

**A STUDY ON SEAWEED'S POTENTIAL TO REDUCE MARITIME  
GHG EMISSIONS**

Project Report Submitted in partial fulfillment for the award of the degree

of

**Master of Business Administration**

in

**International Transportation & Logistics  
Management**

by

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(A Central University, Government of India)

**MAY 2023**

## DECLARATION

I, **Mrunalini D** bearing Register Number: **2103305028**, student of MBA – International Transportation & Logistics Management, at School of Maritime Management, Indian Maritime University, Chennai Campus, hereby declare that the project report titled “**A STUDY ON SEAWEED'S POTENTIAL TO REDUCE MARITIME GHG EMISSIONS**” is my original work. This report is being submitted in partial fulfillment of the requirement for the award of the degree of Master of Business Administration (MBA) In International Transportation and Logistics Management (ITLM). The project report is output of my learnings and observations of my research under the guidance of Dr Lekha Ravi. Assistant professor School of Maritime Management, Indian Maritime University, Chennai Campus.

I declare that the information submitted is true and original to the best of my knowledge.



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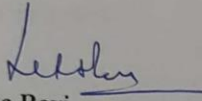
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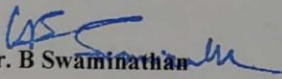
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This is to certify that this project report entitled "A STUDY ON SEAWEED'S POTENTIAL TO REDUCE MARITIME GHG EMISSIONS" submitted to the School of Maritime Management, Indian Maritime University, Chennai Campus in partial fulfilment of the requirement for awarding the degree, MBA in International Transport and Logistics Management is a genuine work of **MRUNALINI D (Reg No. 2103305028)**.



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## **ACKNOWLEDGEMENT**

I extend my heartfelt thanks to Dr B Swaminathan, Head of SMM, Chennai Campus for providing me with the facilities to carry out the project successfully.

With great pleasure, I express my sincere gratitude to Dr Lekha Ravi, Assistant Professor, School of Maritime Management, Indian Maritime University, Chennai Campus for the valuable guidance and suggestions that enabled me to complete this report successfully.

In a special way, I submit my grateful thanks to my family who motivated and encouraged me throughout the project period. I would like to profoundly thank all respondents who helped me in collecting the necessary information for the completion of this project.

Last but the least my prayers and thanks to the “almighty” without whom the work would not have been materialized.

Place: Chennai

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**2103305028**

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## **EXECUTIVE SUMMARY**

The research study " A STUDY ON SEAWEED'S POTENTIAL TO REDUCE MARITIME GHG EMISSIONS " analyses seaweed's GHG regulations and explores at several ways to mitigate carbon dioxide emissions and combat climate change.

The initial focus of the study is to provide an overview of the greenhouse gases emitted by the maritime industry and how this contributes to climate change. Subsequently, the study scrutinizes existing seaweed farming projects, analysing their impact and identifying areas for improvement.

The study also explores potential projects that could be implemented in the oceans to capture the carbon compounds emitted by the shipping industry and making necessary improvements in the existing methods and bringing new innovative solutions. While the manifold advantages of seaweed are progressively being recognized, they are seldom combined to offer a comprehensive overview of their potential - which this statement has sought to provide. Acknowledging seaweed's role as a climate change solution, including through its inclusion in countries' Nationally Determined Contributions, is pivotal to scaling up novel seaweed ventures and restoration initiatives to support pioneers and entrepreneurs in the industry.

As stated in the Seaweed Manifesto (2020), "A regenerated ocean and forests of seaweed farms should be regarded as carbon sinks to alleviate climate change. Recognizing seaweed's role as a carbon sink at the United Nations Framework Convention on Climate Change level and including it in future Conference of the Parties discussions will be vital."

Overall, the project offers valuable insights about following the biological pathways to carbon sequestration and to have an ethical, safe, sustainable, and scientifically informed seaweed industry emerge on a large scale in the forthcoming decades and to ensure safety by avoiding replicating mistakes made on land, such as cultivating monocultures, employing pesticides abusively, destroying genetic diversity, and polluting land, while simultaneously keeping pace with the urgency of the climate crisis.

**CHAPTER 1**  
**INTRODUCTION**

## 1.1 ABOUT CLIMATE CHANGE AND DECARBONIZATION IN THE MARITIME INDUSTRY:

The shipping industry plays a vital role in global trade, but it also contributes significantly to carbon emissions, accounting for approximately 2.89% of all human-caused greenhouse gas (GHG) emissions, according to the International Maritime Organization. With 80% of world trade transported by sea, equivalent to around 11 billion tons of goods annually between 150 countries, the impact of shipping on climate change cannot be ignored. To achieve the goal of becoming carbon neutral by 2050, the shipping industry must explore and implement various strategies and technologies to decarbonize its operations.

### Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years

#### Changes in global surface temperature relative to 1850–1900

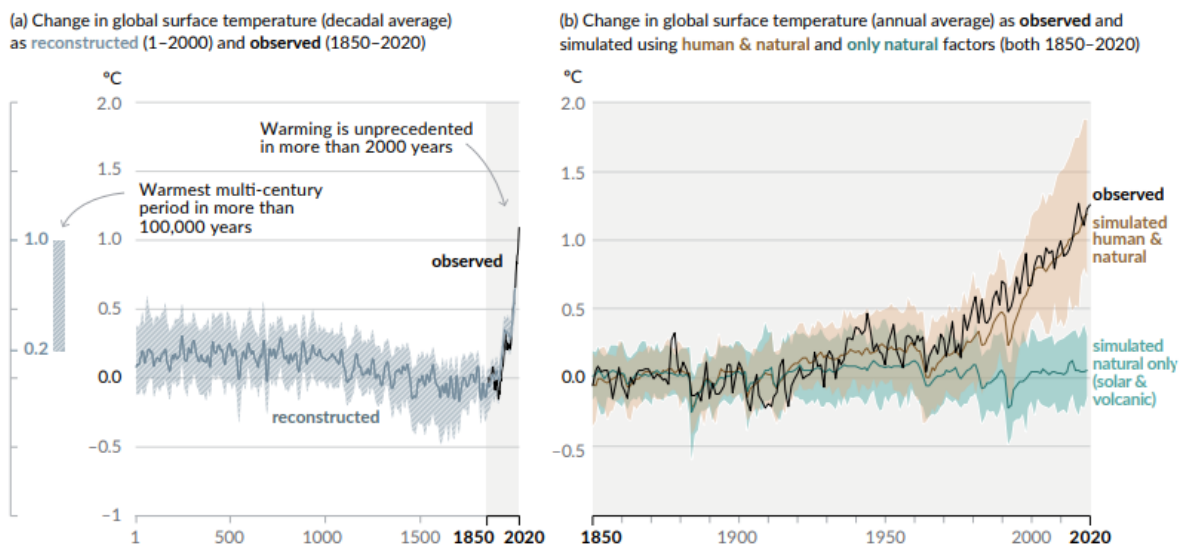


FIGURE 1.1: The causes of current warming and the progression of global warming

The shipping industry plays a vital role in global trade, but it also contributes significantly to carbon emissions, accounting for approximately 2.89% of all human-caused greenhouse gas (GHG) emissions, according to the International Maritime Organization. With 80% of world trade transported by sea, equivalent to around 11 billion tons of goods annually between 150 countries, the impact of shipping on climate change cannot be ignored. To achieve the goal of becoming carbon neutral by 2050, the shipping industry must explore and implement various strategies and technologies to decarbonize its operations.

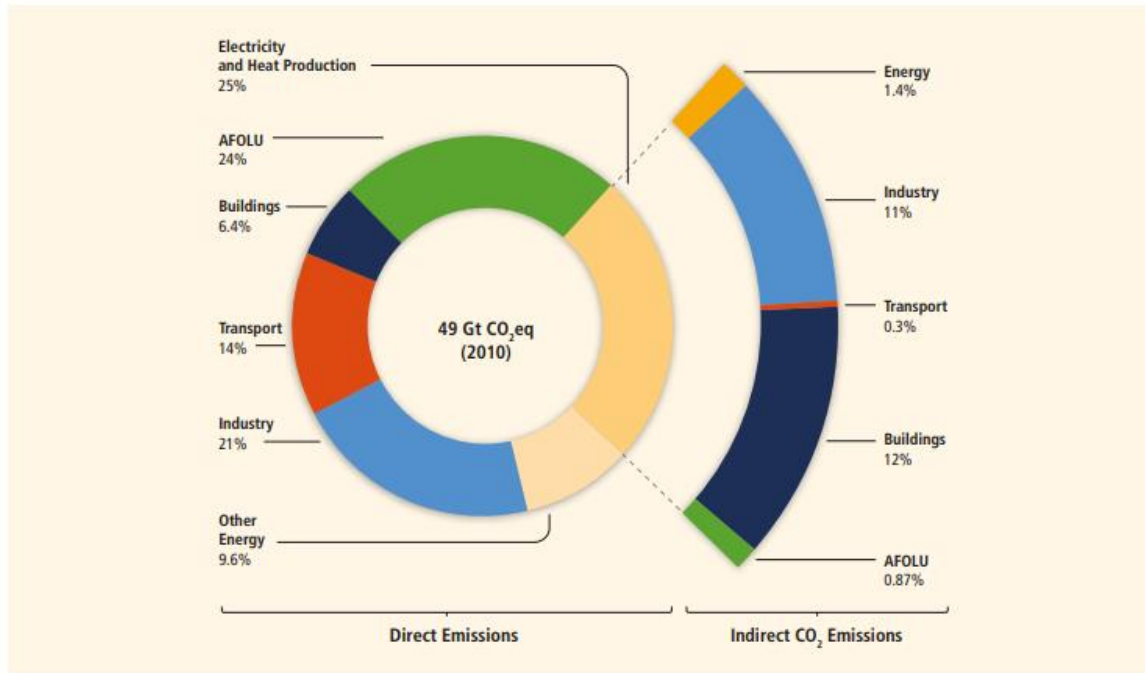


FIGURE 1.2 Emissions of Greenhouse Gases by Economic Sectors

**With every increment of global warming, changes get larger in regional mean temperature, precipitation and soil moisture**

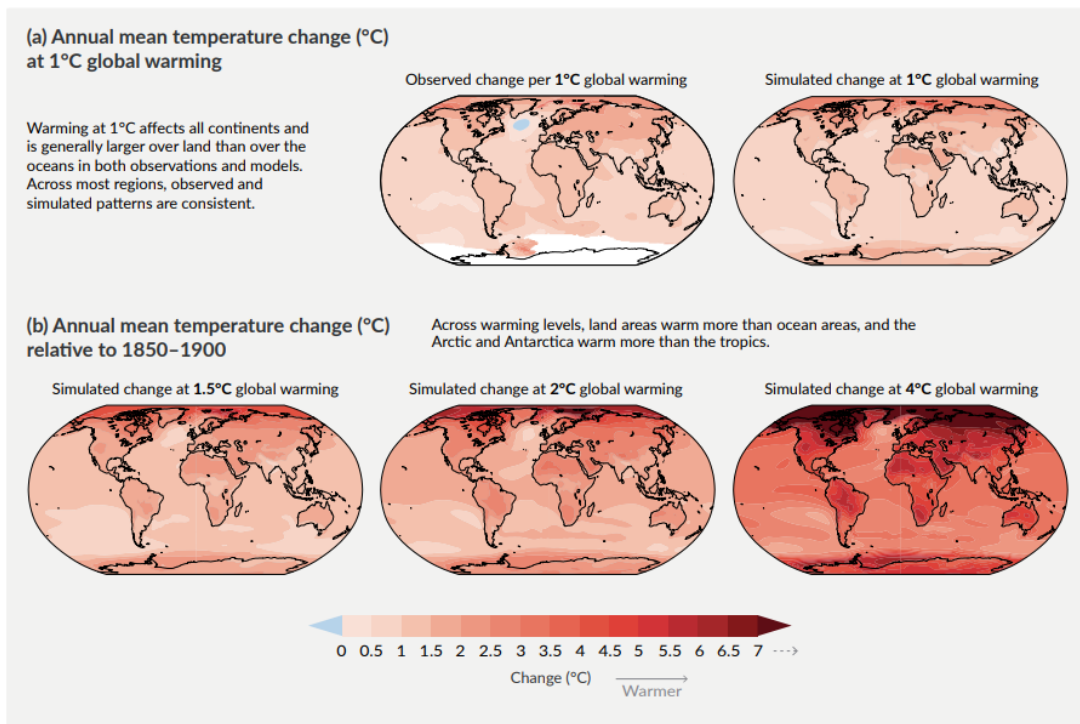


FIGURE 1.3: Impact of Global Warming on the Earth

# Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes

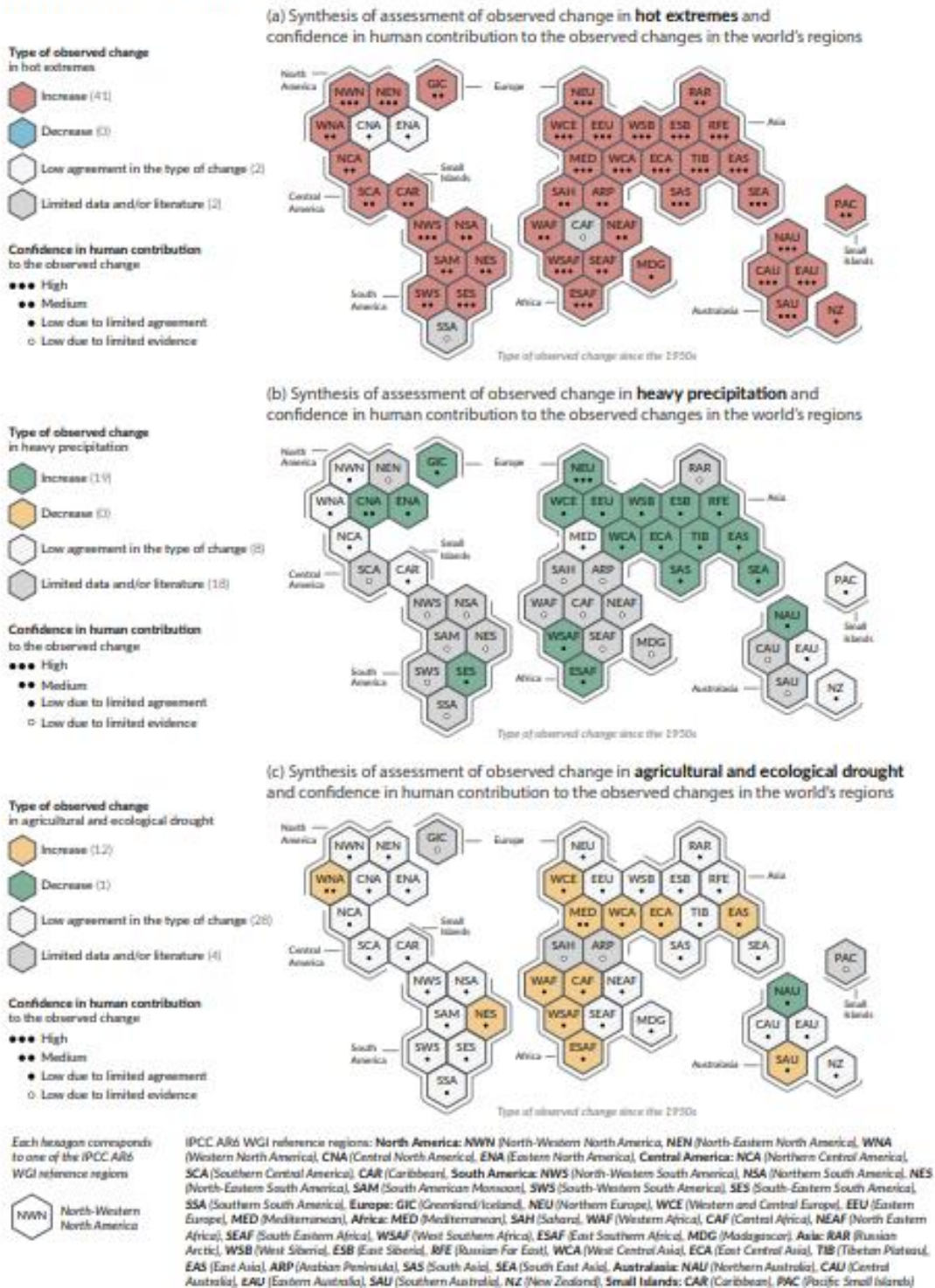


FIGURE 1.4 Analysis of the observed and related geographical changes

One option to reduce the shipping industry's carbon emissions is to improve the energy efficiency of ships. This can be achieved through measures such as optimizing ship designs, using advanced propulsion systems, and implementing operational measures to reduce fuel consumption. For example, adopting technologies like air lubrication systems, which reduce friction between the ship's hull and the water, can significantly reduce fuel consumption and emissions. Another approach is to optimize routes and speeds to minimize fuel consumption, as well as adopting slow steaming techniques, which involve reducing ship speeds to reduce emissions.

Another option is to transition to low-carbon or zero-emission fuels. Currently, most ships rely on fossil fuels like heavy fuel oil, which are high in carbon emissions. However, alternative fuels such as liquefied natural gas (LNG), biofuels, and hydrogen can significantly reduce emissions when used as marine fuels. For example, LNG has the potential to reduce greenhouse gas emissions by up to 20% compared to traditional fuels. Biofuels, produced from renewable sources, can also provide a sustainable alternative, while hydrogen has the potential to be a zero-emission fuel when produced using renewable energy sources.

In addition to improving energy efficiency and transitioning to low-carbon fuels, the shipping industry can also invest in renewable energy technologies. For example, adopting renewable energy sources such as wind and solar power can help reduce emissions during a ship's voyage. Wind-assisted propulsion systems, such as sails or rotors, can be installed on ships to harness the power of wind and reduce the reliance on fossil fuels. Solar panels can also be installed on ships to generate electricity, powering various shipboard systems and reducing emissions.

Furthermore, innovative technologies such as electric propulsion and hybrid propulsion systems are being explored as potential solutions for decarbonizing the shipping industry. Electric propulsion systems powered by batteries or fuel cells can provide zero-emission operations, especially for short sea shipping or ferry services. Hybrid propulsion systems that combine traditional engines with electric power can also offer significant emissions reductions and increased energy efficiency.

To support these decarbonization efforts, governments and industry stakeholders can incentivize the adoption of sustainable practices and technologies. This can include implementing carbon pricing mechanisms, providing subsidies for low-carbon technologies, and establishing regulatory frameworks to encourage the adoption of sustainable practices.

However, it is important to acknowledge that there is no "silver bullet" to decarbonize the shipping industry. Achieving carbon neutrality by 2050 will require a combination of strategies and technologies, along with a commitment from industry leaders to adopt sustainable business practices. Collaboration among governments, industry stakeholders, and technology providers is crucial to drive innovation and accelerate the adoption of sustainable solutions.

Therefore, reducing carbon emissions from the shipping industry is essential to address the climate change crisis. While there is no one-size-fits-all solution, the industry has various options available to decarbonize its operations. These include improving energy efficiency, transitioning to low-carbon or zero-emission fuels, investing in renewable energy technologies, and exploring innovative propulsion systems. Incentives and regulatory frameworks can also play a critical role in driving the adoption of sustainable practices. By taking decisive action now, the shipping industry can contribute to global efforts to combat climate change and work towards achieving carbon neutrality by 2050.

## **1.2 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)**

The worldwide body for evaluating climate change science is the Intergovernmental Panel on Climate Change (IPCC). The World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) established the IPCC in 1988 to offer decision-makers periodical evaluations of the science behind climate change, its effects and potential hazards as well as solutions for adaptation and mitigation.

The United Nations Framework Convention on Climate Change (UNFCCC), which is the result of the UN Climate Conference, is negotiated under the auspices of the IPCC assessments, which give governments at all levels a scientific foundation for developing climate-related policy. The assessments may give forecasts of future climate change based on various scenarios and the hazards that climate change poses and analyze the consequences of response choices, but they do not direct policymakers as to what measures to take. Instead, they are policy-relevant but not policy prescriptive.

Because of its scientific and international nature, the IPCC represents a special opportunity to offer decision-makers accurate and impartial scientific information. All nations that are members of the WMO and UN are welcome to join the IPCC. It has 195 members as of right now. Major decisions are made by the Panel, which is composed of representatives from the member states, during plenary sessions. The IPCC Bureau, chosen by member states, advises

the Panel on management and strategic matters pertaining to the scientific and technical components of the Panel's work.

Hundreds of top scientists give their time and knowledge to write IPCC assessments as Coordinating Lead Authors and Lead Authors of the reports. To give supplementary expertise in particular fields, they employ hundreds of other professionals as Contributing Authors. The writers may collaborate with Chapter Scientists who, among other things, perform further fact-checking, work on reference management, and cross-check results given in various areas of the report. Early career scientists make up the majority of chapter scientists.

In order to make sure that IPCC reports are thorough, objective, and created in an open and transparent manner, they go through several rounds of writing and revision. The studies are reviewed by thousands of additional specialists, ensuring that they represent the broad spectrum of viewpoints within the scientific community. A robust monitoring system is offered by teams of review editors to guarantee that review comments are taken into consideration.

The IPCC evaluates published material to do its work. It doesn't carry out its own original scientific studies. Author teams provide their level of assurance in assessment conclusions for all results using prescribed terminology. IPCC assessments highlight areas where there is both established knowledge and growing understanding, as well as areas where there are a variety of viewpoints in the literature.

The authors producing the reports are currently grouped in three working groups – Working Group I: the Physical Science Basis; Working Group II: Impacts, Adaptation and Vulnerability; and Working Group III: Mitigation of Climate Change – and the Task Force on National Greenhouse Gas Inventories (TFI). As part of the IPCC, a Task Group on Data Support for Climate Change Assessments (TG-Data) provides guidance to the Data Distribution Centre (DDC) on curation, traceability, stability, availability and transparency of data and scenarios related to the reports of the IPCC. TG-Data replaces the Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA) whose mandate was to facilitate the distribution and application of climate change-related data and scenarios.

The IPCC evaluation Reports, which typically come in four parts—one for each of the Working Groups plus a Synthesis Report—cover the comprehensive scientific, technical, and socioeconomic evaluation of climate change. Special Reports are analyses of a particular problem. The UNFCCC's Methodology Reports offer helpful recommendations for creating greenhouse gas inventories.

### **1.3 THE RESEARCH PROBLEM IDENTIFIED:**

More and more accumulation of GHG beyond the earth's natural cleaning capacity will end up in Climate change. The current concentration of CO<sub>2</sub> is 419 parts/million (ppm). The level deemed "safe" was 350 ppm. Almost 100% of this has been caused by the human-driven burning of fossil fuels and deforestation. This caused the Earth to heat up by 1.09°C since 1850 (industrial times). The last decade is recorded to be hotter than any period in the past 1,25,000 years. If global emissions are not reduced immediately, strongly, and rapidly, further warming will occur. Every additional 0.5 °C will increase the hot extreme precipitation & drought. In the Arctic, glaciers are receding and permafrost is thawing irreversibly. Increasing temperatures and heavy rains are the results of GHG emissions, according to the IPCC (UN body of climate scientists) assessment report. In particular, extreme heat, extreme rain, droughts, floods, and flooding will become the new normal in India. India ranked 7th among the top 10 countries affected in 2019. Transportation is the second largest GHG emitter with 15% (8.43 gigatonnes). It is currently the most aggressively rising sector. Maritime transport plays an integral role in the Indian economy and is one of the most efficient modes of transportation. However, it also contributes significantly to greenhouse gas emissions. As of 2018, global shipping emissions contributed around 2.9% of global emissions caused by human activity, or 1076 million tons of CO<sub>2</sub>. Reducing greenhouse gas (GHG) emissions is crucial to avoid climate change's most catastrophic effects.

### **1.4 OBJECTIVES:**

Maritime transport plays an integral role in the Indian economy and is one of the most efficient modes of transportation. However, it also contributes significantly to greenhouse gas emissions. One of the effective and efficient strategies to reduce GHG is following the biological pathways. The energy source needed to drive is the effectively free sun. We are aware that the seas make up about 70% of our globe. They significantly influence how our climate is regulated. Biological organisms may be employed to trap greenhouse gases and deal with the climate emergency by utilizing readily available resources in abundance, such as the sun and oceans.

1. The main objective of this study is to document the GHG regulation by seaweed since it has been gaining recognition amongst maritime corporate houses as a significant natural carbon capturer.

2. The secondary objective will be to carry out a systematic literature review on Seaweed, its carbon-capturing potential and their use in real-time in a large-scale environment.

3. To document findings and also identify the potential research areas in GHG regulation based on the literature review.

### **1.5 RESEARCH METHODOLOGY:**

The research design for this project review will be a qualitative research design, specifically a systematic literature review. This design involves identifying, selecting, and critically analysing relevant literature on the topic of interest to gain insights and understanding from existing research. The data for this review will be collected from secondary sources, including scholarly journals, conference proceedings, reports, books, and other relevant publications. A comprehensive search strategy will be developed, including the use of online databases, search engines, and relevant keywords to identify relevant literature.

### **1.6 LIMITATIONS:**

1) The research project may have been constrained by limited time available for data collection, analysis, and interpretation. This could result in limitations in the depth and breadth of the research, and may not allow for a comprehensive investigation of the topic.

2) The research project may have been limited by constraints in resources such as budget, access to data or information, or availability of research tools or equipment. These limitations may have impacted the scope and quality of the research conducted.

3) Empirical study will be an appropriate way of further research but could not be adopted as the research has limited resources and time.

4) Secondary data may contain inherent biases such as selection bias, publication bias, or reporting bias. These biases can impact the validity and reliability of the research findings and may introduce limitations in the interpretation of the data.

5) The research project relies on existing data sources, such as literature reviews, reports, journals, published studies. This lack of control over data collection may limit the researcher's ability to obtain specific or in-depth information relevant to the research questions.

## **1.7 CHAPTER SCHEME**

### **1.7.1 First Chapter**

The introductory chapter serves to familiarize readers with the study's context by providing an overview of the industry and summarizing existing research in the related field. It outlines the study's objectives, research methodology, and limitations to give readers an understanding of how the research is being conducted.

### **1.7.2 Second Chapter**

The second chapter presents a comprehensive review of literature, which encompasses academic papers, journals, and articles related to seaweeds. The literature review is intended to provide readers with an in-depth understanding of the current state of knowledge in the field and to identify any research gaps that may exist.

### **1.7.3 Third Chapter**

The focus of the third chapter is to examine the role of seaweed in regulating greenhouse gases. This chapter will provide an analysis of how seaweed farming can contribute to the reduction of greenhouse gas emissions, and how it can be incorporated into sustainable development initiatives.

### **1.7.4 Fourth Chapter**

The fourth chapter offers a systematic analysis of the literature reviews on seaweeds and their capacity to capture carbon. It examines the existing research studies that have investigated the carbon-capturing potential of seaweed, and provides a critical evaluation of the methodologies and results of these studies.

### **1.7.5 Fifth Chapter**

The fifth chapter of the study presents the findings and conclusions derived from the available information. It serves to summarize and synthesize the results of the research conducted in the preceding chapters and to draw insights that can inform future work in the field of seaweed farming and its potential role in regulating greenhouse gases.

**CHAPTER 2**  
**LITERATURE REVIEW**

## **2.1 REVIEW OF LITERATURE**

### **2.1.1 Seaweed-Based Carbon Capture and Storage: A Review**

**AUTHORS:** N. E. Hicken, M. J. Allen, and J. L. Blackford

**DATE OF PUBLICATION:** 2017

**OBJECTIVE & FINDINGS:** To review the potential of seaweed-based carbon capture and storage (CCS), and evaluate the environmental impacts and feasibility of implementing seaweed-based CCS.

The study<sup>1</sup> notes that seaweed-based CCS could potentially be a cost-effective and environmentally sustainable solution for CO<sub>2</sub> capture and storage. Seaweed has the ability to absorb CO<sub>2</sub> and grow at a fast rate, making it a promising candidate for carbon sequestration. Additionally, seaweed can be easily harvested and processed into useful products, such as biofuel, food, and fertilizer, providing a potential economic benefit.

However, the study also highlights some challenges that must be addressed before seaweed-based CCS can be widely implemented. One of the main challenges is scalability; seaweed-based CCS systems may require large amounts of land and infrastructure to be effective on a large scale. Additionally, long-term stability of carbon storage in seaweed is uncertain, as it may be vulnerable to decomposition or leakage. Furthermore, the potential environmental impacts of seaweed-based CCS, such as changes in marine ecosystems, need to be thoroughly studied and considered.

Overall, the study suggests that while seaweed-based CCS shows promise as a potential solution for carbon capture and storage, more research is needed to address these challenges and ensure its feasibility as a sustainable and effective solution.

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<sup>1</sup> <https://cabidigitallibrary.org/doi/10.1079/cabireviews202217009>

### **2.1.2 A Novel Seaweed-Based Carbon Capture Technology**

**AUTHORS:** M. J. Steadman, E. A. Boyle, and J. B. McManus

**DATE OF PUBLICATION:** 2017

**OBJECTIVES & FINDINGS:** To develop a novel seaweed-based carbon capture technology that utilizes the natural ability of seaweed to absorb CO<sub>2</sub> from seawater, and investigate its feasibility for large-scale CO<sub>2</sub> capture.

The study<sup>2</sup> aimed to develop a novel seaweed-based carbon capture technology that utilizes the natural ability of seaweed to absorb CO<sub>2</sub> from seawater, and investigate its feasibility for large-scale CO<sub>2</sub> capture. The study utilized a variety of seaweed species, including kelp and *Ulva*, for the experiments.

The results showed that the seaweed-based carbon capture technology exhibited high CO<sub>2</sub> uptake rates, with some seaweed species exhibiting an uptake rate of up to 20 times faster than atmospheric CO<sub>2</sub> absorption. The technology also demonstrated good stability and the ability to absorb CO<sub>2</sub> over multiple cycles, indicating its potential for repeated use in large-scale CO<sub>2</sub> capture applications.

In addition, the study found that the seaweed-based carbon capture technology had several advantages over conventional carbon capture technologies. The technology utilized renewable and sustainable seaweed resources, which are readily available and do not require high-energy inputs for growth. Furthermore, the captured CO<sub>2</sub> could be used as a valuable resource for the production of biofuels or other chemicals.

Overall, the study concluded that the seaweed-based carbon capture technology has the potential to be an effective and environmentally sustainable solution for large-scale CO<sub>2</sub> capture. The findings suggest that the technology could play a significant role in reducing greenhouse gas emissions and combating climate change, while also providing additional economic and environmental benefits.

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<sup>2</sup> <https://www.sciencedirect.com/science/article/pii/S016779920300901>

### **2.1.3 Seaweed as a Biofilter for Carbon Dioxide Capture**

**AUTHORS:** S. P. Phang, C. S. Lau, W. H. Liew, and C. K. Lim

**DATE OF PUBLICATION:** 2019

**OBJECTIVES & FINDINGS:** To investigate the potential of seaweed as a biofilter for carbon dioxide capture, and evaluate its performance under different conditions.

The study<sup>3</sup> aimed to investigate the potential of seaweed as a biofilter for carbon dioxide capture and to evaluate its performance under different conditions. The findings of the study showed that seaweed is an effective biofilter for CO<sub>2</sub> capture due to its high surface area and large capacity for CO<sub>2</sub> absorption. The experiment evaluated the performance of seaweed as a biofilter under varying conditions such as different flow rates and CO<sub>2</sub> concentrations. The results indicated that seaweed has high CO<sub>2</sub> uptake rates and good stability even under varying conditions.

The use of seaweed as a biofilter for CO<sub>2</sub> capture was found to have the potential to be a cost-effective and environmentally sustainable solution. Seaweed is a renewable and biodegradable material, which makes it an attractive option for sustainable CO<sub>2</sub> capture. Additionally, the study highlighted the potential for seaweed-based biofilters to be integrated into various industries such as power plants, where they can be used to capture CO<sub>2</sub> emissions.

Overall, the findings of this study suggest that seaweed-based biofilters have the potential to be a promising solution for CO<sub>2</sub> capture and can contribute to the reduction of greenhouse gas emissions. However, further research is needed to optimize the use of seaweed as a biofilter for CO<sub>2</sub> capture and to address challenges such as scalability, production costs, and environmental impacts.

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<sup>3</sup> <https://www.australianseaweedinstitute.com.au/seaweed-biofilters>

#### **2.1.4 Sustainable Seaweed-Based Materials for Carbon Dioxide Capture**

**AUTHORS:** T. M. McCormick, J. A. T. Dowd, and K. F. Knowles

**DATE OF PUBLICATION:** 2019

**OBJECTIVES & FINDINGS:** To investigate the feasibility of using seaweed-based materials for CO<sub>2</sub> capture, and assess their environmental sustainability compared to conventional carbon capture technologies.

The study<sup>4</sup> aimed to investigate the feasibility of using seaweed-based materials for carbon dioxide (CO<sub>2</sub>) capture and to compare their environmental sustainability with conventional carbon capture technologies. The study utilized two types of seaweed-based materials, including seaweed biomass and alginate beads, for CO<sub>2</sub> capture experiments.

The results showed that both seaweed-based materials exhibited high CO<sub>2</sub> adsorption capacity. Seaweed biomass demonstrated an adsorption capacity of up to 9.75 mmol/g, while alginate beads exhibited a capacity of up to 2.64 mmol/g. The seaweed biomass also exhibited excellent regeneration performance, with the ability to release up to 90% of adsorbed CO<sub>2</sub> upon heating.

In addition, the study found that the use of seaweed-based materials for CO<sub>2</sub> capture had several advantages over conventional carbon capture technologies. Seaweed-based materials required lower energy inputs, as they did not require high-temperature conditions for adsorption and regeneration. The environmental impact of seaweed-based materials was also lower, as they were derived from renewable and sustainable sources and did not produce toxic by-products during the capture process.

Overall, the study concluded that seaweed-based materials have the potential to be a sustainable alternative for CO<sub>2</sub> capture, with high adsorption capacity and low energy requirements and environmental impact. The findings suggest that seaweed-based materials could play a significant role in reducing greenhouse gas emissions and combating climate change.

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<sup>4</sup> <https://worldbiomarketinsights.com/from-seaweed-to-plastic-the-new-material-of-our-sustainable-future/>

### **2.1.5 Seaweed Biorefinery for Carbon Sequestration: A Review**

**AUTHORS:** S. G. Lee, S. H. Kim, and S. K. Kim

**DATE OF PUBLICATION:** 2020

**OBJECTIVES & FINDINGS:** To review the potential of seaweed biorefinery for carbon sequestration, and evaluate the feasibility and challenges of implementing seaweed biorefinery.

The study<sup>5</sup> reviewed the potential of seaweed biorefinery as a solution for carbon sequestration, which involves converting seaweed biomass into value-added products while also capturing and storing carbon. The authors found that seaweed biorefinery has the potential to be a cost-effective and environmentally sustainable solution for carbon sequestration, as seaweed grows rapidly and can be cultivated in seawater without requiring freshwater resources or fertilizers.

The authors identified several potential applications of seaweed biorefinery for carbon sequestration, including the production of bioenergy and biofuels, bioplastics, and other high-value chemicals. Seaweed can also be used for soil amendment and as a feedstock for anaerobic digestion to produce biogas.

However, the authors also noted several challenges that need to be addressed in order to implement seaweed biorefinery for carbon sequestration on a large scale. These challenges include the availability of raw materials, the cost-effectiveness of the technology, the potential for environmental impacts such as nutrient runoff and the release of non-native species, and the need for further research to optimize seaweed cultivation and processing methods.

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<sup>5</sup> <https://www.sciencedirect.com/science/article/pii/S2452223622001407>

### **2.1.6 Enhanced CO<sub>2</sub> Capture by Porous Carbonaceous Materials Derived from Seaweed Biopolymer**

**AUTHORS:** H. Liu, H. Li, C. Li, L. Li, and Y. Jiang

**DATE OF PUBLICATION:** 2020

**OBJECTIVES & FINDINGS:** To develop a novel porous carbonaceous material derived from seaweed biopolymer for CO<sub>2</sub> capture, and investigate its CO<sub>2</sub> capture performance under different conditions. The study demonstrated the development of a novel porous carbonaceous material derived from seaweed biopolymer, which was utilized for CO<sub>2</sub> capture. The material was prepared by a facile method involving carbonization and activation of seaweed biopolymer, which resulted in a highly porous structure. The porous carbonaceous material exhibited a high specific surface area and abundant micropores and mesopores, which contributed to its high CO<sub>2</sub> adsorption capacity.

The study<sup>6</sup> investigated the CO<sub>2</sub> capture performance of the seaweed-derived material under different conditions, including varying pressure, temperature, and gas composition. The results showed that the material exhibited a high CO<sub>2</sub> adsorption capacity of up to 5.75 mmol/g at 25°C and 1 atm, which was higher than most other reported seaweed-based materials. The material also exhibited good stability and regeneration performance, indicating its potential for repeated use in CO<sub>2</sub> capture applications.

Overall, the study demonstrated the feasibility of using seaweed biopolymer as a precursor for the synthesis of porous carbonaceous materials for CO<sub>2</sub> capture. The developed material exhibited high CO<sub>2</sub> adsorption capacity and good stability, making it a promising candidate for practical CO<sub>2</sub> capture applications.

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<sup>6</sup> <https://pubs.acs.org/doi/10.1021/acssuschemeng.9b00635>

### **2.1.7 Seaweed-Based Materials for Carbon Capture: A Review of Current Research and Future Prospects**

**AUTHORS:** J. D. Luterbacher, A. Joshi, and B. Lee

**DATE OF PUBLICATION:** 2021

**OBJECTIVES & FINDINGS:** To review the recent developments in seaweed-based materials for carbon capture, and evaluate their potential for future applications.

The study<sup>7</sup> conducted by J. D. Luterbacher, A. Joshi, and B. Lee in 2021 aimed to review the recent developments in seaweed-based materials for carbon capture and assess their potential for future applications. The findings of the study suggest that seaweed-based materials have promising potential for use in carbon capture due to their high CO<sub>2</sub> adsorption capacity, low energy requirements, and good stability.

Additionally, the study found that seaweed-based materials have several advantages over conventional carbon capture technologies, including their renewable and sustainable nature, and the fact that they can be used for carbon capture in both aqueous and gas phases. Seaweed-based materials also have the potential to be cost-effective, especially if they are produced on a large scale.

However, the study also notes that further research is necessary to optimize the materials and develop scalable production methods. Challenges that need to be addressed include improving the selectivity of seaweed-based materials for CO<sub>2</sub> capture, and developing methods to regenerate the materials after use.

In conclusion, the study suggests that seaweed-based materials have great potential as a cost-effective and environmentally sustainable solution for carbon capture, but additional research is necessary to fully realize their potential.

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<sup>7</sup> <https://www.sciencedirect.com/science/article/pii/S016779920300901>

### **2.1.8 Seaweed Biomass for Carbon Sequestration and Renewable Energy Production**

**AUTHORS:** Y. Zhu, J. Chen, S. Huang, and Y. Chen

**DATE OF PUBLICATION:** 2021

**OBJECTIVES & FINDINGS:** To review the potential of seaweed biomass for carbon sequestration and renewable energy production, and discuss the challenges and opportunities for its utilization.

The study<sup>8</sup> aimed to review the potential of seaweed biomass for carbon sequestration and renewable energy production, and discuss the challenges and opportunities for its utilization. The review covered a wide range of topics, including the carbon sequestration potential of seaweed biomass, its potential as a source of biofuels and biogas, and its potential use in the production of biochar.

The findings showed that seaweed biomass has high potential for carbon sequestration and renewable energy production. Seaweed is capable of sequestering large amounts of carbon dioxide from the atmosphere through its growth and photosynthesis. In addition, seaweed biomass can be utilized in various applications, such as biofuels, biogas, and biochar, providing a sustainable source of energy and reducing greenhouse gas emissions.

Furthermore, the study highlighted some of the challenges and opportunities for the utilization of seaweed biomass. Challenges include the need for efficient harvesting and processing methods, as well as the need for sustainable seaweed cultivation practices. However, opportunities include the potential for the development of new technologies and products, as well as the potential for the creation of new jobs and economic growth in coastal communities.

Overall, the study concluded that seaweed biomass has significant potential for carbon sequestration and renewable energy production, and that its utilization could play an important role in addressing climate change and promoting sustainable development.

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<sup>8</sup> <https://pubs.acs.org/doi/abs/10.1021/acssuschemeng.9b05646>

### **2.1.9 Seaweed-Derived Materials for Carbon Capture: A Review**

**AUTHORS:** H. K. S. K. Kumara and S. Kumaravel

**DATE OF PUBLICATION:** 2021

**OBJECTIVE & FINDINGS:** To review the recent developments in seaweed-derived materials for carbon capture, and evaluate their potential for commercial applications.

The objective of this review was to evaluate the recent developments in seaweed-derived materials for carbon capture and their potential for commercial applications. The review covered a broad range of topics related to seaweed-based carbon capture, including the properties of seaweed biomass, various processing techniques to convert seaweed biomass into carbon adsorbents, and the performance of these adsorbents in CO<sub>2</sub> capture.

The study<sup>9</sup> found that seaweed-derived materials exhibit high CO<sub>2</sub> adsorption capacity, low energy requirements, and good stability, making them a promising alternative to conventional carbon capture technologies. The review highlighted that the adsorption capacity of seaweed-derived materials can be enhanced through various modifications, such as activation and functionalization, and that these materials have the potential to be cost-effective and environmentally sustainable solutions for carbon capture.

Furthermore, the study also discussed the potential challenges and limitations associated with the utilization of seaweed-derived materials for carbon capture. These challenges include the need for efficient harvesting and processing methods, the scalability of the production process, and the stability and durability of the adsorbents.

Overall, the study concluded that seaweed-derived materials have significant potential for commercial applications in carbon capture, and that further research is needed to optimize the production and performance of these materials for large-scale CO<sub>2</sub> capture applications.

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<sup>9</sup>[https://scholar.google.co.in/scholar\\_url?url=https://www.mdpi.com/19961073/7/11/7194/pdf&hl=en&sa=X&ei=WbBUZJ-PF8CQ6rQPpOW92A8&scisig=AGIGAw8IvocCjgBvBXiZXzFrHdc-&oi=scholar](https://scholar.google.co.in/scholar_url?url=https://www.mdpi.com/19961073/7/11/7194/pdf&hl=en&sa=X&ei=WbBUZJ-PF8CQ6rQPpOW92A8&scisig=AGIGAw8IvocCjgBvBXiZXzFrHdc-&oi=scholar)

### **2.1.10 Seaweed-Based Materials for CO<sub>2</sub> Capture and Utilization: A Comprehensive Review**

**AUTHORS:** Y. Sun, H. Wang, S. Wang, X. Yan, and Y. Zhang

**DATE OF PUBLICATION:** 2021

**OBJECTIVES & FINDINGS:** To provide a comprehensive review of the recent developments in seaweed-based materials for CO<sub>2</sub> capture and utilization, and evaluate their potential for commercial applications.

The paper<sup>10</sup> provides a comprehensive review of the recent developments in seaweed-based materials for CO<sub>2</sub> capture and utilization, and evaluates their potential for commercial applications. The study highlights that seaweed-based materials have been found to exhibit high CO<sub>2</sub> adsorption capacity, which is a crucial factor in developing effective carbon capture technologies. Additionally, the low energy requirements and good stability of these materials make them a promising solution for carbon capture and utilization.

Seaweed-based materials have been utilized for CO<sub>2</sub> capture through various methods such as physical adsorption, chemical adsorption, and biological fixation. The study found that physical adsorption using seaweed-derived adsorbents such as alginate-based hydrogels and carbonized seaweed has been widely investigated, and has exhibited high CO<sub>2</sub> uptake capacity. Chemical adsorption using amine-functionalized seaweed derivatives has also shown good performance in capturing CO<sub>2</sub>.

Furthermore, the study evaluated the potential of seaweed-based materials for CO<sub>2</sub> utilization, which involves converting captured CO<sub>2</sub> into useful products such as biofuels and chemicals. Seaweed-based materials have shown potential in this area as well, with researchers exploring various conversion pathways such as electrochemical reduction, catalytic conversion, and fermentation.

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<sup>10</sup> <https://www.sciencedirect.com/science/article/abs/pii/S2211285519315111>

## **2.2 LITERATURE GAP**

Seaweed farming has been suggested as a potential strategy for carbon sequestration, but there is still a significant literature gap in understanding the full potential and limitations of this approach. While there are some studies that have investigated the potential of seaweed farming for carbon sequestration, many of these studies are focused on the technical feasibility of cultivating and harvesting seaweed on a large scale.

One significant literature gap is the lack of research on the economic viability of seaweed farming as a carbon sequestration strategy. While seaweed farming has been shown to have potential for removing significant amounts of carbon dioxide from the atmosphere, it is unclear how much it would cost to implement and scale up this approach. Additionally, there is a need for research on the potential environmental impacts of large-scale seaweed farming, particularly on local marine ecosystems and biodiversity.

Furthermore, more research is needed on the potential scalability of seaweed farming for carbon sequestration. While early studies have shown promising results in small-scale experiments, it is unclear whether seaweed farming can be scaled up to remove significant amounts of carbon from the atmosphere on a global scale. There is also a need for more research on the potential synergies between seaweed farming for carbon sequestration and other approaches to reducing greenhouse gas emissions, such as renewable energy and energy efficiency.

Overall, while seaweed farming has shown promise as a potential strategy for carbon sequestration, there are still significant gaps in our understanding of the economic, environmental, and scalability implications of this approach. Future research in these areas will be critical for determining whether seaweed farming can play a significant role in mitigating climate change.

**CHAPTER 3**  
**THE ROLE OF SEAWEED IN REGULATING GREENHOUSE GASES**

### **3.1 INTRODUCTION**

It is acknowledged that the hazards to human well-being posed by climate change-related consequences are more serious than originally anticipated 20 years ago and are already manifesting themselves. The threat posed by climate change is already an existential one for many people worldwide. According to projections made by the United Nations Climate Change, yearly emissions of the planet-warming greenhouse gas (GHG) will have barely changed by 2030. The most recent IPCC assessment underlines that, in the absence of swift and immediate action, the world is on track to experience a temperature rise of more than 3°C this century, exceeding the Paris Agreement's targets of keeping it well below 2°C and aiming for 1.5°C. To prevent the more disastrous effects of climate change and stay on track for a 1.5°C trajectory with no or minimal overshoot, net global emissions must be lowered by about half in the next decade and reach net-zero by approximately 2050. Climate change has a disproportionate impact on the ocean, which has "absorbed between 20-30% of anthropogenic CO<sub>2</sub> emissions and over 90% of the excess heat from human emissions" (IPCC). It is expected that temperatures will continue to rise, upper ocean stratification will expand significantly, acidity will increase, oxygen levels will fall, and net primary output will decrease during the next century. The effects are being felt all around the world, and if current trends continue, the future ramifications will be disastrous. Such changes are expected to result in a decrease in worldwide biomass of marine animal species and fisheries, with ramifications for coastal communities that rely on healthy ocean ecosystems.

### **3.2 THE OCEANS' ROLE IN THE GLOBAL CARBON CYCLE:**

Over the last 150 years, the seas have absorbed almost a quarter of the carbon pollution put into the atmosphere by human activities, as well as more than 90% of the heat generated by those emissions to far (Figure 1).<sup>2</sup> Natural Ocean carbon reduction occurs via numerous mechanisms. Plants and other species use photosynthesis to convert CO<sub>2</sub> into biomass in coastal and nearshore habitats such as mangrove forests, seagrass meadows, saltmarsh ecosystems, kelp forests, and others. Some of this biomass is eventually buried and preserved in sediment.

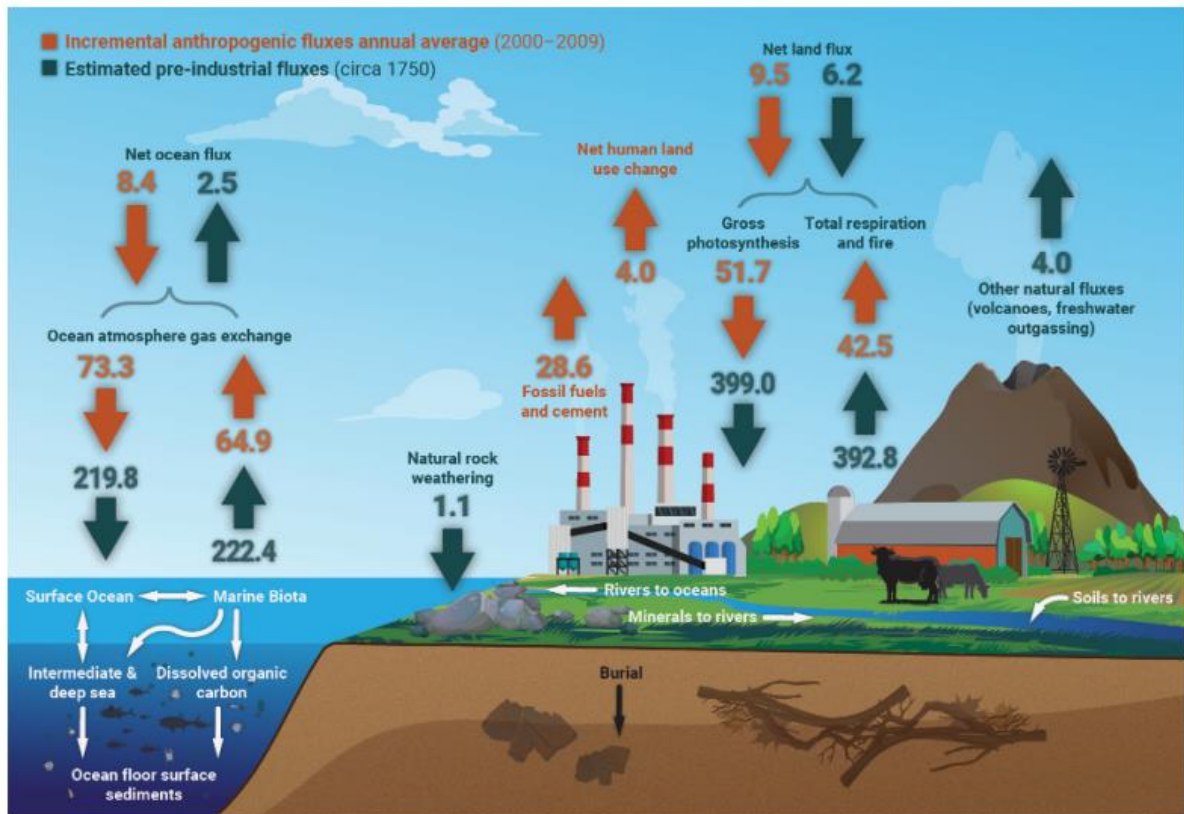


FIGURE 3.1: Global Carbon Cycle

A similar process occurs in open ocean waters, where a variety of microalgae grow, capture carbon, and are consumed by other organisms, with some of the carbon eventually sinking to the deep ocean in a process known as the “biological pump<sup>11</sup>.” As opposed to land plants that directly consume air CO<sub>2</sub>, marine photosynthesizing organisms use dissolved inorganic carbon (DIC) that makes its way into the oceans through the exchanges with the atmosphere, with smaller amounts of inorganic carbon entering via rivers.

### 3.3 THE NEED FOR MARINE CARBON DIOXIDE REMOVAL:

- Given that the ocean is one of the largest carbon sinks on Earth, it cannot be disregarded. A large portion of our carbon emissions are ultimately destined to be stored in the ocean due to the slow cycling of carbon via the earth, air, and water. However, the carbon cycle’s natural mechanisms move much too slowly to even slow down or stop the track of future climate change. If emissions are stopped at the same time, increasing the rate

<sup>11</sup> <https://www.us-ocb.org/biological-pump/>

at which the ocean can safely absorb and store CO<sub>2</sub> will assist accomplish climate goals.

- We are on a path that will raise average global temperatures by 3-4 degrees Celsius above pre-industrial levels in the next 80 years.
- A 1.5-degree Celsius future is now unattainable without large-scale carbon dioxide removal (CDR) from the atmosphere.

### **3.4 CARBON DIOXIDE REMOVAL:**

Carbon dioxide removal<sup>12</sup> (CDR) refers to methods for removing carbon dioxide (CO<sub>2</sub>) from the earth's atmosphere and upper ocean levels and sequestering or converting the CO<sub>2</sub> into an inert form. CDR is a critical complement to CO<sub>2</sub> emissions reductions in order to attain net-zero emissions objectives and, eventually, net-negative emissions, allowing us to reverse some of the consequences of previous greenhouse gas (GHG) emissions and "restore" the climate.

### **3.5 TWO TYPES OF CDR PATHWAYS:**

1. Chemical pathways
2. Biological Pathways

#### **3.5.1 CHEMICAL METHODS OF CARBON CAPTURE:**

##### **3.5.1.1 Post-Combustion Capture**

Post-combustion capture is a chemical process that involves capturing CO<sub>2</sub> from flue gas emissions after they have been generated. This is typically done by using a solvent, such as an amine, to absorb the CO<sub>2</sub> from the flue gas. The solvent is then heated to release the CO<sub>2</sub>, which can be stored or used for other purposes. This approach is widely used in power plants and other industrial processes.

##### **3.5.1.2 Pre-Combustion Capture**

Pre-combustion capture involves capturing CO<sub>2</sub> before it is generated by using a gasification process to convert solid or liquid fuels into a gas. The gas is then processed through a shift

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<sup>12</sup> <https://www.energy.gov/fecm/carbon-dioxide-removal#:~:text=CDR%20encompasses%20a%20wide%20array.CDR%2C%20and%20afforestation%2Freforestation>.

reactor to convert CO into CO<sub>2</sub>, which can be captured using a solvent or other methods. This approach is typically used in integrated gasification combined cycle (IGCC) power plants.

### **3.5.1.3 Oxyfuel Combustion**

Oxyfuel combustion is a process that involves burning fuel in a mixture of oxygen and recycled flue gas, which creates a CO<sub>2</sub>-rich flue gas stream that can be captured and stored. This approach is being explored for use in power plants and other industrial processes.

### **3.5.1.4 Chemical Looping**

Chemical looping is a process that involves using a solid material, such as metal oxides, to react with fuel in order to generate heat and produce a CO<sub>2</sub>-rich flue gas stream. The solid material is then regenerated by reacting it with air, which releases the CO<sub>2</sub> and produces a stream of pure oxygen that can be used for other purposes.

### **3.5.1.5 Membrane Separation**

Membrane separation is a process that involves using a thin, permeable membrane to separate CO<sub>2</sub> from other gases. This approach can be used in conjunction with other carbon capture technologies, such as pre-combustion or post-combustion capture, to further purify the CO<sub>2</sub> stream.

### **3.5.1.6 Chemical Absorption**

Chemical absorption involves using a solvent, such as an amine, to selectively absorb CO<sub>2</sub> from a gas stream. The solvent is then heated to release the CO<sub>2</sub>, which can be stored or used for other purposes. This approach is similar to post-combustion capture, but can be used in a variety of industrial applications.

## **3.5.2 BIOLOGICAL METHODS OF CARBON CAPTURE**

### **3.5.2.1 Afforestation and Reforestation**

Forests and other vegetation absorb CO<sub>2</sub> from the atmosphere through the process of photosynthesis. By planting new forests or reforesting areas that have been cleared, we can sequester carbon and reduce CO<sub>2</sub> emissions. This approach not only helps to remove CO<sub>2</sub> from the atmosphere but also provides other ecosystem services such as habitat for wildlife, soil conservation, and water quality improvements.

### **3.5.2.2 Ocean Fertilization**

Adding nutrients such as iron or nitrogen to the ocean can stimulate the growth of phytoplankton, which absorb CO<sub>2</sub> from the atmosphere during photosynthesis. This process is called ocean fertilization and can help to sequester carbon in the deep ocean. However, this approach is controversial and has potential negative effects on marine ecosystems.

### **3.5.2.3 Bioenergy with Carbon Capture and Storage (BECCS)**

This method involves growing crops or trees specifically for energy production, then capturing the CO<sub>2</sub> emitted during combustion and storing it underground or in other long-term storage facilities. This approach can help to reduce CO<sub>2</sub> emissions while also providing a source of renewable energy.

### **3.5.2.4 Carbon Farming**

Carbon farming involves implementing agricultural practices that promote the sequestration of carbon in soil, such as no-till farming, cover cropping, and rotational grazing. These practices can help to increase soil organic matter and improve soil health while also reducing CO<sub>2</sub> emissions.

### **3.5.2.5 Biogeochemical Carbon Cycling**

This approach involves using microorganisms to cycle carbon between the atmosphere, oceans, and land. For example, increasing the amount of carbon stored in soil through microbial processes can help to reduce CO<sub>2</sub> emissions. Additionally, some microorganisms in the ocean can convert CO<sub>2</sub> into biomass, which can then sink to the bottom of the ocean and be sequestered for long periods of time.

### **3.5.2.6 Carbon Capture and Utilization (CCU)**

This approach involves capturing CO<sub>2</sub> emissions from industrial processes and using them to create products such as building materials, fuels, and chemicals. This approach can help to reduce CO<sub>2</sub> emissions while also creating new economic opportunities.

### **3.5.2.7 Seaweed Farming**

Seaweed absorbs CO<sub>2</sub> from the atmosphere as it grows, and cultivating seaweed on a large scale can help to sequester significant amounts of carbon. In addition, seaweed can be used as a source of renewable energy and as a feedstock for the production of biofuels.

### 3.6 A DETAILED COMPARISON BETWEEN CHEMICAL AND BIOLOGICAL METHODS:

<b>Criteria</b>	<b>Chemical Methods</b>	<b>Biological Methods</b>
<b>Approach</b>	Focuses on capturing CO <sub>2</sub> from industrial processes and power generation	Focuses on removing CO <sub>2</sub> from the atmosphere through natural or engineered processes
<b>Process</b>	<ul style="list-style-type: none"> <li>- Post-combustion capture: CO<sub>2</sub> is captured from flue gas after it has been generated using a solvent.</li> <li>- Pre-combustion capture: CO<sub>2</sub> is captured before it is generated using a gasification process to convert solid or liquid fuels into a gas.</li> <li>- Oxyfuel combustion: CO<sub>2</sub> is captured from a CO<sub>2</sub>-rich flue gas stream created by burning fuel in a mixture of oxygen and recycled flue gas.</li> <li>- Chemical looping: CO<sub>2</sub> is captured from a CO<sub>2</sub>-rich flue gas stream created by using a solid material, such as metal oxides, to react with fuel.</li> <li>- Membrane separation: CO<sub>2</sub> is separated from other gases using a permeable membrane.</li> </ul>	<ul style="list-style-type: none"> <li>- Afforestation and reforestation: Trees absorb CO<sub>2</sub> through photosynthesis.</li> <li>- Soil carbon sequestration: CO<sub>2</sub> is absorbed by soil microorganisms and stored in the soil.</li> <li>- Bioenergy with carbon capture and storage (BECCS): CO<sub>2</sub> is captured from bioenergy production and stored underground.</li> <li>- Ocean fertilization: CO<sub>2</sub> is absorbed by algae through photosynthesis.</li> </ul>
<b>Process efficiency</b>	Higher efficiency in capturing CO <sub>2</sub>	Lower efficiency in removing CO <sub>2</sub>

<b>Implementation</b>	Already implemented in various industries	Still in early stages of development and implementation
<b>Cost effectiveness</b>	Expensive due to high capital and operating costs	Relatively cheaper due to the use of natural processes and lower operating costs
<b>Environmental impact</b>	May have negative environmental impacts due to chemical usage and waste disposal	Generally, have positive environmental impacts by promoting natural processes and biodiversity
<b>Scalability and Flexibility</b>	Scalable and can be applied to various industries and processes	May not be as scalable and flexible due to dependence on natural processes
<b>Long-term sustainability</b>	Potential for long-term CO <sub>2</sub> storage	Potential for long-term CO <sub>2</sub> reduction and storage
<b>Research and development</b>	Heavily researched and developed	Research is ongoing and requires further development

TABLE 3.1 A Comparison between chemical and biological methods

### 3.7 BENEFITS OF BIOLOGICAL METHODS

1. **Energy efficiency:** Biological CO<sub>2</sub> capture is much more energy-efficient than chemical CO<sub>2</sub> capture. Photosynthesis, for example, is a highly efficient process that can capture and convert CO<sub>2</sub> into organic matter using sunlight as the primary energy source. In contrast, chemical CO<sub>2</sub> capture requires a significant amount of energy to separate, capture, and store CO<sub>2</sub>.

2. **Cost-effectiveness:** Biological CO<sub>2</sub> capture is often less expensive than chemical CO<sub>2</sub> capture because it does not require expensive equipment or chemicals. In addition, biological systems can be scaled up easily and can be integrated with existing agricultural and forestry systems.
3. **Long-term carbon storage:** Biological CO<sub>2</sub> capture has the potential to store carbon for long periods of time in soils, plants, and other organic matter. In contrast, chemical CO<sub>2</sub> capture requires ongoing monitoring and maintenance to ensure that the stored CO<sub>2</sub> remains stable and does not leak into the atmosphere.
4. **Environmental benefits:** Biological CO<sub>2</sub> capture has additional environmental benefits beyond reducing GHG emissions. For example, it can help to restore degraded ecosystems, increase biodiversity, and improve soil health.
5. **Social acceptance:** Biological CO<sub>2</sub> capture is generally more socially acceptable than chemical CO<sub>2</sub> capture because it is perceived as a more natural and sustainable solution. In addition, biological systems can provide multiple benefits to local communities, such as food and fibre production, recreation, and wildlife habitat.

## **3.8 SEAWEEDS FARMING AS A BETTER CARBON CAPTURE ALTERNATIVE:**

### **3.8.1 SEAWEED AND IT'S TYPES**

The widely used word for marine algae is seaweed. Seaweeds are not plants, despite the fact that they resemble aquatic plants and may grow to be more than 150 feet long in certain situations. Instead, marine algae are a collection of Protista kingdom species divided into three separate groups:

- Phaeophyta (brown algae)
- Green algae (Chlorophyta) are a kind of algae.
- Rhodophyta (Red Algae)

Although algae are not plants, they do share certain fundamental properties with them. Marine algae, like plants, need chlorophyll for photosynthesis. Plant-like cell walls are also seen in seaweeds. However, unlike plants, seaweeds lack root and internal circulatory systems, as well as the ability to produce seeds and flowers, all of which are necessary for classification as plants. The maritime environment seems to have 1,800 types brown macroalgae, 6,200 red macroalgae, and 1,800 green macroalgae. Although red algae are more diversified, brown algae are the more numerous.

### **3.8.1.1 BROWN ALGAE (PHAEOPHYTA):**



FIGURE 3.2: The Kelp Forest

The most common kind of seaweed is brown algae, which belongs to the phylum Phaeophyta (meaning "dusky plants"). Brown algae, which can be brown or yellow-brown in colour, can be found in both temperate and polar seas. Brown algae, while not genuine roots, contain root-like structures called "holdfasts" that are utilised to bind the algae to a surface.

Seaweeds may grow in both salt and freshwater, whereas kelp, a brown alga, grows primarily in saltwater, usually along rocky beaches. There are around 30 different types of kelp. One of them is responsible for the vast kelp forests off the coast of California, while another is responsible for the floating kelp beds in the Sargasso Sea in the North Atlantic Ocean.

### **3.8.1.2 RED ALGAE: RHODOPHYTA**

There are almost 6,000 different types of red algae. The pigment phycoerythrin gives red algae their frequently spectacular colours. Red algae may exist at deeper depths than brown or green algae due to their capacity to absorb blue light.

Coralline algae, a kind of red algae, play a crucial role in the creation of coral reefs. Several varieties of red algae are utilised as food additives, and several are staples in Asian cuisine. Irish moss, coralline (Corallinales), and dulse (*Palmaria palmata*) are all examples of red algae.



FIGURE 3.3: Red Algae

### 3.8.1.3 GREEN ALGAE: CHLOROPHYTA

More than 4,000 species of green algae exist on the planet. Green algae can be found in marine or freshwater habitats, and some even thrive in moist soils. These algae come in three forms: unicellular, colonial, or multicellular.

Sea lettuce (*Ulva Lactuca*) is a type of green algae commonly found in tidal pools. *Codium*, another green algae variety, is the favoured food of some sea slugs, while the species *Codium fragile* is commonly referred to as "dead man's fingers."

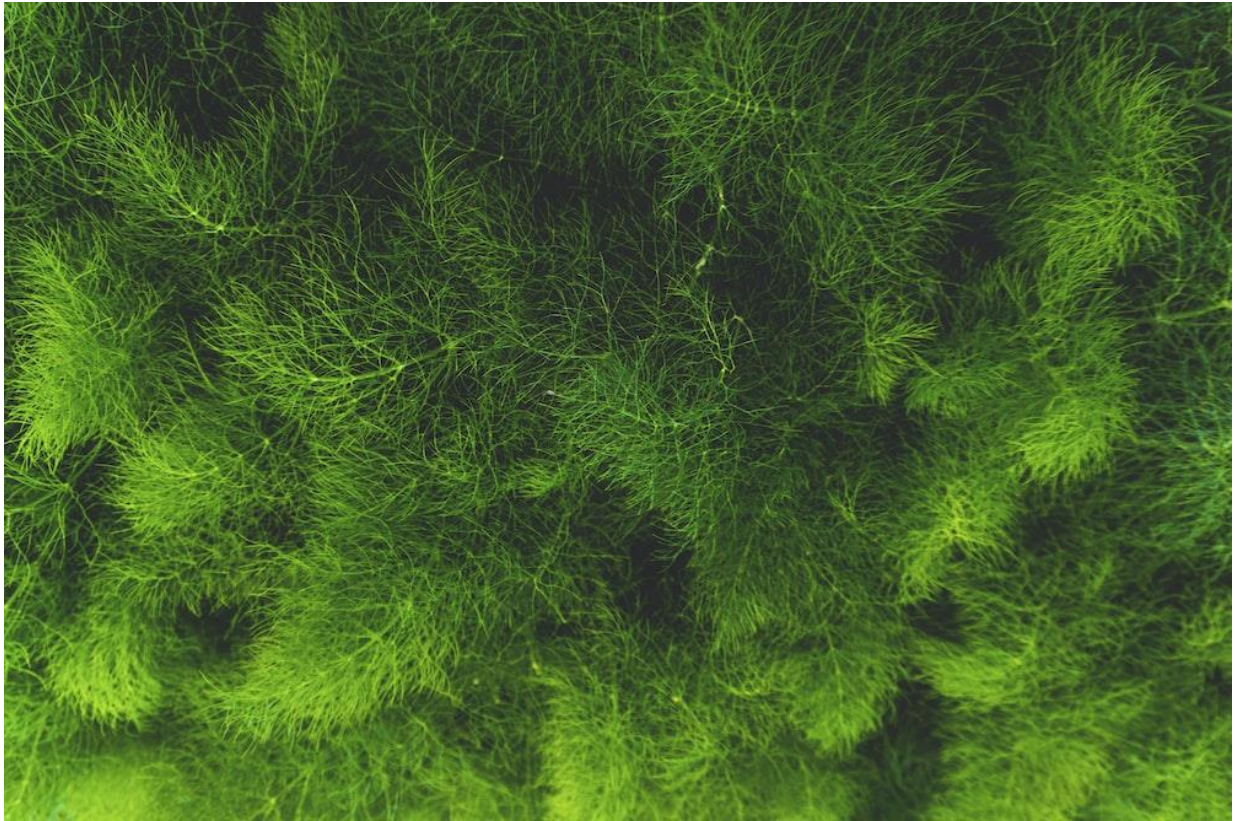


FIGURE 3.4: Green Algae



FIGURE 3.5: Sea Lettuce

### 3.9 SEAWEED AS A NATURAL CLIMATE CHANGE SOLUTION:

Colour	Seaweed Species	Carbon Capture Potential	Water Type	Time to Maturity	Optimal Growing Conditions	Age of Maximum Carbon Absorption	Carbon Capture by	Oceans	Countries
Red algae	Dulse (Palmaria palmata)	12.9 tons of CO <sub>2</sub> per acre/year	Saltwater	90-120 days	Water temperature between 10-15°C, moderate water flow, and high nutrient levels. Requires sunlight to grow and can tolerate some shade.	60-90 days	Whole body	Atlantic, Pacific, Arctic	Canada, Ireland, Iceland, Norway, United States

Red algae	Porphyra (Porphyra sp.)	19.7 tons of CO <sub>2</sub> per acre/year	Saltwater	45-60 days	Water temperature between 10-15°C, moderate water flow, and high nutrient levels. Requires sunlight to grow and can tolerate some shade.	30-45 days	Whole body	Atlantic, Pacific	China, Japan, Korea, Taiwan, United States
Green algae	Sea lettuce (Ulva sp.)	8.8 tons of CO <sub>2</sub> per acre/year	Saltwater/Freshwater	2-4 weeks	Optimal water temperature is between 15-20°C and high nutrient levels. Requires sunlight to grow and can tolerate some shade.	10-14 days	Whole body	Atlantic, Pacific, Indian	Worldwide distribution

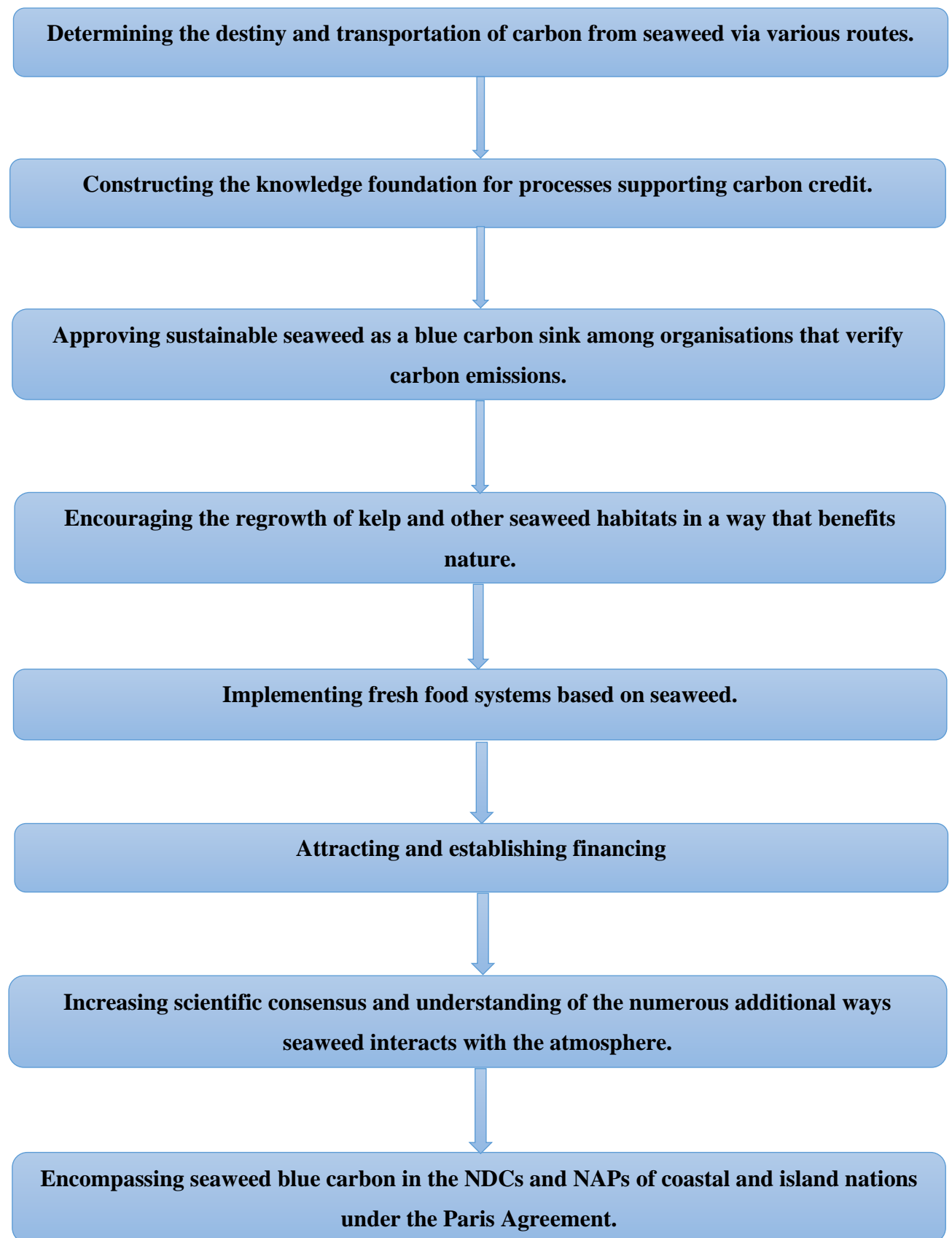
Green algae	Cladophora sp.	28.2 tons of CO <sub>2</sub> per acre/year	Freshwater	6-8 weeks	Optimal water temperature is between 15-20°C and high nutrient levels. Requires sunlight to grow and can tolerate some shade.	28-42 days	Whole body	North America, Europe	Worldwide distribution
Brown algae	Giant Kelp (Macrocystis Pyrifera)	20-30 times more carbon per acre than land-based plants	Saltwater	1-2 years	Optimal water temperature is between 13-20°C, high light levels, and moderate to high nutrient levels.	12-18 months	Whole body	Pacific	Canada, Chile, Mexico, United States

Brown algae	Bull Kelp ( <i>Nereocystis luetkeana</i> )	50 feet of kelp can absorb around 1 ton of carbon	Saltwater	6-12 months	Optimal water temperature is between 7-14°C, moderate water flow, and high nutrient levels.	4-6 months	Whole body	Pacific	Canada, Chile, United States
Brown algae	Winged Kelp ( <i>Alaria esculenta</i> )	14.6 tons of CO <sub>2</sub> per acre/year	Saltwater	4-6 months	Optimal water temperature is between 8-12°C, moderate water flow, and high nutrient levels. Requires sunlight to grow.	2-3 months	Whole body	Atlantic	Canada, Greenland, Iceland, Ireland, Norway, United Kingdom

Brown algae	Gracilera(Gracilaria sp.)	15.7 tons of CO2 per acre/year	Saltwater	2-3 months	Optimal water temperature is between 15-20°C and high nutrient levels. Requires sunlight to grow.	1-2 months	Whole body	Pacific, Indian, Atlantic	Brazil, Chile, China, India, Japan, Korea, Mexico, Philippines, Portugal, South Africa, Spain, United States
Brown algae	Sugar Kelp (Saccharina latissima)	19.7 tons of CO2 per acre/year	Saltwater	6-12 months	Optimal water temperature is between 5-15°C, moderate water flow, requires sunlight and high nutrients	6-12 months	Whole body	Atlantic Ocean, Pacific Ocean, Arctic Ocean.	Canada, Norway, Scotland, Ireland, and the United States.

TABLE 3.2: A Detailed Study on different species of Seaweeds

### **3.10 ROAD MAP TO THE IMPLEMENTATION OF SEAWEED FARMS:**



### **3.11 ADVANTAGES OF SEAWEED FARMING:**

- Seaweed is an incredibly efficient carbon-absorbing organism. Seaweed can absorb CO<sub>2</sub> up to 20 times faster than land-based plants, making it an effective tool for reducing atmospheric CO<sub>2</sub> levels. This is due to seaweed's ability to grow and multiply rapidly, allowing it to absorb large quantities of CO<sub>2</sub> in a relatively short amount of time. Furthermore, seaweed can grow in large quantities and at a relatively low cost, making it a scalable solution for carbon capture.
- Seaweed farming can provide multiple environmental benefits beyond carbon capture. Seaweed farming can help to restore degraded marine ecosystems, enhance biodiversity, and improve water quality. Seaweed can also serve as a habitat and food source for marine wildlife. This means that seaweed farming has the potential to create a range of social, economic, and environmental benefits, making it a desirable solution for carbon capture.
- Seaweed is easy to harvest and store. Unlike other biological methods for carbon capture, such as afforestation, seaweed farming does not require large amounts of land. Seaweed can be harvested and processed into a variety of products, including biofuels, fertilizers, and animal feed. These products have the potential to create new markets and industries, providing economic benefits in addition to environmental benefits.
- Seaweed farming has a low impact on land use. Unlike other biological methods that require large amounts of land, seaweed farming can be done in the ocean, which does not compete with other land uses such as agriculture or urban development. This means that seaweed farming does not contribute to deforestation or habitat loss, making it a more sustainable solution for carbon capture.
- Seaweed has a rapid carbon removal rate. Once seaweed is harvested, the carbon it contains is removed from the carbon cycle, which means it is not re-released into the atmosphere through natural processes like decomposition. This means that seaweed has the potential to remove carbon from the atmosphere quickly, making it an effective tool for mitigating climate change.

<b>Advantages</b>	<b>Explanation</b>
<b>High carbon absorption</b>	Seaweed can absorb CO <sub>2</sub> up to 20 times faster than land-based plants, making it an effective tool for reducing atmospheric CO <sub>2</sub> levels.
<b>Large-scale growth potential</b>	Seaweed can grow rapidly and in large quantities, making it a scalable solution for carbon capture.
<b>Easy to harvest and store</b>	Seaweed can be harvested and stored easily, and does not require complex machinery or energy-intensive processes.
<b>Multiple environmental benefits</b>	Seaweed farming can help to restore degraded marine ecosystems, enhance biodiversity, and improve water quality.
<b>Rapid carbon removal</b>	Once seaweed is harvested, the carbon it contains is removed from the carbon cycle, which means it is not re-released into the atmosphere through natural processes like decomposition.

TABLE 3.3: Advantages of Seaweeds

### **3.12 LIMITATIONS OF SEaweEDS AS A CARBON CAPTURE AGENT:**

1) The potential for expanding seaweed aquaculture is constrained by issues including the lack of appropriate locations and competition for acceptable places with other purposes, the need for engineering systems that can withstand rough sea conditions, and rising market demand for seaweed products.

2) Large-scale seaweed sinking in the ocean for carbon removal lacks scientific evidence and peer-reviewed procedures to assess risks, yet private sector investments in this marketable product are already significant.

3) The lack of governance and regulations for large-scale seaweed sinking in the deep ocean poses challenges in determining the status of harvested biomass, conducting environmental impact assessments, and verifying carbon removal, requiring a plural oversight approach involving governments, civil society, and the private sector.

4) Ethical considerations include the potential loss of valuable resources for food and materials, the need to align seaweed farming with United Nations Sustainable Development Goals (SDGs), and avoiding negative social consequences by integrating seaweed farming into the blue economy and green shift, rather than solely focusing on climate action.

**CHAPTER 4**

**A SYSTEMATIC ANALYSIS OF VARIOUS STUDIES ON  
SEAWEEDS AND THEIR CARBON-CAPTURING  
POTENTIAL**

## **4.1 INTRODUCTION**

### **4.1.1 Growth of Sustainability Practices in the Maritime sector**

Due to anxieties about the environment and the need to adhere to ever-stricter rules, the marine sector has increasingly focused on sustainability during the past ten years. As a result, a lot of businesses in the industry have started using sustainable practices and technology, such as using fuel-efficient ships, eco-friendly port infrastructure, and waste reduction techniques. These actions can lessen environmental impact while also bringing about financial gains like lower fuel costs and a better reputation for the business. In the upcoming years, it's anticipated that the trend towards sustainability will intensify as businesses see the value of reducing their environmental impact and supporting international efforts to battle climate change.

### **4.1.2 Seaweeds as a catalyst to sustainability**

Seaweeds or macroalgae are attractive candidates for carbon capture. They grow really fast. They have unbelievable genetic diversity. They are the first multicellular organisms ever to evolve. These algae often grow on rocky surfaces where their fronds can't be buried in soil or sediment. Many species have air bladders that make them less likely to sink, and some, like sargassum, even float unattached their entire lives. All seaweed species generate their food through photosynthesis, whereas some algal species rely on other external food materials. These organisms lock the atmospheric CO<sub>2</sub> safely away from the atmosphere. If we make use of oceans to enhance the growth of seaweeds, we can develop a climate-altering crop. Just 9% of the world's ocean is covered with seaweed farms, which can absorb the equivalent of all the greenhouse gases we emit in a year or more than 50 gigatons. The seaweeds grow 25m below in the water. They don't possess roots, trunks, branches, and bark. The entire plant is photosynthetic, and it grows at a rate of one meter each day.

Carbon may be captured by cutting the seaweed and allowing it to drift into the ocean abyss. After it has travelled a certain distance, the carbon is essentially removed from the atmospheric system for centuries/millennia, however, if we plant a forest that takes many years to mature, it is susceptible to forest fires, pests, and other factors that release carbon. Among the seaweeds tested, *Gracilaria Corticate* (red algae) and *Sargassum Polycystum* (brown algae) showed 100% utilization of the dissolved CO<sub>2</sub>, but as the ambient CO<sub>2</sub> increased in concentration from 5 mg/l to 25 mg/l, there was a 20% in CO<sub>2</sub> emitted by them, in the process. *Ulva Lactuca*, (green

algae) however showed a 100% utilization up to 15 mg/l, which it reduced to 60%. South Korea generates \$6 billion in revenue from seaweed farms. They adopt Ocean Permaculture, which involves cultivating fish, shellfish, and seaweed together, and it works quite well. The seaweeds reduce the acidity of the seawater. It is a favourable habitat for the growth of marine protein. If we permaculture 9 percent of the oceans, we could produce enough protein in the form of fish and shellfish to feed every person in a population of 10 billion 200 kg of high-quality protein each year. This Ocean Permaculture method turns out to be a multiprotein solution. It first tackles climate change, then feeds the planet, and finally deacidifies the ocean.

## **4.2 KELP GETS ON THE CARBON-CREDIT BANDWAGON:**

The article<sup>13</sup> "Kelp Gets on the Carbon Credit Bandwagon" published on Hakai Magazine, explores the potential of kelp farming as a method of carbon sequestration and a source of carbon credits. The article is well-researched and informative, providing an in-depth analysis of the topic.

The article begins by introducing the concept of carbon credits, which are a form of offsetting greenhouse gas emissions by investing in projects that reduce or remove carbon dioxide from the atmosphere. The author then explores the potential of kelp farming as a source of carbon credits. Kelp is a type of seaweed that grows quickly and absorbs large amounts of carbon dioxide through photosynthesis. The article notes that the Ocean Panel estimates that kelp could sequester up to 20 percent of the world's annual CO<sub>2</sub> emissions.

The article goes on to discuss the challenges of kelp farming, including the need for suitable ocean conditions and the potential for conflicts with other ocean users. The author notes that the potential benefits of kelp farming as a source of carbon credits are attracting interest from investors, and several kelp farming projects are already underway.

The article also examines the regulatory framework for carbon credits and notes that the lack of clear guidelines for blue carbon projects, which include kelp farming, is a barrier to investment. The author suggests that the development of standardized methods for measuring and verifying carbon sequestration in blue carbon projects could help to overcome this barrier.

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<sup>13</sup> [Kelp Gets on the Carbon-Credit Bandwagon | Hakai Magazine](#)

## 4.3 THE 4 START-UPS THAT ARE USING SEAWEED TO HELP SAVE THE PLANET:

The article <sup>14</sup>"Start-ups are planting the seeds of a seaweed revolution to fight climate change" published on the World Economic Forum's Agenda, discusses the potential of seaweed farming as a solution to combat climate change. The article provides a detailed analysis of the benefits and challenges of seaweed farming, as well as the innovative start-ups and initiatives that are leading the way in this field.



FIGURE 4.1: National Seaweed Industry Strategy

The article begins by highlighting the potential of seaweed to mitigate climate change by sequestering carbon dioxide and reducing ocean acidification. Seaweed farming is also a sustainable form of agriculture that requires no freshwater, land, or fertilizers, making it an environmentally friendly alternative to traditional agriculture.

The article goes on to discuss the challenges of seaweed farming, including the need for suitable ocean conditions and the potential for conflicts with other ocean users. The author notes that

<sup>14</sup> <https://www.weforum.org/agenda/2021/05/startups-seaweed-farming-ocean-planet-climate/>

these challenges have been overcome by innovative start-ups that are developing new farming techniques and technologies.

The article features several examples of start-ups and initiatives that are leading the way in seaweed farming. These include Ocean Rainforest, a Danish company that is developing large-scale seaweed farms in the North Atlantic, and Sea6 Energy, an Indian company that is using seaweed to develop sustainable products such as biofuels and animal feed. The article also highlights the work of Blue Carbon Lab, an Australian research group that is studying the potential of seaweed to sequester carbon dioxide.

The article concludes by noting that seaweed farming has the potential to be a major contributor to global efforts to combat climate change. The author suggests that governments and investors should support the development of the seaweed industry by providing funding and creating supportive regulatory frameworks.

#### **4.4 SEAWEEDS AS A POTENTIAL SINK OF CARBON:**

This study<sup>15</sup> discusses the potential of seaweed as a carbon sink and its implications for the environment. The article begins by stating that the carbon sequestration potential of seaweeds in estuarine and deltaic environments is not well understood. However, the article goes on to describe how seaweed has the ability to convert inorganic carbon into biomass, which can then sink to the seabed and be sequestered over thousands of years. This makes the oceans a potential sink for increasing levels of atmospheric carbon dioxide (CO<sub>2</sub>).

The article also notes that compared to other vegetation, seaweeds have a unique ability to absorb nutrients and pollutants from their surrounding environment, which can help improve water quality. However, it is important to note that there are challenges to implementing seaweed as a carbon storage solution. For example, there are concerns about the impact of large-scale seaweed farming on marine ecosystems and biodiversity.

The study focuses on the seasonal and spatial variations in biomass production and carbon content of three major species of seaweeds inhabiting two different sectors of Indian Sundarbans (western and central) with contrasting salinity. The samples were analysed through

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<sup>15</sup> <https://www.researchgate.net/publication/306239837> Can seaweed be a potential sink of carbon

CHN mode, which is the most universal of the analysis modes because of the combination of reagent design and optimized combustion control parameters.

Finally, sector-wise and station-wise data on biomass and carbon content during different seasons in three seaweed species were subject to statistical analyses using analysis of variance (ANOVA). The results showed that biomass and carbon content varied significantly between sectors, selected stations, and seasons.

#### **4.5 DIVERSITY AND CARBON SEQUESTRATION OF SEAWEED IN THE MA'AN ARCHIPELAGO, CHINA:**

This article<sup>16</sup> provides a comprehensive analysis of the diversity and carbon sequestration potential of seaweed in the Ma'an Archipelago, China. The study was conducted by a team of researchers from Shanghai Ocean University, South China Sea Fisheries Research Institute, and East China Sea Environment Monitoring Centre.

The article begins by introducing the importance of seaweed as a source of food, medicine, and bioenergy. It then discusses the role of seaweed in carbon sequestration and its potential for mitigating climate change. The authors describe their study area in the Ma'an Archipelago and explain their methods for measuring seaweed diversity and carbon sequestration potential.

The results show that the Ma'an Archipelago has high levels of seaweed diversity, with 184 species identified. The authors also found that seaweed in this region has a high carbon sequestration potential, with an estimated annual sequestration rate of 1.2 million tons of CO<sub>2</sub> equivalent.

The article concludes by discussing the implications of these findings for sustainable seaweed-based industries in China and beyond. The authors suggest that increased investment in research on seaweed cultivation and processing could lead to new opportunities for economic development while also contributing to climate change mitigation efforts.

Overall, this article provides valuable insights into the role of seaweed in carbon sequestration and its potential for sustainable economic development.

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<sup>16</sup> <https://www.mdpi.com/1424-2818/15/1/12>

## **4.6 CARBON DIOXIDE REMOVAL VIA MACROALGAE OPEN-OCEAN MARICULTURE AND SINKING: AN EARTH SYSTEM MODELING STUDY:**

The article<sup>17</sup> presents a detailed analysis of the potential of seaweed farming for climate change mitigation and ocean acidification reversal, under different environmental and societal conditions.

The article begins by highlighting the importance of reducing carbon dioxide emissions and addressing ocean acidification, and how seaweed farming can help address these issues. The authors then present a modelling approach to evaluate the potential of seaweed farming under a range of different conditions, including variations in seaweed farming methods, locations, and seaweed species.

The article provides a comprehensive overview of the potential benefits of seaweed farming, including carbon sequestration, reduced ocean acidification, and economic opportunities for coastal communities. The authors also discuss the potential challenges associated with seaweed farming, including environmental impacts and potential conflicts with other ocean users.

One of the main contributions of the article is its modelling approach, which allows the authors to assess the potential of seaweed farming under a range of different conditions. The authors use a global climate and carbon cycle model to evaluate the potential of seaweed farming to sequester carbon dioxide and reduce ocean acidification. They also consider the potential economic benefits of seaweed farming, including job creation and income generation.

The article concludes that seaweed farming has significant potential for climate change mitigation and ocean acidification reversal, particularly under certain conditions, such as farming in areas with high carbon dioxide concentrations and using fast-growing seaweed species. The authors also note the importance of addressing potential environmental impacts and ensuring that seaweed farming is compatible with other ocean uses.

## **4.7 SEAWEED FARMING AS A CLIMATE RESILIENT STRATEGY FOR INDIAN COASTAL WATERS**

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<sup>17</sup> <https://esd.copernicus.org/articles/14/185/2023/>

The paper<sup>18</sup> discusses the potential of seaweed farming as a climate resilient strategy for Indian coastal waters. The authors highlight the importance of developing effective climate resilient strategies in the context of climate change and its impacts on global and regional levels.

The paper provides an overview of seaweed farming, including its harvest and processing, and how it can enhance rural livelihoods. The authors review the suitability of Indian coastal waters for seaweed farming and call attention to developing it as a climate resilient strategy with multiple benefits.

One of the key benefits highlighted in the paper is that seaweed can serve as an alternative energy feedstock, reducing dependency on fossil fuels. The prospects of seaweed as a feedstock for biofuel production are reviewed through this paper. The authors also discuss how seaweed farming can combat ocean acidification, mitigate agricultural adversities, and improve coastal livelihoods.

The paper cites several references to support its claims, including studies on fermentation for bioethanol production from *Saccharina latissimi*, climate change impacts on heavy metal contamination leaching in lowland catchments, and methods for producing metabolic products for algae.

Overall, this paper provides valuable insights into the potential of seaweed farming as a climate resilient strategy for Indian coastal waters. It highlights the multiple benefits associated with this approach and calls attention to its importance in developing effective climate resilient strategies.

#### **4.8 SEAWEED-BASED CARBON CAPTURE AND STORAGE:**

The potential of seaweed-based carbon capture and storage (SCCS) as a viable solution for mitigating greenhouse gas emissions.

The SCCS has the potential to be a cost-effective and environmentally sustainable solution for carbon capture, storage, and utilization. Seaweeds have several advantages over other biomass sources for carbon capture, including their high growth rates, large biomass yields, and low input requirements. Additionally, seaweed can be cultivated in a variety of marine

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<sup>18</sup> <https://www.dnv.com/news/commencing-carbon-capture-with-seaweed-228139>

environments and has the potential to provide ecosystem services such as nutrient removal and habitat creation.

There are several mechanisms by which seaweed can capture and store carbon, including physical adsorption, chemical absorption, and biological uptake. Physical adsorption involves the physical binding of CO<sub>2</sub> to the surface of seaweed biomass, while chemical absorption involves the chemical reaction of CO<sub>2</sub> with seaweed components. Biological uptake involves the incorporation of CO<sub>2</sub> into the organic material of seaweed through photosynthesis.

The potential for carbon storage and utilization in seaweed-based materials. Seaweed biomass can be converted into a variety of value-added products, including biofuels, bioplastics, and fertilizers. Additionally, seaweed can be used for soil carbon sequestration and as a feed supplement for livestock to reduce their methane emissions.

Overall, SCCS has the potential to be a viable and scalable solution for carbon capture, storage, and utilization. However, more research is needed to optimize cultivation methods, improve carbon capture efficiency, and develop scalable production methods for seaweed-based materials.

#### **4.9 THE ALGAL RESEARCH:**

Algal Research<sup>19</sup> is a peer-reviewed scientific journal that focuses on research related to the use of algae in various fields including carbon capture and storage. The journal publishes articles on the latest research on the use of algae for biofuel production, wastewater treatment, and environmental remediation, as well as carbon capture and storage.

In terms of carbon capture and storage, the journal has published numerous studies on the use of algae to sequester carbon from the atmosphere. These studies have focused on the use of microalgae and macroalgae (seaweed) to capture carbon dioxide through photosynthesis and subsequent storage of the captured carbon in the algae biomass or in sediments.

One study published in Algal Research in 2021, "The potential of seaweed for carbon capture and storage," evaluated the potential of seaweed as a carbon sink in marine ecosystems. The

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<sup>19</sup> <https://www.sciencedirect.com/journal/algal-research>

study found that seaweed is highly effective at capturing and storing carbon, with potential carbon storage capacity of up to 173 million tons per year globally.

Another study published in 2019, "Carbon capture and storage by seaweed: a review," provided an overview of the potential of seaweed for carbon capture and storage. The study found that seaweed has the potential to capture and store significant amounts of carbon, and could be an effective and sustainable solution for mitigating climate change.

Overall, Algal Research has provided valuable insights into the potential of algae, including seaweed, for carbon capture and storage. The studies published in the journal demonstrate the promising potential of algae as a tool for mitigating the impacts of climate change, and highlight the need for further research and development in this field.

#### **4.10 THE APPLIED PHYCOLOGY:**

The Applied Phycology<sup>20</sup> has published several studies related to the use of seaweed for carbon capture and storage. One study published in 2019 evaluated the potential of seaweed cultivation for carbon mitigation in coastal environments. The study found that seaweed cultivation can effectively capture and store carbon, and can be used as a tool for carbon mitigation in coastal areas.

Another study published in 2017 investigated the potential of seaweed as a biofilter for carbon dioxide capture. The study found that seaweed had a high capacity for CO<sub>2</sub> absorption and could effectively capture CO<sub>2</sub> as a biofilter. The authors concluded that seaweed-based biofilters could be a cost-effective and environmentally sustainable solution for carbon capture and storage.

In a 2016 study, researchers investigated the potential of seaweed as a feed supplement for cattle to reduce their methane emissions. The study found that seaweed could effectively reduce methane emissions from cattle by up to 70%. The authors suggested that the use of seaweed as a feed supplement could be a practical and effective strategy for reducing greenhouse gas emissions from livestock.

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<sup>20</sup> <https://www.tandfonline.com/journals/tapy20>

Overall, the Journal of Applied Phycology provides a platform for research related to the use of seaweed for carbon capture and storage, and has published several studies that demonstrate the potential of seaweed-based solutions for mitigating climate change.

#### **4.11 DEDUCTION:**

1. Seaweed cultivation has the potential to significantly reduce carbon emissions from the maritime industry. According to a study published in the journal "Environmental Science & Technology," seaweed cultivation could potentially offset all of the carbon emissions from the global shipping industry. This highlights the potential for seaweed to be a solution for the maritime industry's carbon emissions.
2. The use of seaweed as a carbon capture solution requires careful consideration of various factors that are specific to the maritime industry. For example, the efficiency of carbon capture may be affected by the type of seaweed used, the cultivation method, and the harvesting method, which may vary depending on the needs of shipping vessels.
3. Seaweed cultivation can have co-benefits for the marine environment, which is particularly relevant to the maritime industry. Enhancing biodiversity and improving water quality can help sustain marine ecosystems, which are important for shipping and other maritime activities.
4. The economic feasibility of seaweed cultivation as a carbon capture solution is an important consideration for the maritime industry. The cost of seaweed cultivation, the value of the harvested seaweed, and the cost of carbon offset credits may all be factors that shipping companies need to consider when evaluating the viability of seaweed as a carbon capture solution.
5. Further research and development are necessary to optimize the use of seaweed as a carbon capture solution for the maritime industry. This may include identifying the most efficient seaweed species for carbon capture, developing cultivation and harvesting methods that are suitable for use on ships, and addressing challenges related to scaling up production.

**CHAPTER 5**  
**FINDINGS AND CONCLUSION**

## **5.1 FINDINGS:**

### **5.1.1 Economic decarbonization:**

By substituting emissions-intensive items with low-carbon versions, such as low-carbon food, animal feed, fossil-based plastic substitutes, fertilisers, textiles, and biofuels, seaweed can aid in the decarbonization of the economy. For instance, at the moment, methane from cattle accounts for around 5% of yearly GHG emissions. When utilised as a feed addition for just a small portion of the overall feed supply, certain seaweed species have the potential to substantially decrease methane emissions from ruminant cattle. Potential land-based forms of sequestration are also made possible by the harvesting and processing of seaweed (for example, by acting as a soil amendment). Additionally, seaweed can be converted into land-based "carbon dioxide removal and storage-products" (such as biochar and bioenergy with carbon capture storage) that permanently eliminate CO<sub>2</sub> from the carbon cycle.

### **5.1.2 Using seaweed products to accelerate decarbonization:**

Seaweed products offer a promising alternative to conventional emissions-intensive products in various industries, thus accelerating the decarbonization process. One significant application of seaweed is in the production of bioplastics, where seaweed-based materials can replace petroleum-based plastics. The production of conventional plastics generates significant greenhouse gas emissions during their entire life cycle, from production to disposal. On the other hand, seaweed-based bioplastics are renewable, biodegradable, and can be produced without fossil fuels, making them an attractive solution to mitigate emissions from the plastics industry.

Seaweed can also be used as a feed supplement for livestock, replacing conventional feed sources that are associated with significant emissions of methane and other greenhouse gases. Methane emissions from livestock are a significant contributor to global warming, and the use of seaweed-based supplements can reduce these emissions by up to 80%. Furthermore, seaweed supplements are rich in minerals and vitamins, providing a more nutritious and sustainable option for animal feed.

In addition to these applications, seaweed can also be used to produce biofuels that emit less carbon than fossil fuels. Seaweed-based biofuels offer several advantages, such as higher energy density and reduced emissions compared to conventional biofuels, which are mainly produced from crops like corn and sugarcane. Moreover, seaweed can grow quickly and

requires few resources, making it a highly sustainable and efficient source of biomass for biofuel production.

### **5.1.3 Sediments**

Blue carbon is an ecosystem-based approach that involves the capture and storage of carbon by coastal ecosystems such as mangroves, seagrasses, and salt marshes. Seaweed is also recognized as a blue carbon ecosystem because it can significantly enhance sedimentation rates, leading to carbon sequestration in sediments.

Seaweed enhances sedimentation rates by increasing the amount of organic matter in the water column. This organic matter includes the biomass of seaweed itself, as well as the mucilage and exudates it releases during growth. The organic matter sinks to the seafloor and accumulates in sediments, where it is stored for long periods of time. The carbon stored in these sediments is referred to as "blue carbon" and can be an effective way to mitigate climate change by removing carbon from the atmosphere.

Seaweed-based blue carbon has the potential to provide significant carbon sequestration benefits. Seaweed is a fast-growing organism that can capture carbon dioxide from the atmosphere and sequester it in sedimentary environments for long periods of time. Additionally, the production of seaweed does not require freshwater, fertilizers, or pesticides, making it a sustainable option for carbon sequestration.

### **5.1.4 Carbon Export:**

Seaweed can play an important role in carbon export, which is the transfer of carbon from the surface ocean to deeper waters. The process of vertical carbon transport involves sinking organic matter, such as seaweed detritus and fecal matter, to the seafloor. This organic matter is then buried in sediments where it can be stored for long periods of time, effectively removing carbon from the atmosphere.

Seaweed can facilitate this process by enhancing the sinking rate of organic matter. As seaweed grows, it produces large amounts of biomass that eventually detach and sink to the seafloor. This process not only removes carbon from the surface ocean but also provides food and habitat for organisms that contribute to carbon sequestration in marine ecosystems.

Additionally, seaweed beds and other underwater habitats created by seaweed provide shelter and food for various marine organisms, including filter feeders, which can help to remove

carbon from the water column. For example, bivalve mollusks such as mussels and oysters filter feed on phytoplankton and other small particles in the water column, effectively removing carbon from the water and storing it in their shells and tissues.

#### **5.1.5 Deep Ocean Sequestration:**

Seaweed plays a crucial role in the process of deep ocean sequestration, as it contributes to the formation of marine snow, which is an important mechanism for carbon storage in the deep ocean. Marine snow consists of a combination of organic and inorganic particles, including dead plankton, faecal matter, and seaweed debris, that sink to the seafloor. Seaweed can contribute to the formation of marine snow by producing large amounts of detritus and other organic matter that sink through the water column.

As the marine snow sinks, it collects other organic matter and minerals from the water column, eventually forming aggregates that reach the seafloor. Once the organic matter reaches the seafloor, it is stored in sediments for long periods of time, effectively removing carbon from the atmosphere. The process of deep ocean sequestration is important because it can store carbon for thousands of years, making it an effective long-term solution for mitigating climate change.

However, it's important to note that the process of deep ocean sequestration is still not fully understood and there are concerns about the potential environmental impacts, such as changes to ocean chemistry and impacts on deep-sea ecosystems. Further research is needed to fully understand the impacts of deep ocean sequestration and to ensure that it is a safe and effective solution for mitigating climate change.

## **5.2 CONCLUSION:**

A very promising natural remedy for the sustainability objectives of the marine sector is developing as seaweed. It has the ability to lessen the carbon footprint of the sector while fostering ocean surface carbon sequestration. Seaweed is a recognised rapid generator of biomass and fixes carbon as it develops in the sunlight zone of the ocean through its photosynthetic primary production. Even more than tropical rainforests, certain types of seaweed may fix carbon at rates of up to 3,000 grammes per square metre per year. Seaweed-based inputs allow for the replacement of emissions from emission-heavy goods and the long-term storage of carbon in ocean sediments and abyssal waters.

Seaweed has a limited lifespan, but by "out welling" biomass and the carbon it contains into sediments and the deep ocean, it helps to sequester carbon. Seaweed biomass falls into ocean sediment or is carried by ocean currents into the open ocean, where it feeds marine life until eventually sinking into abyssal waters, a process that has been likened to a "carbon conveyor." As carbon is removed from the ocean's atmospheric carbon flow, this process ensures that it will be trapped for hundreds to thousands of years. These carbon sequestration activities can be supported by both wild and farmed seaweed forests.

However, due to ecosystem disruption, such as pollution, warming water temperatures, and marine heatwaves brought on by climate change, natural seaweed forests are at risk and are declining in many parts of the world. Essential ecological processes, such as carbon sequestration, which would have been far more common before industrialisation, have been hampered by the disappearance of seaweed forests. The expansion of seaweed farming and the purposeful protection and restoration of natural seaweed forests are both necessary to advance sustainability in the maritime sector.

Given that various species have demonstrated the ability to grow extensively, even in open ocean situations, seaweed farming has a considerable potential to support the maritime industry's sustainability aims. In the world of business, seaweed may be used for a variety of things, such as food, fertiliser, animal feed, biofuels, and bioplastics. Although carbon sequestration might not be the main factor boosting the seaweed farming sector's growth in the near future, its potential should not be disregarded. Through the adoption of seaweed-based solutions and encouragement of the expansion of the seaweed farming sector, the maritime sector can significantly contribute to the goals of global sustainability.

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