emission reduction rewards based on the CO_2 contributed to agricultural practices, aiding them in meeting regulatory compliance and sustainability goals.

- Farmers: Receive financial incentives for participating in soil enrichment programs, which simultaneously improve their crop yields and reduce dependency on chemical fertilizers.

Monitoring and Evaluation

- IoT Integration (Optional): IoT sensors monitor soil carbon levels, pH, and microbial activity before and after CO_2 injection. Data from IoT devices is fed into the blockchain to ensure real-time validation of outcomes.

- Evaluation Metrics: Amount of CO_2 sequestered.Improvement in soil organic carbon levels.

Economic benefits for farmers and industries.

Scalability and Optimization

Matching Algorithm: An algorithm pairs industries and farmers based on proximity and soil requirements, optimizing logistics and reducing costs.Iterative Improvements: The blockchain platform is updated continuously based on feedback from stakeholders to enhance system usability and efficiency.

This revised methodology focuses solely on pressurized tank transportation and ensures alignment with your project's practical implementation. Let me know if further refinements are needed!

Objectives:

iv.Results:

The study highlights an integrated low-carbon system combining CO_2 capture, utilization, and storage (CCUS) with renewable energy sources, advanced materials like bilayer graphtriyne for efficient CO_2 separation, and BECCS for dual energy and agricultural benefits. Case studies demonstrate significant emission reductions, enhanced CO_2 utilization pathways, and feasibility of integrated systems, showcasing a scalable, cost-effective solution for decarbonization and sustainable development.

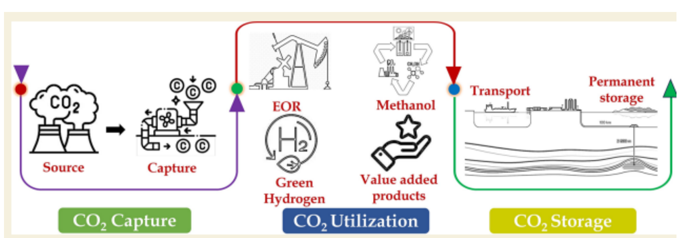

Fig3: Methadalogy

Decarbonization is the process of reducing or eliminating carbon dioxide (CO2) emissions with the goal of mitigating the effects of climate change. CO2 is a greenhouse gas (GHG's) that contributes to global warming by trapping heat in the atmosphere, and reducing its emissions is critical for achieving climate goals. The Intergovernmental Panel on Climate Change (IPCC) has identified decarbonization as one of the key strategies for limiting global warming to below above preindustrial levels.

- To Reduces atmospheric CO_2 levels, contributing to the fight against climate change.
- The need for innovative frameworks supported by blockchain for transparency and carbon reward incentives is critical for implementation
- Enriches the soil fertility, leading to higher crop productivity and food security.
- Creates new revenue opportunities for industries through carbon reward.

Provides farmers with additional income sources, improving their financial stability

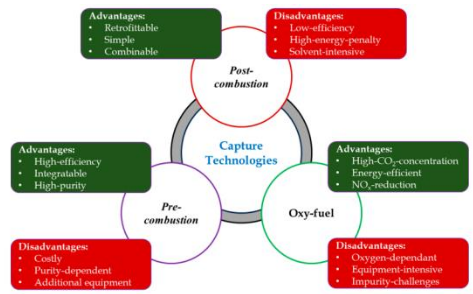

Fig4:Process Flow

Post-combustion capture is a technology designed to capture CO2 from the exhaust gases of power plants or industrial operations subsequent to the combustion process.17,66−69 Post-combustion capture is the most mature and widely deployed CCUS technology, with a number of large-scale demonstration projects and commercial applications in operation around the world.17,20,66,70−72 Post-combustion capture typically involves the use of chemical solvents, such as amine-based solutions, to absorb CO2 from flue gas. The CO2-rich solvent is then separated from the flue gas and regenerated, producing a concentrated CO2 stream that can be compressed and transported for storage or utilization.

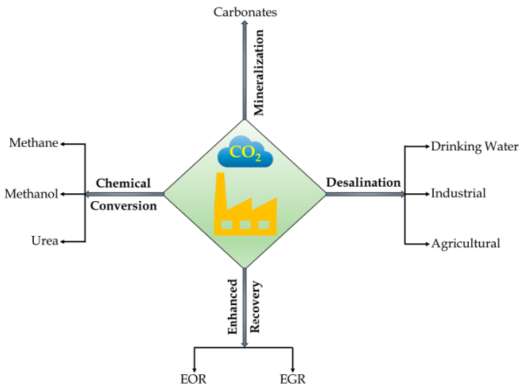

Fig5: Conversion of Carbon Process

v.CONCLUSION:

The blockchain-based software developed in this project serves as a reliable platform for managing the entire process of CO_2 collection, transportation, and utilization. It ensures secure and transparent interactions between industries and farmers, streamlining data exchange, transactions, and tracking. By leveraging blockchain technology, the software guarantees trust, accountability, and efficiency in operations, making it a robust solution for managing CO_2 emissions. This platform not only supports environmental sustainability but also enables a seamless and scalable system for stakeholders to collaborate effectively.

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