Carbon Capture and Storage Potential in India

Suriya prabhakaran M [1], Rohith V[2], Dr.Prabu T[3]
{22md07@psgtech.ac.in[1], 22md05@psgtech.ac.in[2], tpr.mech@psgtech.ac.in[3]}

ME engineering design , PSG college of technology[123]

Abstract. A developing country such as India which is one of the most populous and rapidly industrialising country, now faces a compelling need to reduce its carbon emissions and contribute to climate change mitigation efforts. The needs for carbon storage in India are driven by several factors, including the country's heavy reliance on coal for energy, expanding urbanization, and increasing emissions from industrial sectors. These factors contribute to rising CO2 levels, air pollution, and climate-related vulnerabilities. Therefore, India must prioritize strategies to mitigate emissions. Which can be achieved with the help of carbon capture and storage techniques. This paper explores the specific needs and methods for carbon storage in India. The paper also stresses the importance of reducing greenhouse gas emissions, particularly carbon dioxide (CO2), and emphasizes the unique challenges and opportunities that India encounters on its path to sustainable carbon management. The topic of carbon storage is covered in detail, including both technical and natural options. Afforestation and reforestation initiatives are examples of nature-based solutions that can be used to boost the carbon sequestration in forests, wetlands, and agricultural fields. Also investigated as ways to improve terrestrial carbon storage are sustainable farming methods and soil carbon sequestration. Technology-based strategies like Carbon Capture and Storage (CCS) are also taken into consideration. The study discusses the difficulties of implementing CCS technology widely in India as well as the promise of these technologies in capturing CO2 emissions from industrial processes and power production facilities. This paper also discusses about the importance of integrated strategies that combine nature-based solutions, technological advancements, and policy incentives to achieve effective CCS in India. It further emphasizes the need for international collaboration, research, and investment to support India's efforts in addressing its carbon storage needs while advancing global climate goals.[1]

Keywords: carbon capture; carbon storage; carbon sequencing and afforestation

1 Introduction

Over the past few decades, India, a nation with a vast array of cultural traditions and a booming economy, has experienced extraordinary growth and development. The swift urbanisation and industrialisation that have driven this shift have propelled India into the spotlight as a major economic force. But this expansion has come at a price: the country's carbon content has significantly

ICSETPSD 2023, November 17-18, Coimbatore, India

DOI 10.4108/eai.17-11-2023.2342860

increased (30).[2] For India, industrialization has been a double edged sword. On the one hand, it has aided in the evolution of technology and served as an engine for economic growth, pulling millions out of poverty. However, it has also resulted in a variety of environmental and sustainability issues, with the rise in carbon emissions being of particular concern. In-depth analysis of the causes, effects, and potential mitigation measures of India's rapid industrialization and its rising carbon content is provided in this paper.[3] A planned programme of economic self sufficiency and moderate industrialization defined India's post-independence era. However, India started moving towards economic liberalisation and globalisation in the early 1990s, which led to a surge in industrial growth. Along with services, the manufacturing sector emerged as a key engine of the Indian economy, greatly boosting GDP and employment. In India, the energy-intensive industrial sector, which includes the steel, cement, and chemical industries, has been a significant source of carbon emissions.[4] Significant amounts of carbon dioxide (CO2) have been released into the atmosphere as a result of the burning of fossil fuels, particularly coal, for the production of electricity and industrial activities (2-4). In addition, the expansion of the Automobile sector and the rise in demand for energy-hungry equipment has led to anincrease in emissions from the household and transportation sectors.[5] Many Indian cities air quality has gotten worse along with the rise in carbon emissions. The release of CO2 coupled with particulate matter, sulphur dioxide (SO2), nitrogen oxides (NOx), and volatile organic compounds (VOCs) has led to significant air pollution (22-24). Poor air quality has a significant negative impact on public health, increasing the risk of cardiovascular disease, respiratory ailments, and shorter life spans. India's growing carbon footprint has a substantial impact on climate changes worldwide. A variety of climate related risks, such as extreme weather occurrences, shifting rainfall patterns, and increasing sea levels, are present throughout the country. These effects have an influence on infrastructure, water resources, and agriculture, providing significant obstacles to India's sustainable growth.[6]

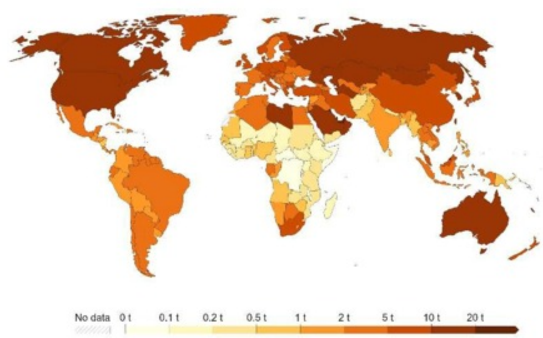


Fig. 1. Global per Capita CO2 emissions as of 2021(32)

India has produced almost 1 to 2 tonnes of CO2 in the year 2021 which can be seen in the above figure. To reduce its CO2 production India has taken several policy measures and mitigation strategies. The National Action Plan on Climate Change (NAPCC) outlines a comprehensive framework to address climate change, including the development of renewable energy sources, energy efficiency measures, and afforestation programs. India has also made ambitious commitments to expand its renewable energy capacity. While India's efforts to mitigate carbon emissions are commendable, they face numerous challenges. Energy access for a growing population, energy security, and the economic costs of transitioning to low-carbon technologies are some of the key hurdles. Balancing industrial growth with environmental sustainability is an ongoing challenge but also an opportunity to leverage green technologies, create jobs, and secure a more resilient future (31).[7] The relationship between India's fast industrialization and the rise in carbon content is a complicated and multidimensional problem. Also, India contributes to almost 7.3% of CO2 in the entire world (32).[8] As we shift toward cleaner energy systems and reduce emissions in high-impact sectors like construction and transportation, people are actively striving to extract carbon from the atmosphere. We are adjusting our approaches to building, consumption, travel, and energy generation. Techniques like CCS demonstrate our ability to collaborate with the natural environment in addressing the climate crisis[9] While industrialization has helped millions of people live better lives and contribute to economic progress, it has also had negative effects on the environment, including an increase in carbon emissions, air pollution, and climate vulnerability (14). India is attempting to reconcile industrial expansion with sustainability through new policy measures in light of these difficulties. The nation's capacity to negotiate this complex terrain and carve a route towards sustainable development that is both economically successful and environmentally responsible will determine the trajectory of India's carbon content in the future, which is in accordance with SDG (Sustainable Development Goals) 13, which deals with the climate action that advocates to reduce the net zero carbon production.[10]

2 STEPS AND SIGNIFICANCE CCS

Climate change is primarily caused by an increase in greenhouse gases, particularly carbon dioxide (CO2), in the Earth's atmosphere. These gases trap heat, which causes global warming. By capturing and storing CO2 emissions, carbon storage devices help to reduce the amount of CO2 released into the atmosphere, so halting the rise in global temperatures.[11] Carbon Capture and Storage (CCS) 1s a technology designed to reduce the release of carbon dioxide (CO2) emissions into the atmosphere, primarily from industrial processes and power generation (1-4). It is an essential component of efforts to combat climate change by mitigating greenhouse gas emissions. Generally, CCS is performed in 3 steps: capture, transportation, and storage (7-10).[12]

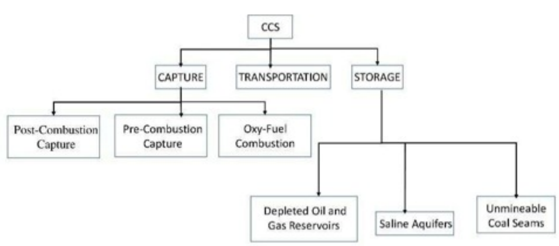


Fig. 2. Steps in CCS

2.1 Capture

It refers to the initial step in the CCS process where isolation and capture of CO2 is performed. The source of CO2 can be any emission source ranging from large thermal power plants to any small-scale industries. The primary goal of this step is to separate CO2 from the other gases produced in combustion or industrial processes so that it can be transported and stored separately. It can be further classified as follows Post-Combustion Capture: This method involves capturing CO2 emissions after the combustion of fossil fuels. It uses chemical solvents or sorbents to absorb CO2, separating it from other emissions, hence called as Absorption process.[13] The chemical solvents or sorbents are used to remediate CO2 flue gas emissions. These substances pick out CO2 from the flue gases and absorb it. The CO2 is then released for transit and storage after the solvent or sorbent, which is now laden with CO2, is separated.[14] Pre-Combustion Capture: In this process, fuel is first converted into a gas mixture of hydrogen and carbon monoxide (syngas) through gasification process. CO2 is captured from this syngas before combustion, from which CO2 is separated with the help of chemical solvents.[15] Oxy-Fuel Combustion: Oxy-fuel combustion involves burning fuel in a mixture of oxygen and recirculated flue gas. This results in a concentrated production of CO2 that can be captured more efficiently[16]

2.2 Transportation

The act of carrying collected carbon dioxide (CO2) from the capture location, such as an industrial facility or power plant, to the storage site, where it will be safely held to prevent its escape into the atmosphere, is referred to as transportation. To deliver CO2 to the storage location safely and effectively, proper conveyance is required.[17] This is often achieved through pipelines, similar to natural gas pipelines, or by transporting CO2 in specialized tanks or ships. The transportation method depends on the distance between the capture source and the storage site. To deliver CO2 safely and effectively to the storage location, proper conveyance is required.[18]

2.3 Storage

After transportation, it becomes necessary to store CO2 to prevent its release into the atmosphere. The most commonly used storage method is geographical storage (15, 20), where deep holes are dug and CO2 is dumped into them. There are three main types of geological storage sites: Depleted Oil and Gas Reservoirs: These are previous oil and gas fields whose hydrocarbon reserves have been depleted. These reservoirs can be filled withCO2, which will safely store the CO2 while displacing any leftover hydrocarbons.[19] Saline Aquifers: These are saltwater-soaked porous rock strata that are located deep beneath. Saline aquifers can be used to inject CO2, which is stored in the gaps between the rock grains.[20] Un-mineable Coal Seams: In some circumstances, CO2 can be injected into unmineable coal seams, where it is either trapped inside the coal or adsorbed onto the coal's surface.[21]

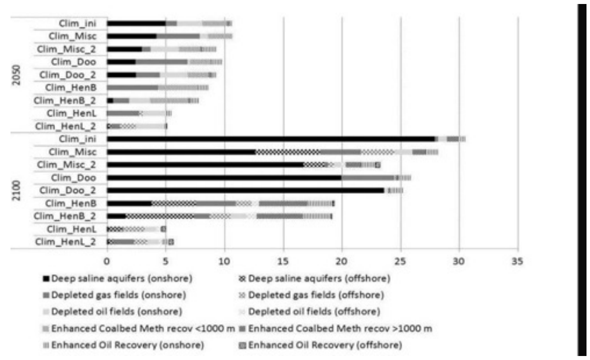


Fig. 3. Carbon storage by site with onshore/offshore classification (Gt CO2) (3)

2.4 Significance of CCS

CCS is considered an important technology for mitigating carbon emissions for several reasons. From the above graph we can interpret that introducing CCS can decrease the amount of CO2 content in the atmosphere by a great margin. Some other significances of CCS are given as follows

• Emissions Reduction: In industries with few other options, CCS can drastically reduce CO2 emissions from industrial operations and power plants.[22]

• Negative Emissions: By extracting more CO2 from the atmosphere than is emitted, some CCS systems, such Bioenergy with Carbon Capture and Storage (BECCS), can provide net-negative emissions (4).[23]

•Carbon Management: CCS aids in controlling carbon emissions from sources like heavy industries that are difficult to entirely decarbonize.[24]

• Energy Security: CCS can enable the continued use of fossil fuels while reducing their environmental impact by trapping CO2 from their combustion.[25]

However, CCS also faces challenges such as planning, location, cost, infrastructure, maintenance and most importantly public acceptance. Also, it is necessary to provide long-term safety and security of stored CO2 is a critical consideration. These issues are being addressed by ongoing CCS technology research and development, making CCS a more practical weapon in the battle against global warming.[26]

3 TYPES OF CCS

Techniques for capturing and storing carbon dioxide (CO2) emissions from various sources are known as carbon storage techniques, carbon sequestration, or carbon capture and storage (CCS). These methods aid in lowering atmospheric CO2 levels, which play a significant role in climate change and global warming. Some of the most commonly used carbon capture and storage techniques are listed below.[27]

3.1 Geological Storage

a. Carbon Capture and Storage (CCS): CCS involves capturing CO2 emissions from industrial processes or power plants and injecting them into underground geological fonnations, such as depleted oil and gas reservoirs, saline aquifers, or deep coal seams. This prevents the CO2 from escaping to the atmosphere[28]

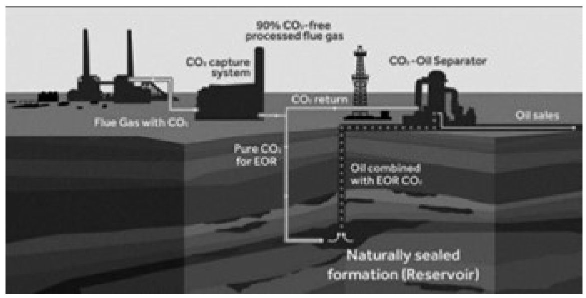


Fig. 4. Schematic of EOR (33)

b. Enhanced Oil Recovery (EOR): In some cases, CO2 is injected into oil reservoirs to increase oil recovery. This is a form of CCS where the CO2 is stored underground while also aiding in energy production

3.2 Terrestrial Carbon Storage

a. Afforestation: Planting trees in areas where they did not previously exist or have been removed. Trees absorb CO2 during photosynthesis and store it in their biomass and in the soil.[29] b. Reforestation: Restoring previously forested lands that have been deforested or degraded. This can help increase carbon storage in ecosystems.[30]

c. Soil Carbon Sequestration: Implementing practices that enhance carbon storage in soils, such as no-till agriculture, cover cropping, and agroforestry. Healthy soils can store significant amounts of carbon.[31]

d. Wetland Restoration: Wetlands are highly effective at sequestering carbon. Restoring or conserving wetland ecosystems can help store CO2 in vegetation and soil.[32]

3.3 Oceanic Carbon Storage

a. Ocean Fertilization: This involves adding nutrients (such as iron) to the ocean to stimulate the growth of phytoplankton, which absorbs CO2 during photosynthesis. However, this technique is controversial due to potential ecological risks.[33] b. Ocean Alkalinity Enhancement: Increasing the alkalinity of seawater can enhance its capacity to absorb and store CO2, but this approach also has potential environmental impacts.[34]

Accelerating the natural weathering process of certain minerals (e.g., olivine) can capture CO2 directly from the atmosphere and store it in the form of stable carbonates. This approach is considered a long-term and secure method for removing and storing CO2. Mineralization is often referred to as ”mineral carbonation” or ”enhanced weathering.[35]

3.4 Direct Air Capture (DAC)

A cutting-edge technology in the area of carbon capture and storage (CCS) is direct air capture (DAC). Instead, then capturing carbon dioxide (CO2) emissions at their source, such as industrial sites or power plants, it is intended to remove CO2 straight from the atmosphere. DAC is a promising strategy to combat climate change by decreasing the atmospheric concentration of CO2. An emerging technique called direct air capture has the potential to be very helpful in combating climate change and achieving net-zero emissions. It shows potential as a useful instrument in the larger portfolio of climate mitigation methods as research and development in DAC proceed.[36]

3.5 Biomass Energy with Carbon Capture and Storage (BECCS)

This combines biomass energy generation (e.g., from crops or forestry residues) with CCS to achieve negative emissions. CO2 is captured during biomass combustion and then stored underground. The trees help in a greater magnitude to store the biomass as a

3.6 Deep Ocean Storage

This technique involves storing CO2 at great depths in the ocean, where the CO2 is turned into a dense liquid-like fonn due to high pressure and low temperature.

Each of these carbon storage techniques has its advantages and challenges, also their effectiveness can vary depending on factors such as geological conditions, ecosystem health, and the availability of resources. Sometime a combination of these techniques may be necessary to effectively reduce carbon emissions and combat climate change. Additionally, it’s important to consider the environmental and social implications of these techniques when implementing them on a large scale.

4 POSSIBLE TECHNOLOGIES IN COIMBATORE

India, like many countries, is exploring various Carbon Capture and Storage (CCS) technologies to reduce carbon dioxide (CO2) emissions from industrial processes, power generation, and other sources. The suitability of specific CCS technologies in India relies on various elements such as the type of emissions, geographical location, and available resources (3, 8). Some of the technologies that have a lot of scope in India are Bioenergy with Carbon Capture and Storage (BECCS), Carbon Sequestration, Direct Air Capture (DAC) and Geological storage (28). To gauge the potential of CCS in a city like Coimbatore, it’s essential to begin by comprehending the city’s geological positioning.

Coimbatore is the third largest city in Tamil Nadu, with a population of about 1.85 million covering an area of 257 sq. km. The city is situated on the banks of the river Noyyal surrounded by the Western Ghats. The city is renowned for its production of motor pump sets and a wide range of

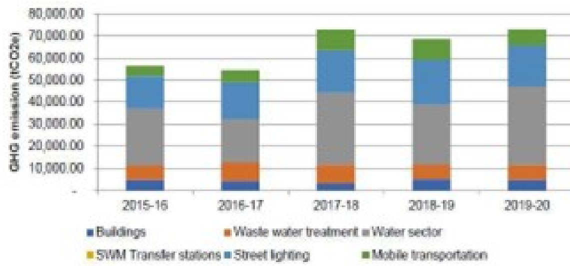


Fig. 5. Trend of GHG-CO2 emission from 2015 -20

engineering goods, including textile machinery, automotive components,motors, electronics, as well as steel and aluminium foundry products. The city boasts a bountiful supply of hills, woodlands, rivers, and wildlife. The Western Ghats within the district are the sources of rivers like Bhavani, Noyyal River, Aliyar, and Siruvani, which serve as crucial water sources for drinking and irrigation purposes for both the city's residents and local farmers. The district's forests cover an expansive 693.48 square kilometers within its total area of 7,433.72 square kilometres. The need for CCS technologies in Coimbatore becomes necessary as the city produces almost 70 tonnes of CO2 per year as of 2020, which can be observed from the above graph. By the close of this century, Coimbatore is projected to experience a rise in the average maximum temperature of 3.3°C and an increase in the average minimum temperature of 3.4°C. Additionally, there is an expected uptick in rainfall of up to 0.5% by 2050, accompanied by a growing occurrence of brief, high intensity rainfall events (42). Also, the rapid industrialization after the COVID-19 pandemic has led to further increase in CO2 emissions much greater than the recorded values. For a city like Coimbatore, boasting several advantages in geological location as well as a plethora of Industries, the most suitable CCS methods would be Carbon Sequestration/ Terrestrial Carbon storage with major focus on Afforestation and Reforestation, and the second most suitable method would be Bioenergy Carbon Capture and Storage (BECCS). It also becomes necessary to understand about these methods in detail to further support this claim.

4.1 Carbon sequestration

Carbon sequestration, involves the process of extracting carbon from the atmosphere and securely storing it, represents just one of the numerous strategies employed in the fight against climate change. Halting further warming of the Earth's atmosphere is a substantial and collaborative endeavour by humanity to curtail CO2 emissions. Carbon sequestration is widely acknowledged as a pivotal means of extracting carbon from the Earth's atmosphere.

It's crucial to highlight that approximately 45% of the carbon dioxide released by human activities remains within the atmosphere, a major contributor to global warming. Carbon sequestration serves as a means to both mitigate and manage additional emissions that would otherwise exacerbate planetary warming, as illustrated in the provided figure. Carbon sequestration is generally possible in two basic forms: biologically or geologically sequestration. Additionally, even while it is pro-

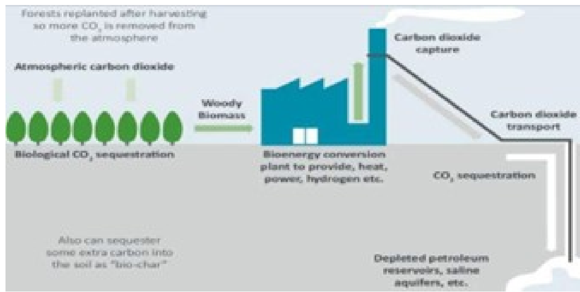


Fig. 6. A working Schematic of Carbon Sequestration (43)

moted artificially through a variety of techniques, sometimes it also occurs naturally on a massive scale.

4.1.1 Biological carbon sequestration

When carbon is stored in the enviromnent, 1t 1s called as Biological Carbon sequestration. This includes the so-called ”carbon sinks,” which include soil, meadows, oceans, and other bodies of water in addition to trees. Another name for this is ”indirect” or passive method of sequestration.

4.1.2 Forests

Woodlands and forests are thought to be among the greatest natural systems for storing carbon. During photosynthesis, CO2 binds to plants and exchanges it for oxygen as a purifying emission. Also, each plant/tree has its own capacity to store CO2. Forests absorb twice as much carbon as they release, while other vegetative types like grasslands and rangelands (fields, prairies, shrublands, etc.) are thought to store an additional 25% of the world's carbon emissions. as illustrated in the below graph where different type of forest absorbs different rates of CO2.

Thus, maintaining these natural habitats is essential to guaranteeing that carbon sinks efficiently absorb CO2. The main threats to this natural process areconstruction and intensive agriculture, together with deforestation.

4.1.3 Soil

Carbon can be sequestered and preserved as carbonates in bogs, peat, and swamps. As CO2 combines with various mineral elements like calcium or magnesium over thousands of years, these carbonates accumulate. Carbon eventually escapes the planet, though not for an exceptionally lengthy duration-more than 70,000 years, in some situations.

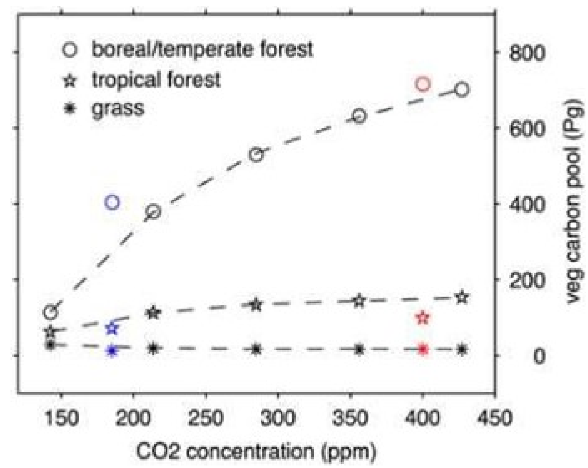


Fig. 7. Simulated Carbon Storage through Carbon Sequestration for different types of reforestations (34)

4.1.4 Oceans

Massive reservoirs of water and aquatic habitats are excellent CO2 absorbers. They take up an additional 25% of the CO2 that is sent into space by the earth's atmosphere. The ocean's upper layers contain the majority of this carbon. However, too much may acidify the water, endangering the biodiversity below - another reason to reduce the amount of carbon in our atmosphere.

4.1.5 Geological carbon sequestration

It happens whenever carbon is sequestered in materials like rocks or subterranean geological formations. This mechanism, which is primarily artificial or "direct," is a useful means of offsetting emissions from human activities like building and manufacturing. As a result, it's also mostly technological, with new developments demonstrating more efficient large-scale carbon sequestration. They generally include:

4.1.6 Graphene Production

CO2 is a basic ingredient needed in the synthesis of graphene. Though restricted to specific sectors, it plays a significant role in the manufacturing of everyday technological goods like computer chips and cell phones.

4.1.7 Engineered Molecules

By absorbing carbon from the atmosphere, scientists are able to reshape molecules into new substances. In actuality, this might offer a productive means of producing raw materials and lowering atmospheric carbon.

4.1.8 Scaling of Carbon Sequestration

Researchers are still trying to create technologies that would enable large-scale carbon sequestration in a short amount of time. Any activity that captures carbon dioxide emissions will hasten our transition to carbon neutrality. The easiest method to scale up carbon capture is to support the expansion of our natural environment while protecting what is already in place. Large-scale carbon capture will be made possible by rewilding, reforesting, or reclaiming of agriculturalland. Pollution removal from our lakes, seas, and oceans will also aid in this process.

4.2 Bioenergy Carbon Capture and Storage (BECCS)

A new strategy called bioenergy with carbon capture and storage (BECCS) combines the production of bioenergy with carbon capture and storage (CCS) to attain zero carbon dioxide (CO2) emissions. It entails removing CO2 from the environment by capturing more CO2 from the atmosphere than is released. Anaerobic digestion of organic solid waste is one of the mechanisms for sustainable development since it permits both the energy-efficient disposal of solid waste and the use of biogas (36). After combustion a lot of CO2s is released into the atmosphere, due to burning of organic materials. The CO2 emissions are captured before they are released into the atmosphere after the bioenergy has been produced. Pre-combustion capture, post-combustion capture, and other capture technologies any suitable method can be used to accomplish this. Then the captured CO2 is transported to the storage location from the place of capture using suitable transportation methods. Also, the type of storage is dependent upon the geographical location, cost etc. The sustainability and economic viability of BECCS are essential to its success. The price of biomass feedstock, the effectiveness of energy generation, and the environmental effects of biomass sourcing are all factors to be taken into account. The main benefit of BECCS is its capacity to remove CO2 from the environment on a net basis, helping to balance out emissions from other sources. However, the technique has issues with cost effectiveness, energy efficiency, and sustainably sourced biomass.

Fig 8. The process of carbon Sequestration through trees (24) It is necessary to understand that different species of plants/ trees have different capacities to store CO2 within it. Some trees along with their CO2 storing capacity for each tree are given in the table below. Table 1. Various trees with their CO2 equivalent storage

5 SUITABLE FAUNA FOR CARBON SEQUESTRATION IN COIMBATRE

It is important to select the species of fauna or trees for carbon sequestration. The selection depends on geographical location, soil fertility, monsoon, land availability, cost, maintenance and security. Some of the selective species of fauna will have a comparatively high carbon sequestration. Timber wood trees are good in carbon sequestration and valuable for its market needs too. Hence agricultural lands can be suggested with these types of trees like teak and mahogany It is also important to select it based on the geographical conditions and a simple representation of carbon sequestration using trees is shown in the fig 8 below.

It is necessary to understand that different species of plants/ trees have different capacities to store CO2 within it. Some trees along with their CO2 storing capacity for each tree are given in the

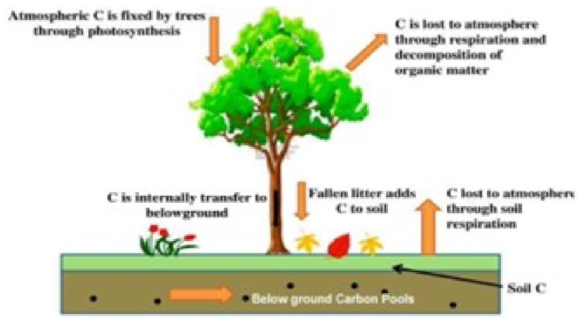


Fig. 8. The process of carbon Sequestration through trees (24)

table below.

Table 1: Various trees with their CO2 equivalent storage

Scientific Name	Common Name	CO2 Eq
Ficus benjamina	Weeping fig	70.02
Alstonia scholaris	Scholar's Tree	53.18
Plumeria Obtusa	White Frangipani	70.47
Delonix regia	Flame Tree	68.77
Neolamarckia cadamba	Kadam	69.04
Ficus microcarpa	Laurel fig	69.85
Phoenix dactylfera	Date Palm	67.13
Gravillea robusta	Silver oak	69.24
Roystonea regia	Royal palm	69.44
Callistemon vinninalis	Bottlebrush tee	70.49
Eucalyptus sp.	Eucalyptus	67.69
Musasp	Banana	70.46
Minnusops elengi	Spanish cherry	69.55
Azadirachta indica	Neem	68.94
Cassia fistu/a	Indian Laburnum	70.69
Phyllanthus emblica	Indian Gooseberry	68.30
Dalbergia Sissoo	Indian Rosewood	69.36
Ficus virens	White fig	69.01
Ficus religiosa	Sacred Fig	65.54
Marus alba	White mulberry	68.74
Largestromia speciosa	Pride of india	70.04
Peltophorum pterocmpum	copper pod	311.71
moringa oleifera	Drumstick tree	68.79
Bauhinia acuminate	Dwarf white orchid tree	69.99
Bambusa vulgaris	Bamboo	53.75
Syzygium cumini	Jamun	459.55
Jatropha curcas	Jatropha	70.50
Psidium guajava	Guava	57.06
Ficus elastica	Rubber tree	70.42
Magnifera indica	Mango	57.06

From the above table we can find the combined CO2 Equivalent of the above ground and below ground biomass carbon storage in various tree species. Peltophorum pterocmpum and Syzygium cumini shows the maximum CO2 Equivalent in terms of biomass carbon capture and storage.

Carbon sequestration in different parts of trees follows a sequence, with the bole storing the most in the early stages, followed by the branch, root, and bark. In later stages, the sequence changes to bole, root, branch, and bark. In the case of teak, carbon sequestration increases with age, and at

50 years, each tree was found to store 332.88 kg of carbon in the bole, 60.63 kg in the branches, and 80.06 kg in the roots.

Teak has the highest capacity for carbon sequestration among trees in India. This is the finding of a study conducted by the Gujarat Ecological Education andResearch (GEER) to prepare a hierarchy of local trees in India that can reduce the carbon dioxide content of the atmosphere. Carbon dioxide traps heat and is the main villain insofar as global warming is concerned. Carbon sequestration is the process by which carbon dioxide is captured from the atmosphere by trees for long-term storage. In its lifetime, a teak tree with a girth of 10-30 cm can absorb 3.70 lakh tonnes of carbon dioxide from the atmosphere. Teak's is common name in India is sagwaan while its botanical name is Tectona Grandis. It is followed by Neelgiri tree which absorbs 2.46 lakh tonnes of carbon dioxide and the Neem tree with a carbon sequestration capacity of 1.45 lakh tonnes in its lifetime. A total of 33.66 million tonnes of carbon dioxide had been sequestered by trees in non-forest areas of Gujarat.

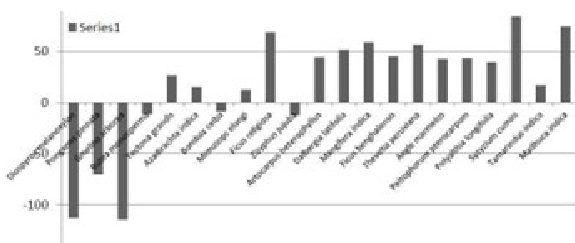
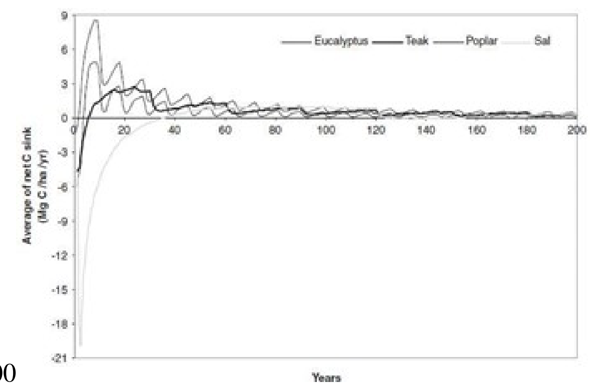


Fig. 9. Percentage change in annual carbon sequestration of trees in experimental sites over the control site, [21]

Table 2

Scientific name of tree	Carbon(kg/tree)	CO2 Sequestrated (kg/tree)
Kigelia pinnata(sausage tree)	9.7324	35.681
Agardirchta indica(Neem tree)	2.3750	8.7074
Milingtonia hortensis(cork tree)	14.342	52.583
Cyatheadeal bata(silvertree ferm)	7.0031	25.675
Peltophorum ferrogenium(Yellow flame)	6.5204	23.905

Table 2 shows the amount of carbon stored and sequestrated by the single tree of five different species from Woodstock of VIT University. From that it is clearly known that Millingtonia hortensis is the species which sequestrates carbon in large amount among the five species of trees in their consideration. These five tree species are more commonly known and well grown in most of the areas of Tamilnadu The results indicate that among the species studied, poplars have the highest potential to sequester carbon, followed by Eucalyptus plantations. These plantations hold promise for higher orgamc matter production in the Terai region



00

Fig. 10. CO2 capture with respect to age of trees (29)

6 POLICIES AND SHCEMES

In India, the use of CO2 capture is still in its infancy. Only a few industries, like steel and refineries, have carried out small-scale carbon capture operations. The National Aluminium Company (NALCO), ONGC, Bharat Heavy Electrical 228 Limited (BHEL), and Andhra Pradesh Power Generation Corporation (APGENCO) are a few enterprises that have started the process of establishing CCS plants (39).

Dalmia Cement also announced setting up of a large scale carbon capture unit (CCU) at one of its plants in Tamil Nadu as a move towards becoming carbon neutral by 2040. From the various technologies available for CO2 capture, the post-combustion solvent capture and stripping with amine-based pressure swing adsorption system is the most common.

Typically, CO2 sequestration projects are expensive and therefore not implemented in isolation in India. A dialogue has been initiated between US-DoE and DST on clean coal technologies, supercritical carbon dioxide (sCO2) power cycles and carbon capture utilisation & storage (CCUS) technologies. One of the notable outcomes of the dialogue is the participation of India in the multilateral platform for Accelerating CCUSTechnologies (ACT) through which avenues have been generated for possible US - India collaboration (DST, 2020) (38).

The introduction of newer technologies 1s significantly simplified and made more cost-effective with the presence of government policies and incentives.

There are no policies or directives from government in regards to CCS technology, which makes it hard for several small and medium scale industries to adopt. However, it's essential to note that the government's policies and programs related to climate change and environmental conservation indirectly support CCS projects. All climate change related policies advocate about CO2 reduction which is one of the major objectives of CCS. Hence incentives can be received for CCS using these government policies.

A general list of Government Policies with regards to climate change, which indirectly promotes the use of CCS technologies are given below

6.1 National Action Plan on Climate Change (NAPCC):

The NAPCC delineates India's approach to tackle climate change challenges. This encompasses initiatives such as the National Mission on Enhanced Energy Efficiency and the National Solar Mission, which indirectly play a role in diminishing carbon emissions and the demand for CCS.

6.2 Renewable Energy Development:

The state of Tamil Nadu has been a leader in renewable energy, especially in the wind energy sector. Expanding of renewable energy sources can help reduce the carbon footprint. When integrated with CCS the net carbon rate can be brought to zero

6.3 Afforestation and Reforestation

The government of Tamil Nadu, in line with national policies, supports afforestation and reforestation projects to sequester carbon dioxide. The government also offers financial aids to small industries which help in carbon sequestration through reforestation.

6.4 Industrial Initiatives

Some industries in Tamil Nadu, such as BHEL (Bharat Heavy Electrical), which have already implemented CCS technologies as part of their corporate social responsibility (CSR) to reduce the carbon content in the atmosphere to reduce global warming.

6.5 Research and Development:

Research institutions and universities in Tamil Nadu receive grants and funding for green and new technologies, which also includes CCS research and development projects.

Additionally, local environmental organizations and research institutions in Tamil Nadu that are involved in CCS projects or related research to reduce CO2 in the atmosphere are given as follows.

1. **The Energy and Resources Institute (TERI)** - Southern Regional Centre: TERI is a prominent environmental research institution in India. The

Southern Regional Centre, located in Bengaluru, Karnataka.

2. **Indian Institute of Technology Madras (IIT Madras)**: IIT Madras is one of India's premier engineering institutions. It often engages in research related to sustainable energy and environmental technologies, which includes CCS.

3. **Anna University**: Located in Chennai, Anna University is a leading educational and research institution. It has several departments or researchers working on environmental and energy-related projects.

4. **Centre for Climate Change and Adaptation Research (CCCAR) at Anna University**: This centre focuses on climate change research and may have projects related to carbon capture and storage or climate mitigation.

5. **The Nature Conservancy India (TNC India)**: TNC is a global environmental organization that works in India on a range of sustainability and conservation projects, including those that mitigate climate change.

6. **M.S. Swaminathan Research Foundation (MSSRF):** MSSRF is dedicated to sustainable agriculture and rural development. While their primary focus is agriculture, they also focus on environmental projects and initiatives in Tamil Nadu.

7. **Society for Integrated Development and Environmental Awareness (IDEA)**: IDEA is a Tamil Nadu-based local environmental group that promotes environmental conservation and awareness.

8. **The Tamil Nadu State Council for Science and Technology (TNSCST)**: This government organization supports technical advancement and scientific research inside the state. Additionally, they are working on research initiatives pertaining to energy and environmental concerns, such as CCS.

Not only government agencies but several Non Governmental Organisations (NGOs) are also interested in development and deployment of green and new technologies like CCS to have a clean environment without any CO2 in the atmosphere to reduce the risk of global warming. Some of the NGOs which take an active role in this region are mentioned below.

1. **Siruthuli**: Based in Coimbatore, Siruthuli is a well-known environmental group. Although their main focus has been on revitalizing water bodies and conserving water, they might have knowledge of or engagement with more general environmental projects that can utilize CCS.

2. **CAG Coimbatore Green Alliance:** Coimbatore Green Alliance is a local group dedicated to environmental conservation. While their primary focus may not be CCS, they could have information on climate-related projects in the region.

3. **Poovulagin Nanbargal**: This NGO is engaged in various environmental and social initiatives in Tamil Nadu. While their primary focus is on enviromnental education and conservation, they might have information on climate change and related projects.

4. **Society for Rural Education and Development (SRED)**: SRED is based in Coimbatore and works on various rural development and environmental projects. They may have insights into local environmental initiatives.

5. **The Nature Conservancy India (TNC India)**: TNC is an international environmental organization with a presence in India. They work on various conservation projects, including climate change mitigation efforts.

In a world where cutting carbon emissions is critical, CCS policies and programs are essential tools in the transition to a more sustainable and ecologically conscious future. To drive CCS deployment and achieve the required reduction in greenhouse gas emissions, governments, businesses, and stakeholders must work together in unison as technology and approaches continue to evolve.

7 ADVANTAGES AND LIMITATIONS

CCS technology has several advantages as well as limitations when introduced in a developing country like India. Some of the advantages of CCS can be summarised as follows

- Emissions Reduction: The release of carbon dioxide (CO2) from a variety of industrial activities, such as India's widely used coal-based power generation, can be greatly reduced by CCS. It can be quite important in assisting the nation in achieving its climate goals.
- Diverse Energy Sources: India has a varied energy mix, and CCS is a flexible approach to reducing emissions since it can be used for a variety of energy sources, such as coal, natural gas, and industrial pollutants.
- Energy Security: With CCS, the environmental impact of fossil fuels can be minimized while ensuring their continued usage. Given that India's energy infrastructure is still expanding and developing, this is crucial for energy security.
- Negative Emissions: In an effort to remove more carbon dioxide from the atmosphere overall, CCS in conjunction with Bioenergy with Carbon Capture and Storage (BECCS) can produce negative emissions.
- Job Creation: In order to promote economic growth, CCS projects can provide jobs in the engineering, construction, and research and development sectors. Which leads to increase in employability rate in the country.

It is also important to know and understand the limitations of CCS related projects in the country. Some of them are discussed below

- Cost: The high implementation costs of CCS provide a major obstacle to its widespread adoption, particularly in developing nations like as India. CCS project funding can be difficult to come by.
- Energy Intensity: Energy-intensive CCS may need more energy for capturing carbon and reduction. Power plants may become less efficient as a result.
- Regulatory Framework: India's legislative framework governing the deployment of CCS may require additional development and strengthening to meet concerns related to accountability and prolonged safety.
- Public Acceptance: It can be difficult for the public to comprehend and perceive CCS technology, especially when it comes to worries about the safety of subterranean storage and its effects on the environment.

- Resource Availability: One important consideration is the lack of suitable storage sites, such as saline aquifers or exhausted oil and gas reservoirs. India must evaluate these sites' suitability for carbon capture and storage (CCS).
- Competing Priorities: India has several development-related issues to deal with, such as expanding access to electricity and lowering air pollution. The implementation of CCS may be subordinated to these goals.
- Alternative Solutions: India is a desirable alternative for cutting emissions because of its rapid expansion of renewable energy potential. Purchasing renewable energy may seem like a more practical and affordable option in some circumstances.[37]

Therefore, it becomes necessary to understand the implications of using CCS technologies, but also to start implementing them in our country. The negative aspects of CCS discussed above does not rule out the possibility of using Carbon sequestration or Bioenergy Carbon Capture and Storage.[38]

8 Conclusion

The paper offers an in-depth examination of the prospects of Carbon Capture and Storage (CCS) in India, with a particular emphasis on Coimbatore. It highlights the critical role of CCS in addressing climate change and cutting down on carbon em1ss10ns, particularly in a nation marked by expanding industrial and energy sectors, such as India.[39]

It's crucial to grasp the various elements, which encompass technological choices, appropriate geological sites for storage, and the amalgamation of CCS within India's energy and industrial framework. The document accentuates the varied origins of emissions in Coimbatore and underscores the significance of custom, location-specific strategies for implementing CCS. Trend of GHG-CO2 emissions from year 2015 - 20 shows that the major sectors of CO2 emissions are the water distribution sector and buildings with an average range of 35000T CO2 equitant and 17500T CO2 equitant respectively in the Coimbatore district.[40]

Over 14 lakh saplings planted in Coimbatore forest division in 9 years.As part of efforts to increase green cover, officials of Coimbatore Forest Division planted 14.33 lakh saplings between 2012 and 2021, which supports the idea of carbon sequestration in cities ecology.[41]

Additionally, it's essential to recognize the vital role played by government policies and incentives in driving CCS initiatives, recognizing that well structured regulatory frameworks and financial backing can expedite the adoption of CCS. The paper also centres on the obstacles and constraints linked to CCS, including cost assessments, public approval, and the availability of resources.[42]

Tress like Peltophorum pterocarpum and Syzygium cumznz shows the maximum CO2 Equivalent of about 311.71 kg of CO2 and 459.55 kg of CO2 in terms of biomass carbon capture and storage. In its lifetime, a teak tree (Tectona Grandis) with a girth of 10-30 cm can absorb 3.70 lakh tonnes of carbon dioxide from the atmosphere.[43]

In summary, it can be stressed that while CCS offers a hopeful avenue for India to curtail its carbon emissions, its full potential can only be realized through collaborative endeavours involving government agencies, industries, and stakeholders. As India aims to strike a balance between economic growth and environmental sustainability, CCS emerges as a valuable instrument in working toward net-zero emissions and confronting the worldwide issue of climate change.

References

[1] Pianta S, Rinscheid A, Weber EU. Carbon Capture and Storage in the United States: Perceptions, preferences, and lessons for policy. Energy Policy. 2021 Apr;151:112149. Available from: http://dx.doi.org/10.1016/j.enpol.2021.112149.

[2] SHIGETOMI N, SHIBUYA Y, NAKANO M, AKAI M. In: CO2 underground storage and potential of CDM. Elsevier; 2005. p. 2323–2326. Available from: http://dx.doi.org/10.1016/b978-008044704-9/50326-8.

[3] Selosse S, Ricci O. Carbon capture and storage: Lessons from a storage potential and localization analysis. Applied Energy. 2017 Feb;188:32–44. Available from: http://dx.doi.org/10.1016/j.apenergy.2016.11.117.

[4] Almena A, Thornley P, Chong K, Röder M. Carbon dioxide removal potential from decentralised bioenergy with carbon capture and storage (BECCS) and the relevance of operational choices. Biomass and Bioenergy. 2022 Apr;159:106406. Available from: http://dx.doi.org/10.1016/j.biombioe.2022.106406.

[5] Kato E, Moriyama R, Kurosawa A. A Sustainable Pathway of Bioenergy with Carbon Capture and Storage Deployment. Energy Procedia. 2017 Jul;114:6115–6123. Available from: http://dx.doi.org/10.1016/j.egypro.2017.03.1748.

[6] Cuéllar-Franca RM, Azapagic A. Carbon capture, storage and utilisation technologies: A critical analysis and comparison of their life cycle environmental impacts. Journal of CO2 Utilization. 2015 Mar;9:82–102. Available from: http://dx.doi.org/10.1016/j.jcou.2014.12.001.

[7] Tan Y, Nookuea W, Li H, Thorin E, Yan J. Property impacts on Carbon Capture and Storage (CCS) processes: A review. Energy Conversion and Management. 2016 Jun;118:204–222. Available from: http://dx.doi.org/10.1016/j.enconman.2016.03.079.

[8] Linzenich A, Arning K, Offermann-van Heek J, Ziefle M. Uncovering attitudes towards carbon capture storage and utilization technologies in Germany: Insights into affective-cognitive evaluations of benefits and risks. Energy Research & Social Science. 2019 Feb;48:205–218. Available from: http://dx.doi.org/10.1016/j.erss.2018.09.017.

[9] Ferguson M, Ashworth P. Message framing, environmental behaviour and support for carbon capture and storage in Australia. Energy Research & Social Science. 2021 Mar;73:101931. Available from: http://dx.doi.org/10.1016/j.erss.2021.101931.

[10] Wang M, Gong Y, Wang S, Li Y, Sun Y. Promoting support for carbon capture and storage with social norms: Evidence from a randomized controlled trial in China. Energy Research & Social Science. 2021 Apr;74:101979. Available from: http://dx.doi.org/10.1016/j.erss.2021.101979.

[11] Broecks K, Jack C, ter Mors E, Boomsma C, Shackley S. How do people perceive carbon capture and storage for industrial processes? Examining factors underlying public opinion in the Netherlands and the United Kingdom. Energy Research & Social Science. 2021 Nov;81:102236. Available from: http://dx.doi.org/10.1016/j.erss.2021.102236.

[12] Raza A, Gholami R, Rezaee R, Rasouli V, Rabiei M. Significant aspects of carbon capture and storage – A review. Petroleum. 2019 Dec;5(4):335–340. Available from: http://dx.doi.org/10.1016/j.petlm.2018.12.007.

[13] Low S, Schäfer S. Is bio-energy carbon capture and storage (BECCS) feasible? The contested authority of integrated assessment modeling. Energy Research & Social Science. 2020 Feb;60:101326. Available from: http://dx.doi.org/10.1016/j.erss.2019.101326.

[14] Shaw P. Eckardt, F. D. (ed.) (2022): Landscapes and Landforms of Botswana. Springer, Cham, Switzerland. xxiii, 403 p., 265 figures and tables. ISBN 978-3-030-86101-8. https://doi.org/10-1007/978-3-030-86102-5. Zeitschrift für Geomorphologie. 2022 Dec;64(1):73–75. Available from: http://dx.doi.org/10.1127/zfg/2022/0770.

[15] Rakesh SS, Davamani V, Kamaludeen SPB, Maragatham S, Lakshmanan A, Parameswari E, et al. Carbon Sequestration Potential of Oil Palm Plantations in Tamil Nadu Regimes, India. International Research Journal of Pure and Applied Chemistry. 2020 Jul:7–17. Available from: http://dx.doi.org/10.9734/irjpac/2020/v21i1130220.

[16] Hanssen SV, Daioglou V, Steinmann ZJN, Doelman JC, Van Vuuren DP, Huijbregts MAJ. The climate change mitigation potential of bioenergy with carbon capture and storage. Nature Climate Change. 2020 Aug;10(11):1023–1029. Available from: http://dx.doi.org/10.1038/s41558-020-0885-y.

[17] Wei YM, Kang JN, Liu LC, Li Q, Wang PT, Hou JJ, et al. A proposed global layout of carbon capture and storage in line with a 2° climate target. Nature Climate Change. 2021 Jan;11(2):112–118. Available from: http://dx.doi.org/10.1038/s41558-020-00960-0.

[18] Gabrielli P, Gazzani M, Mazzotti M. The Role of Carbon Capture and Utilization, Carbon Capture and Storage, and Biomass to Enable a Net-Zero-CO2 Emissions Chemical Industry. Industrial & Engineering Chemistry Research. 2020 Mar;59(15):7033–7045. Available from: http://dx.doi.org/10.1021/acs.iecr.9b06579.

[19] Deolalkar SP. In: Carbon Capture and Storage (CCS). Elsevier; 2016. p. 49–58. Available from: http://dx.doi.org/10.1016/b978-0-12-803420-0.00007-x.

[20] Pandro P, Shrotriya A. Archaeological Investigations in Baihar Tehsil of District Balaghat, Madhya Pradesh. The Indian Journal of Research in Anthropology. 2023 Feb;8(2):79–94. Available from: http://dx.doi.org/10.21088/ijra.2454.9118.8222.4.

[21] Chaurasia S, Munoth N. Carbon Sequestration Potential of Urban Trees: A Case of Kolar Area in Bhopal City, India. Journal of The Institution of Engineers (India): Series A. 2022 Mar;103(2):359–374. Available from: http://dx.doi.org/10.1007/s40030-022-00621-9.

[22] Chayaporn P, Sasaki N, Venkatappa M, Abe I. Assessment of the overall carbon storage in a teak plantation in Kanchanaburi province, Thailand – Implications for carbon-based incentives. Cleaner Environmental Systems. 2021 Jun;2:100023. Available from: http://dx.doi.org/10.1016/j.cesys.2021.100023.

[23] Sharma R, Pradhan L, Kumari M, Bhattacharya P. Assessment of Carbon Sequestration Potential of Tree Species in Amity University Campus Noida. In: The 1st International Electronic Conference on Forests—Forests for a Better Future: Sustainability, Innovation, Interdisciplinarity. IECF 2020. MDPI; 2020. Available from: http://dx.doi.org/10.3390/iecf2020-08075.

[24] Peter Lang;. Available from: http://dx.doi.org/10.3726/978-3-0351-0222-2/11.

[25] Schmidt H, Anca-Couce A, Hagemann N, Werner C, Gerten D, Lucht W, et al. Pyrogenic carbon capture and storage. GCB Bioenergy. 2018 Sep;11(4):573–591. Available from: http://dx.doi.org/10.1111/gcbb.12553.

[26] Todd AC. Carbon Capture and Storage, a Global Concern Requiring Global Solutions. Chemical Engineering Research and Design. 2006 Sep;84(9):737–738. Available from: http://dx.doi.org/10.1205/cherd.ed.0609.

[27] Kaul M, Mohren GMJ, Dadhwal VK. Carbon storage and sequestration potential of selected tree species in India. Mitigation and Adaptation Strategies for Global Change. 2010 Apr;15(5):489–510. Available from: http://dx.doi.org/10.1007/s11027-010-9230-5.

[28] ICMSBE 2017. Francis Academic Press; 2017. Available from: http://dx.doi.org/10.25236/icmsbe.2017.00.

[29] Saral AM, SteffySelcia S, Devi K. Carbon storage and sequestration by trees in VIT University campus. IOP Conference Series: Materials Science and Engineering. 2017 Nov;263:022008. Available from: http://dx.doi.org/10.1088/1757-899x/263/2/022008.

[30] Wang Y, Pan Z, Zhang W, Borhani TN, Li R, Zhang Z. Life cycle assessment of combustion-based electricity generation technologies integrated with carbon capture and storage: A review. Environmental Research. 2022 May;207:112219. Available from: http://dx.doi.org/10.1016/j.envres.2021.112219.

[31] Springer International Publishing; 2022. p. 1103–1103. Available from: http://dx.doi.org/10.1007/978-3-030-87745-3_300442.

[32] LaMoreaux JW, Dörhöfer G, Kolditz O. Environmental earth sciences. Environmental Earth Sciences. 2015 Mar;73(9):5211–5212. Available from: http://dx.doi.org/10.1007/s12665-015-4260-7.

[33] Lu Z, Miller PA, Zhang Q, Wårlind D, Nieradzik L, Sjolte J, et al. Vegetation Pattern and Terrestrial Carbon Variation in Past Warm and Cold Climates. Geophysical Research Letters. 2019 Jul;46(14):8133–8143. Available from: http://dx.doi.org/10.1029/2019gl083729.

[34] Greenhouse gas emissions: Thousand tonnes CO2 equivalent. Organisation for Economic Co-Operation and Development (OECD); 2014. Available from: http://dx.doi.org/10.1787/factbook-2014-table163-en.

[35] Nair SP. In: Coimbatore II. Routledge India; 2022. p. 168–205. Available from: http://dx.doi.org/10.4324/9781003267089-10.

[36] Chandrasekaran R, Busetty S. Estimation of biogas generation rate and carbon sequestration potential from two landfill sites in southern India. Environmental Science and Pollution Research. 2023 Aug;30(41):95013–95024. Available from: http://dx.doi.org/10.1007/s11356-023-28933-8.

[37] Hari M, Srinivasan S, Rajasekaran A, Tyagi B. Above ground carbon stock mapping over Coimbatore and Nilgiris Biosphere: a key source to the C sink. Carbon Management. 2021 Jul;12(4):411–428. Available from: http://dx.doi.org/10.1080/17583004.2021.1962979.

[38] Boyd-Bowman S. Biennial Report: The Third International Television Studies Conference. Screen. 1989 Mar;30(1–2):140–143. Available from: http://dx.doi.org/10.1093/screen/30.1-2.140.

[39] Sharp JH, Lawrence CD, Yang R. Calcium sulfoaluminate cements—low-energy cements, special cements or what? Advances in Cement Research. 1999 Jan;11(1):3–13. Available from: http://dx.doi.org/10.1680/adcr.1999.11.1.3.

[40] Reginald LJ, Mahendran C, Kumar SS, Pramod P. Birds of Singanallur lake, Coimbatore, Tamil Nadu. Zoos' Print Journal. 2007 Nov;22(12):2944–2948. Available from: http://dx.doi.org/10.11609/jott.zpj.1657.2944-8.

[41] Shaw R, Mukherjee S. The development of carbon capture and storage (CCS) in India: A critical review. California Digital Library (CDL); 2022. Available from: http://dx.doi.org/10.31223/x59621.

[42] Davis MF. In: Local Governments, Climate Action, and Sustainability: The Role of Human Rights. Cambridge University Press; 2023. p. 115–131. Available from: http://dx.doi.org/10.1017/9781009039642.007.

[43] Quader MA, Ahmed S. In: Bioenergy With Carbon Capture and Storage (BECCS). Elsevier; 2017. p. 91–140. Available from: http://dx.doi.org/10.1016/b978-0-12-805423-9.00004-1.