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The Future of Agriculture in A Carbon Constrained World

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Abstract

In a world grappling with the far-reaching consequences of climate change and a growing imperative to lower emissions of greenhouse gases, agriculture's potential finds itself at a critical juncture. This paper explores the intricate dynamics of agriculture in a carbon-constrained world, presenting a nuanced analysis of the multifaceted challenges and opportunities that lie ahead. With a focus on sustainable practices, carbon sequestration, and innovative technologies, this study elucidates the pathways through which agriculture can transition towards a low-carbon and climate-resilient future. From precision farming and agroforestry to advanced breeding techniques and digital agriculture, a spectrum of strategies emerges to mitigate the carbon footprint of agriculture while concurrently enhancing productivity and food security. Moreover, the paper underscores the indispensable role of policy frameworks, international cooperation, and public-private partnerships in ushering in a transformative era for agriculture that aligns harmoniously with global climate goals. This review explores carbon foot printing methodologies in agriculture and their implications for sustainable practices. Additionally, it highlights role of carbon foot printing in informing decision-makers, examines emerging trends like precision agriculture, and addresses associated challenges. This review identifies these gaps and offers recommendations for future research. In elucidating these key themes, this paper advances to a thorough comprehensive understanding of the imperative to embrace innovation and sustainability as guiding principles for the future of farming in a carbon-constrained world.

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Introduction

Plants and animals are made of Carbon, Hydrogen, and Oxygen mixture. Through biogeochemical cycles, elements including C, N, P, S, H, and O enter the biological organism. During respiration, stomata let atmospheric carbon, or CO_2, to enter

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the plant. This carbon is utilized by plants to break down carbohydrates during photosynthesis. Carbon enters the animal's body along with the rest of the biomass when it consumes plant products for food. From the dry weight of plant matter, we find that structural elements present in plants are in percentage as follows Carbon 48%, Hydrogen 6%, Oxygen 45% present in the form of CO_2, H_2O, and CO_2+H2O, respectively.[1] Due to different anthropogenic activities like the use of chemicals, inorganic farming, deforestation, erosion, and the dumping of hazardous wastes with the time left for soil life, soil is losing its ability to push life.[2] This study focuses on several components of the agricultural sector's carbon footprint, such as emissions from pre and post-farm operations. Different farming practices mitigation measures are proposed and methodologies for footprint estimation are examined. The entire amount of greenhouse gases (GHGs) released as a result of agricultural operations is referred to as the sector's carbon footprint. These activities include things like keeping animals, cultivating crops, and employing inputs like fertilizer. Nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2) are the main greenhouse gases connected to agriculture. Due of the negative consequences of climatic change on plants, some inventories are created as preventative measures against weather factors and to raise awareness. The amount of greenhouse gases (GHGs) emitted during the creation of a certain item or system is simply referred to as the "carbon footprint". Life-Cycle Assessment (LCA), which evaluates GHGs, includes a component called carbon footprint, while all other environmental factors impacts are associated with a product which are being assessed by LCA.[3] We could calculate carbon footprint by dividing the complete process into the tier-wise system, which is been separated by hypothetical boundaries. The study of carbon footprint is done mainly to reduce the effect of GHGs emitted from carbon footprints in the agriculture sector which causes global warming in the ecosystem. The carbon footprint is generated by the global warming potential of all levels.[4] Since there are no standards in the agricultural system, they do not have a set of specific boundaries. Tier 1 covers all direct on site greenhouse gas emissions which were identified as an activity within the carbon footprint and are dangerous to nature, i.e. that of soil and machinery. Indirect agricultural emissions, e.g. from electricity generation and transport of agriculturally produced chemicals and machines etc. form part of tiers 2 and 3, respectively; all in their own right are covered by the third tier.5 According to data on overall greenhouse gas emissions, we discovered that one of the largest contributors was the agricultural industry. Global warming is considerably exacerbated by the emission of greenhouse gases (GHGs) at every stage of agricultural activities, from the farm to the house to the market.[6] The earlier study on carbon emissions was mostly focused on the macro level of mechanism, carbon sources and carbon emissions, and economic growth with energy structure evolution, even though low carbon development has now become one of the consensuses of the world's social development. Crop production, food processing, and product marketing, everything at every step generates GHGs which becomes a major contributors for emitting total GHGs, which also has a high contribution to global climatic change.[7] To reduce carbon footprint we should from the improvements in livestock production efficiency, a decrease in the use of synthetic fertilizers and pesticides, and the promotion of sustainable land use techniques are just a few of the actions being taken to lessen the carbon footprint of the agriculture industry.[8] In order to reduce agricultural emissions, new technologies including precision agriculture and carbon sequestration techniques are also being developed. Agriculture's carbon impact includes both direct and indirect emissions. Livestock and their manure account for the majority of direct emissions from agriculture. Enteric fermentation in ruminants such as cows, sheep, and goats is a significant source of methane emissions Manure management is another source of methane emissions, as well as nitrous oxide emissions. Agriculture produces indirect emissions through processes including altering the use of the land, making fertilizer, and running farm equipment on fuel. Deforestation for agriculture and other land use changes are major contributors to carbon emissions.[9] Synthetic fertilizer manufacture also generates emissions, mostly from the energy needed in the process. Additionally, the use of fuel in farm machinery and transportation of agricultural products also results in emissions.[10] Agriculture is also responsible for emissions from soil carbon sequestration. When farmers use tillage practices or overuse fertilizers, it can lead to carbon

loss from the soil. However, the employment of organic farming methods or conservation tillage by farmers can lead to the sequestration of carbon in the soil.[11] The style of farming, the kinds of crops and animals being farmed, as well as the particular techniques and technology being employed, may all affect the carbon footprint of the agriculture industry. For instance, compared to organic and agro ecological farming systems, which are more regenerative and sustainable, industrial agricultural systems often have a bigger carbon footprint.[12] These sustainable systems focus on using natural inputs, reducing external inputs, and emphasizing soil health, which in turn reduces emissions. It is crucial to emphasize that the agricultural sector possesses the capacity not just to lower emissions but also to capture carbon from the atmosphere and store it there. As a result, it is crucial to think about implementing sustainable and regenerative farming methods to reduce the agriculture sector's carbon footprint and mitigate the effects of climate change.[13]

Current State of Carbon Footprints in the Agriculture Sector

Chemical use is one of the primary sources of emissions from the agriculture industry. Also e-energy and fossil fuels due to the growing population need[14] (Table 1). The pace of natural resource exploitation as measured by the consumption of fossil fuels, minerals, and earth's crustal carbon is gradually escalating day by day. Also, these days' pesticides, insecticides, and other fungicides are made available for cheap prices so that farmers could get their hands directly on them, besides farmers prefer them, instead of slow time-consuming organic manures and cultural or other methods. On the other hand, natural resources are continuously deteriorating and over-exploited. These deteriorations occur mainly due to anthropogenic activities that take place like deforestation, erosions, usage of chemicals far beyond the recommended doses, and improper disposal of hazardous waste from different industries.[15] One-fourth of total GHG emissions have increased due to different anthropogenic activities in the agricultural sector. According to the IPCC data survey released in the year 2014 (1990-2014) gives information the world population contributes 36% and the agricultural sector is contributing 42.5% and still going increasing to date. The percentage never declined or got reduced with the passage of years, the worst is these keep on inclining and get exacerbated with time.[16] Looking only at the agriculture industry, which has historically been one of the major sources of greenhouse gas emissions, most of which is due to practices like deforestation for cropland expansions, slash & burn practices, burning of stubborn, stover, straws, stalk, plant litters and other crop residues after each crop season, enteric fermentation in livestock and use of synthetic fertilizers in the fields.[17] About 24% of greenhouse gas emissions are attributed to the agriculture industry, according to the Food and Agriculture Organization of the United Nations.[18] This includes emissions from crops, livestock, fisheries, aquaculture, and forestry. According to information provided by the FAO, emissions of GHGs from forestry, agriculture, and other land uses rose by 1.1% in 2015. Additionally, India's emissions of the same had gone up by 11.8%. Asia accounts for the largest portion of global emissions from agricultural areas and industries, accounting for 44.8% of all emissions, followed by America, Africa, Europe, and Oceania.[19]

Table 1: Percentage of various sectors contributions to global greenhouse gas emissions

Sector	Percentage of global greenhouse gas emissions
Agriculture	10-12%
Energy	25%
Industry	24%
Transportation	14%
Other	16%

Agriculture Component and its Contribution to the Carbon Footprint

The main components of agriculture (Figure 1) that contribute to the carbon footprint are

Land use Change

Carbon dioxide (CO_2) is released into the atmosphere when natural ecosystems like forests, marshes, and grasslands are turned into agricultural land, which contributes to the greenhouse gas effect. Additionally, the loss of ecosystem services and biodiversity may result from this process.

Livestock Production

Methane (CH_4) released during enteric fermentation (digestion) and manure management are the main sources of methane, which is a substantial contributor to greenhouse gas emissions from the production of livestock, including beef, dairy, and poultry. About 14.5% of the world's greenhouse gas emissions are attributed to livestock production, according to the Food and Agriculture Organization of the United Nations (FAO).

Fertilizer use

Nitrous oxide (N_2O), a powerful greenhouse gas that contributes to the greenhouse effect and ozone depletion, is released when nitrogen-based fertilizers are applied. According to another research,China's consumption of nitrogen fertilizer might be reduced by up to 10 million tons annually. According to this study, increasing fertilizer usage efficiency may minimize carbon footprint. Fertilizers are responsible for approximately 5% of global greenhouse gas emissions, primarily due to the production and use of nitrogen fertilizers.[20] Studies have looked into how using fertilizer affects carbon footprints globally, with a focus on identifying ways to reduce emissions while maintaining agricultural productivity. For example, a study published in the journal Global Change Biology estimated that reducing nitrogen fertilizer use in the United States by 20% could the annual reduction of up to 5 million tons of greenhouse gas emissions.[21] Numerous case studies have looked into how using fertilizer affects carbon footprints in various parts of the world. An analysis of the effects of various nitrogen fertilizer management practices on greenhouse gas emissions in the wheat production systems of South Asia, for instance, was published in the journal Nutrient Cycling in agro ecosystems. The study found that the use of controlled-release fertilizers and improved nitrogen management practices could reduce emissions while maintaining crop yields.[22] Yet another study examined how various fertilizer management techniques affected greenhouse gas emissions in Vietnamese rice production systems. The study found that reducing nitrogen fertilizer use and using organic fertilizers could significantly reduce greenhouse gas emissions while maintaining rice yields.[23] To reduce the carbon footprint associated with fertilizer use, several approaches have been proposed, including improving fertilizer use efficiency, reducing nitrogen losses, and promoting the use of organic fertilizers. For example, a study published in the journal Nature Sustainability suggested that promoting the use of legumes, which can fix nitrogen from the atmosphere, could reduce the need for nitrogen fertilizers and help reduce the carbon footprint of agriculture. Substantially, research on fertilizer use has highlighted the need for sustainable practices that can reduce the carbon footprint while maintaining agricultural productivity. By promoting more efficient and sustainable fertilizer use practices, we can help mitigate the effects of fertilizer use on carbon emissions and how they relate to the fight against climate change.[24]

Energy use

Agriculture relies on energy for irrigation, mechanization, transportation, and processing. For using of fossil fuels in the purposes to releases carbon dioxide into the atmosphere.[25]

Soil Management

Crop rotation and other soil management techniques, such as tillage, can have an effect on the amount of carbon held in the soil. Conservation tillage and cover crops are two methods that can help enhance soil carbon storage while lowering greenhouse gas emissions.[26]

Crop Production

Different crop production practices, such as tillage, irrigation, and crop selection, have different impacts on the carbon footprint, and reducing emissions from agriculture requires targeted strategies. Crop production is a significant contributor to the carbon footprint, accounting for about 12% of global greenhouse gas emissions.Studies have examined the effects of various crop production methods on carbon footprints globally, with an emphasis on figuring out how to cut emissions while keeping agricultural output. For instance, a research that appeared in the journal Agriculture, Ecosystems and Environment looked into how reduced tillage affected greenhouse gas emissions in Australian wheat production systems. According to the study, decreased tillage techniques can increase crop output while cutting greenhouse gas emissions by up to 23%.[27]

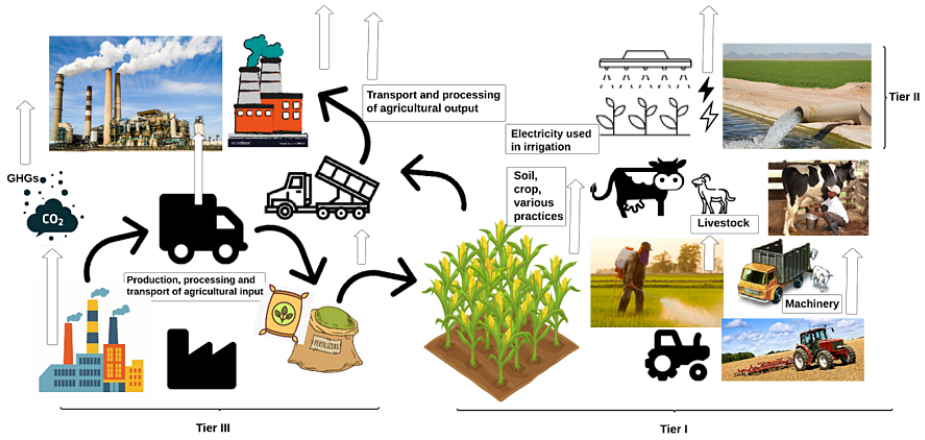

Fig. 1: Emission sources under different tiers of agriculture

A different investigation into the effects of climate change on Canadian wheat output was published in the journal Global Change Biology. According to the study, climate change may result in lower wheat yields and higher greenhouse gas emissions, highlighting the need for targeted adaptation strategies to maintain agricultural productivity and reduce emissions. A number of case studies have looked at how various crop production methods have affected the carbon footprint in various parts of the world, including Australia, Canada, and New Zealand. For instance, a case study that was published in the journal Agriculture, Ecosystems and Environment examined how various irrigation techniques affected greenhouse gas emissions in Australian cotton production systems. About 25.31% of the world's carbon footprint is attributable to cotton production in Australia. 26.3% of the carbon footprint of cotton production is due to post-farm activities such transportation, gin garbage treatment, bale packing, cotton seed drying, and ginning equipment. Through various agriculture operations and practices, the remaining 48.4% of emissions are produced.[28] Another example study that was published in the journal Environmental Science and Pollution Research looked at how various crop management techniques affected greenhouse gas emissions in Canadian maize production systems. The study found that drip irrigation could reduce greenhouse gas emissions by up to 25% while maintaining maize yields. The study found that using cover crops and reducing tillage could reduce greenhouse gas emissions by up to 48% while maintaining maize yields.[30]

Study on the Methods used In Different Locations of the World for Agricultural Production Practices Including India

India

In a research that was published in the journal Environmental Monitoring and Assessment, it was examined how various irrigation techniques affected the amount of greenhouse gases released during rice cultivation in Punjab, India. According to the study, drip irrigation can keep rice yields the same while cutting greenhouse gas emissions by up to 43%.[31]

Iran

The production of sunflowers accounts for 70.31% of the nation's primary energy consumption. This energy consumption primarily originates from labor-intensive irrigation, electrical power, and human labor (direct energy), with the remaining 29.69% attributed to machinery, seeds, fertilizer, and pesticides (indirect energy). Within this energy consumption, 20.97% is derived from renewable sources, while the remaining 79.03% relies on non-renewable sources. Furthermore, the FAO reported in 2014 that worldwide emissions in 2010 totaled 785 million tons of CO_2 equivalent. These studies highlight the significance of using sustainable agricultural production methods to cut down on global agriculture's carbon impact. Sustainable agricultural production techniques can help us combat climate change by lowering greenhouse gas emissions, enhancing soil health, and other benefits.[32] These studies highlight the importance of transitioning away from fossil fuel use in Gulf

countries to reduce the carbon footprint associated with energy production. These nations may drastically lower their greenhouse gas emissions and aid in the fight against climate change by investing in renewable energy sources and putting carbon capture and storage technologies into practice.

Soil Management

Sustainable agriculture and lowering the carbon footprint associated with agriculture both greatly benefit from good soil management methods. Here are a few instances of research looking at how soil management techniques affect the environment

Australia

In grazing systems in Australia, the effect of soil management techniques on greenhouse gas emissions was examined in a research that was published in the journal Soil Biology and Biochemistry. According to the study, employing compost and reducing grazing intensity might greatly cut greenhouse gas emissions while enhancing soil health.[33]

USA

The effect of soil management techniques on greenhouse gas emissions in corn production systems in the USA was examined in a research that was published in the Soil Science Society of America Journal. According to the research, utilizing cover crops and minimizing tillage can considerably lower greenhouse gas emissions while enhancing soil health.[34]

Kenya

A research that was written up in the journal Agriculture, Ecosystems and Environment looked into how soil management techniques affected greenhouse gas emissions on Kenyan smallholder farms. The study found that using organic fertilizers and reducing tillage could significantly reduce greenhouse gas emissions while improving soil health and crop yields.[35]

Brazil

An analysis of soil management strategies' effects on greenhouse gas emissions in Brazilian soybean production systems was published in the journal Agriculture, Ecosystems and Environment. In addition to enhancing soil health and agricultural yields, the study discovered that utilizing cover crops and lowering tillage might dramatically cut greenhouse gas emissions.[36] These studies show how crucial sustainable soil management techniques are for lowering greenhouse gas emissions and enhancing soil health throughout the globe. By putting these strategies into action, we can support sustainable agriculture while tackling the issue of climate change.

Crop Production

Crop production is an important aspect of agriculture in different states of India, and different crop production practices have been studied to understand their impact on the carbon footprint. Here are a few examples of studies on crop production practices in different states of India

Punjab

According to a research that was published in the journal Environmental Science and Pollution Research, rice-wheat cropping systems in Punjab were examined to see how different crop management techniques affected greenhouse gas emission.[37] According to the study, greenhouse gas emissions might be cut by up to 35% by lowering fertilizer consumption and encouraging the use of organic fertilizers.

Maharashtra

A research on the effects of various irrigation techniques on greenhouse gas emissions in sugarcane producing systems in Maharashtra was published in the journal Agricultural Water Management.38 The study found that drip irrigation could reduce greenhouse gas emissions by up to 32% while maintaining sugarcane yields.

Tamil Nadu

An investigation on the effects of various irrigation techniques on greenhouse gas emissions in Tamil Nadu's rice production systems was published in the journal Agricultural Water Management.[38] According to the study, alternate wetting and drying irrigation can keep rice yields the same while reducing greenhouse gas emissions by up to 30%.

Karnataka

A study published in the Journal of Environmental Management investigated the effect of various crop management techniques on greenhouse gas emissions in Karnataka's maize producing

systems.39The study found that using organic fertilizers and reducing tillage could reduce greenhouse gas emissions by up to 60% while maintaining maize yields.

Rajasthan

A study published in the journal Current Science investigated the impact of diverse crop management techniques' effects on greenhouse gas emissions in Rajasthan's pearl millet production systems. The study found that using organic fertilizers and promoting the use of legume crops in crop rotations could reduce greenhouse gas emissions by up to 45%.[40]

Methods for Carbon Foot Print Calculation

Different Tools are used for Calculating the Carbon Footprints are

Life Cycle Assessment (LCA)

It is a technique which is used to evaluate how agricultural production practices affect the environment.[41] LCA considers all stages of the production cycle, from input production to final product delivery. It also takes into account the energy and resources used at each stage, as well as the emissions generated. When the Coca-Cola Company examined its beverage packaging in the late 1960s, the LCA approach was initially developed .LCA was distinguished by the comprehensive analysis of how activities or goods affect the environment.[42] Land use, energy use, global warming, eutrophication, acidification, and human toxicity, among other things were categories used in LCA to classify environmental effect. In LCA, CF essentially represented the impact of global warming. The LCA technique has been employed a lot in CF research because of the comprehensive and synthetic qualities.

Cool Farm Tool (CF)

CF is a method for estimating the carbon emissions associated with a particular product or activity. In agriculture, CF typically focuses on estimating the greenhouse gas emitted during the process of the production and transport of crops and livestock.[43] A farm-level greenhouse gas (GHG) emissions calculator called The Cool Farm Tool can be used to calculate the carbon footprint of various activities related to agriculture. It is a user-friendly online tool that can be used to evaluate different farm management practices and their impact on GHG emissions.[44]

Holistic Management Framework

The Holistic Management Framework is a management tool that is designed to help farmers and ranchers make better decisions about land use, grazing management, and other factors that can impact the carbon footprint of their agricultural operations.[45]

Global Dairy Environmental Assessment Tool (GDEA)

The GDEA tool is a method to calculate the carbon impact of dairy production method.[46] In order to determine the carbon footprint of dairy farms, elements including feed production, herd management, and management of manure are considered to calculate the carbon footprint of dairy farms. The most used methods are Carbon foot printing (CF) and Life Cycle Assessment (LCA). LCA is widely utilized technique for assessing the effects of agricultural production systems on the environment. LCA considers the energy and resources used at each stage, as well as the emissions generated.[47] The results of LCA could be used to recognize the main sources of ecological impacts and to develop strategies for reducing these impacts.

Strategies for Mitigation

These few strategies can be used to mitigate the carbon footprint of agriculture, including

Improving Soil Health

Healthy soil can store carbon, which helps to offset emissions from other agricultural activities. There are several ways to improve soil health, including

Reducing Tillage

Tillage is the process of breaking up the soil with a plow or other implement. This can release carbon from the soil and can also damage the soil structure. Reducing tillage can help to improve soil health and reduce emissions.

Cover Cropping

Plants that are cultivated in between cash crops are known as cover crops. They aid in reducing erosion, enhancing soil health, and suppressing weeds.

Carbon from the atmosphere can also be captured by cover crops.

Crop Rotation

Crop rotation helps maintain a healthy soil and prevents the accumulation of pests and illnesses. Additionally, it aids in the removal of atmospheric carbon.

Making use of manure or compost organic elements like manure and compost can be applied to the soil to enhance its health. They also aid in removing carbon dioxide from the air.

Improving Animal Management

Methane, another potent greenhouse gas, is a major byproduct of the production of cattle. Methane emissions from animals can be decreased in a number of methods, [61] including: Feeding animals, a diet that is lower in methane-producing feedstuffs: Some feedstuffs, such as corn, produce more methane than others.[62] Feeding animals, a diet that is lower in these feedstuffs can help to reduce methane emissions.

Improving Manure Management

Manure is a major source of methane emissions. Improving manure management can help to reduce these emissions. This can be done by

Storing Manure Properly

Manure should be stored in a way that prevents it from being exposed to the air.[63] This will help to prevent the formation of methane.

Using Anaerobic Digesters

Anaerobic digesters are devices that convert manure into methane gas. This gas can be used to generate electricity or heat.

Switching to Renewable Energy Sources

The agricultural sector relies heavily on fossil fuels for energy, which contributes to emissions.[64] Improving water management: Improving water management can help to reduce emissions by

Using more Efficient Irrigation Systems

More efficient irrigation systems can use less water, which can help to reduce emissions.

Reusing Water

Water that has already been used for irrigation can be reused for other purposes, such as livestock watering.[65] This can help to reduce the amount of water that is needed.

Promoting Sustainable Agricultural Practices

Some other sustainable agricultural practices can help to mitigate emissions, such as

Agroforestry

Agroforestry is a system of agriculture that combines trees and crops. This system can help to improve the soil health, reduce the erosion, and capture all the carbon from the atmosphere.[66]

Conservation Tillage

It is a type of tillage that causes the least amount of soil disturbance possible. This technology has the potential to lessen emissions while enhancing soil health.[67] These are just a few of the strategies that can be used to mitigate the carbon footprint of agriculture. By implementing these strategies, farmers could contribute to a more sustainable food system by lowering their environmental effect. In addition to the strategies listed above, there are many other ways to mitigate the carbon footprint of agriculture. These include

Aiding in the Creation of New Technologies

New technologies like enhanced livestock feed additives and Carbon Capture and Storage (CCS) offer the potential to lower agricultural emissions. Supporting these technologies' research and development could hasten their uptake and lower their cost.[67]

Creating Market Incentives for Sustainable Agriculture

Governments and businesses can create market incentives for sustainable agriculture, such as carbon pricing or subsidies for sustainable farming practices. These incentives can help to make sustainable agriculture more economically viable and encourage farmers to adopt these practices.[68] By taking these steps, we can help to mitigate the carbon footprint of agriculture and make a positive contribution to the fight against climate change (Figure 2).

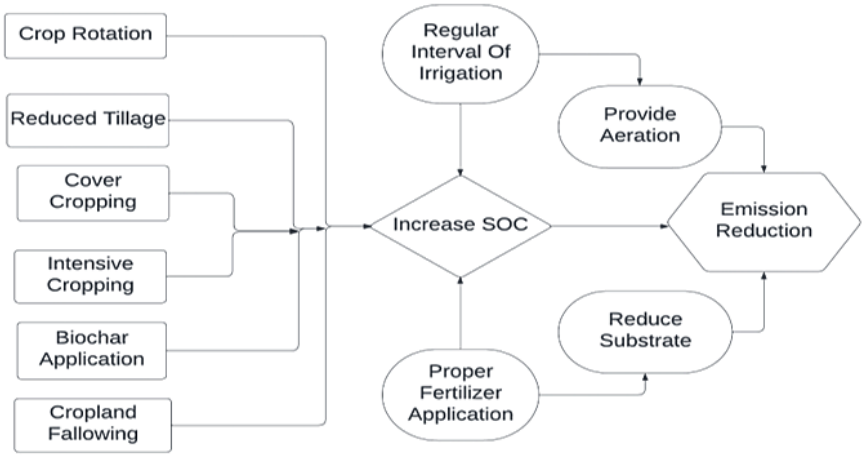

Fig. 2: Mitigation strategies to reduce carbon footprinting in agriculture

Innovative Modern Models for Carbon Foot Printing

The major modern models adopted in carbon foot printing in agriculture are FAOSTAT. A global database that provides estimates of GHG emissions from agri-food systems in 245 countries and territories from 1990 to 2019. It covers emissions from land use change, crop and livestock production, food processing, packaging, transport, consumption, and waste. FAOSTAT is a global database that provides estimates of GHG emissions from agri-food systems in FAOSTAT uses a Life Cycle Assessment (LCA) method to calculate carbon footprint in agri-food systems. LCA considers all the system's pertinent inputs and outputs, such as energy, materials, emissions, and waste.[68]

FAOSTAT includes three main GHGs in its calculations: CO, methane (CH4), and nitrous oxide (N_2O). FAOSTAT provides different indicators to measure the carbon footprint of agri-food systems, such as total emissions, emissions intensity, emissions per capita, and emissions per food calorie.[68] FAOSTAT also allows users to compare emissions across countries, regions, years, and food categories. FAOSTAT aims to support decision-making and policymaking for low-carbon and sustainable agri-food systems.[69]

McKinsey MACC

A MACC is a graphical representation of cost-effectiveness of different options for reducing GHG emissions. It shows the amount of emissions that can be abated by each option and the cost or benefit (on the vertical axis) of doing so. Options below the horizontal axis have negative costs, resulting in net lifetime savings. Options above the axis have positive costs, i.e., net investments are necessary. For the purpose of calculating GHG emissions from agricultural, forestry, and other land use (AFOLU), it also uses data from other sources, such as FAOSTAT, IEA, and GLEAM. McKinsey MACC reports the carbon footprint of different farming practices. McKinsey MACC includes three main GHGs in its calculations: CO_2, CH_4, and N_2O. McKinsey MACC provides different indicators to measure the carbon footprint of different farming practices, such as emissions intensity, abatement potential, abatement cost, and net present value (McKinsey MACC) McKinsey MACC also allows users to compare different scenarios, such as business-as-usual, 1.5-degree pathway, and net-zero pathway. McKinsey MACC aims to support decision-making and policymaking for low-carbon and sustainable agriculture.[70]

Overseer

A farm-specific model that calculates the carbon footprint of agricultural byproducts to the farm gate in New Zealand, including milk, meat, and wool. It takes fertilizer use, manure management, enteric fermentation, and lime application into account, cultivation, and irrigation. Overseer is a farm-specific model that calculates the carbon footprint of agricultural co-products (such as milk, meat, and wool) to the farm gate in New Zealand.[71] The carbon

footprint of different farming systems in terms of carbon dioxide equivalent (CO_2e), a commonly used unit, that expresses the global warming potential of different GHGs relative to CO_2 (Over seer). Over seer includes three main GHGs in its calculations: CO_2, CH_4, and N_2O. Overseer provides different indicators to measure the carbon footprint of different farming systems, such as emissions intensity, emissions per hectare, and re and emissions per product. Overseer also allows users to compare different scenarios, such as baseline, mitigation, and best practice. Overseer aims to support decision-making and policymaking for low-carbon and sustainable agriculture in New Zealand.[72]

Indian Agriculture Carbon Calculator

A web-based tool that estimates the carbon footprint of crop production in India. It considers emissions from fertilizer use, irrigation, tillage, residue burning, and electricity consumption.[73] Indian Agriculture Carbon Calculator is a web-based tool that estimates the carbon footprint of crop production in India. It considers emissions from fertilizer use, irrigation, tillage, residue burning, and electricity consumption.[74] Indian Agriculture Carbon Calculator uses a life cycle assessment (LCA) approach to calculate the carbon footprint of different cropping systems. It also uses data from other sources, such as the India GHG Program, the Ministry of Environment, Forest and Climate Change (MoEFCC) and the World Economic Forum (WEF).[75] Indian Agriculture Carbon Calculator includes three main GHGs in its calculations. CO_2, CH_4, and N_2O .Indian Agriculture Carbon Calculator provides different indicators to measure the carbon footprint of different cropping systems, such as emissions intensity, emissions per hectare and emissions per product. Indian Agriculture Carbon Calculator also allows users to compare different scenarios, such as baseline, mitigation, and best practice. Indian Agriculture Carbon Calculator aims to support decision-making and policymaking for low-carbon and sustainable agriculture in India.[76]

Farm Carbon Calculators

It refers to a comparison of three UK-based tools that measure the carbon footprint of farms or farm enterprises. They are Cool Farm Tool, Agrecalc, and Farm Carbon Cutting Toolkit (Farm carbon calculator). They differ in their data requirements, calculation methods, output formats, and user interfaces. They also use data from other sources, such as the UK National Inventory Report (NIR), the UK Fertilizer Manual (RB209,) and the UK Farm Practices Survey (FPS). All three tools report the carbon footprint of different farming systems in terms of carbon dioxide equivalent (CO_2), which is a common unit that expresses the global warming potential of different GHGs relative to CO_2.[77]

Cool Farm Tool

It is an online tool that requires registration and login. It covers a wide range of crops and livestock systems, as well as agroforestry and bioenergy. It allows users to compare different scenarios, such as baseline, mitigation, and best practice.[78] It provides graphical and numerical outputs, as well as benchmarks and recommendations.

Agrecalc

It is an online tool that requires registration and login. It covers a wide range of crops and livestock systems, as well as horticulture and organic farming.[79] It allows users to compare different scenarios, such as baseline, mitigation, and best practice. It provides graphical and numerical outputs, as well as benchmarks and recommendations.[80]

Farm Carbon Cutting Toolkit

It is an Excel-based tool that can be downloaded for free. It covers a wide range of crops and livestock systems, as well as agroforestry and bioenergy. It allows users to compare different scenarios, such as baseline, mitigation, and best practice. It provides numerical outputs, as well as benchmarks and recommendation.[80]

Future Perspective on Carbon Foot Printing

The future perspective of carbon foot printing in the agriculture sector is promising. There is a growing awareness of the necessity to cut back greenhouse gas emission agriculture, and there are several innovative approaches to carbon foot printing that are being developed.[48] One of the most promising trends in carbon foot printing in the agriculture sector is the development of new technologies that make it easier and more accurate to measure emissions. For example, new satellite data is being used to track deforestation, and new sensors are being used to measure methane emissions from livestock.[49] These technological advancements are making it possible

to measure carbon footprints at a much finer level of detail than ever before. As a result, the sources of emissions are becoming clearer and to find of more opportunities to reduce them. Another trend that is shaping the future of carbon foot printing in the agriculture sector is the changing behavior of consumers.[50] As consumers become more aware of the environmental impact of their choices; they are demanding products and services that have a lower carbon footprint. This is leading to a growing market for low-carbon agricultural products. Businesses that can reduce their carbon footprint are likely to be more successful in this market.[51] The future of the agriculture sector is sustainability. We need to find ways to produce food that is both nutritious and environmentally friendly. The good news is that we have the technology and the know-how to do this. We just need to have the political will to make it happen. If we can reduce the carbon footprint of agriculture, we will be making a major contribution to the fight against climate change. We will also be ensuring that future generations have a healthy planet to live on. Many trends are emerging that could help to cut down the carbon footprint of agriculture. The increasing use of data and technology: Farmers are increasingly using data and technology to improve their operations. This includes using sensors to monitor crop health and soil conditions and using drones to survey fields. This data can be used to locate potential emission reduction sites. For example, sensors can be used to measure soil moisture levels and provide information to farmers on when to water crops.[52] This could help to reduce water use and emissions from irrigation. The growth of sustainable agriculture: Sustainable agriculture is a broad phrase that encompasses a variety of practices that lessen the effects of agriculture on the environment. The practices include cover cropping, crop rotation, and no-till farming.[53] These practices could aid in lowering emissions from agriculture while also improving soil health and water quality. For example, cover cropping could help to cut down erosion and amend soil carbon sequestration. This can help to cut down emissions from agriculture and advance with the long-term productivity of soil.[54] The development of new carbon markets. Carbon markets are a way to trade carbon credits. Carbon credits are certificates that represent the right to emit a certain amount of greenhouse gases. Farmers obtaining credits for carbon by cutting back on pollution.[55] After that, these carbon credits can be traded for other companies or organizations that need to offset their emissions. For example, a company that emits greenhouse gases could purchase carbon credits from a farmer who has reduced their emissions. This would allow the company to offset its emissions and meet its sustainability goals.[56] These trends could help to shape the future of carbon foot printing in the field of agriculture. Farmers can discover locations where emissions can be decreased by using data and technology. By adopting sustainable agriculture practices, farmers can reduce emissions while also improving soil health and water quality. And by participating in carbon markets, farmers can earn money by reducing their emissions. There are many articles which are published on the carbon footprinting which are increasing year by year (Figure 3).

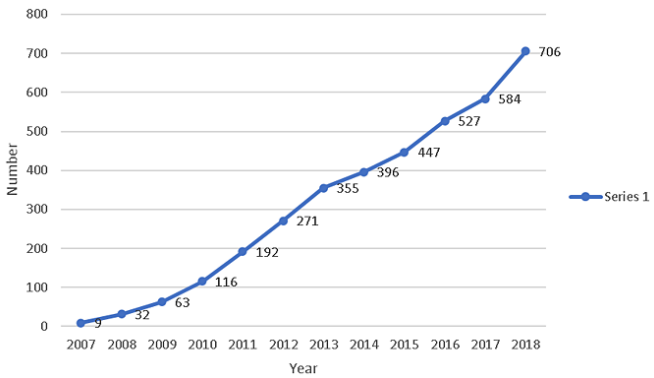

Fig. 3: Number of articles published on carbon footprinting from 2007 to 2018.58

Adaptive agricultural practices are designed to assist farmers in adjusting to the impacts of climate change. For example, drought-tolerant crops can be planted in areas that are becoming more prone to drought, and water-efficient irrigation systems can be used to conserve water. Regenerative is a kind of farming that prioritizes on building soil health and sequestering carbon.[59] This can lessen agriculture's impact on the environment and increase crop production. Precision agriculture is the leveraging technology to collect and analyze data about crops and soil. This data can be used to optimize agricultural practices and reduce the use of inputs like fertilizer and insecticides. By adopting these and other technologies, we could contribute to ensure that agriculture has a sustainable future, in a carbon-constrained world.[60]

Conclusion

With over 25% of all anthropogenic emissions coming from the agricultural sector, it is a significant source of global greenhouse gas emissions. These emissions come from issues. Types of sources, including livestock, crop production, and land-use change. Carbon footprint in the topic of agriculture is complicated, and there are no single solutions to reducing it. Another promising approach is to opt for more sustainable crop production practices. This can include using less fertilizer and pesticides, as well as planting crops that are more efficient at capturing carbon dioxide from the atmosphere. Finally, it is important to reduce land-use changes. This can be done by protecting forests and grasslands, as well as by increasing the efficiency of agricultural land use. By reducing the carbon footprint in agriculture, we could help reduce climate change, improve food security, and protect our natural resources. Demand our government to take action in their capability to reduce agricultural emissions and take appropriate measures to control them. By taking all these steps, we can help to protect the Earth's ecosystem and ensure that future generations have a healthy planet to live on. Although in recent years, we have seen several promising developments in the field of reducing the carbon footprint of agriculture. The major developments we have seen include the development of new feed additives that can reduce methane emissions from livestock. These varieties are often bred to have a higher ratio of carbon-fixing leaves to other plant parts and also the development of new technologies for capturing and managing agricultural emissions. These technologies include methane digesters, which can be used to capture methane from livestock manure and convert it into energy, and nitrous oxide scrubbers, which can be used to remove nitrous oxide from agricultural runoff. All these developments offer a great deal of potential to reduce the amount of carbon footprint in the sector of agriculture. These technologies strive to continue but still are in the early stages of development, so it's crucial to keep in mind that they might not be broadly accessible for some time. However, we are aware that there needs to be ongoing innovation in this area as lowering agriculture's carbon footprint is crucial. We must create new techniques and technology that will enable us to further cut emissions from agriculture. We also need to make sure that these technologies and practices are accessible to all farmers, regardless of their size or location. This will require a concerted effort from governments, businesses, and farmers themselves. New technological advancements and shifting consumer habits, and government policy are all driving the demand for carbon-foot printing data. As a result, carbon foot printing is becoming increasingly important for businesses, organizations, and individuals in the agriculture sector. It is a valuable tool for understanding the environmental effects of agricultural operations and for identifying opportunities to reduce emissions.

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Conflict of Interest

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References

1. Liu, E. K., He, W. Q., Yan, C. R. White revolution'to 'white pollution'agricultural plastic film mulch in China. *Environmental Resea Letters.*2014; 9(9): 091001.
2. Kovda, V. A. The world's soils and human activity. *The Environmental Futu.* 1972; 359-81.
3. Pattara, C., Raggi, A., & Cichelli, A. Life cycle assessment and carbon footprint in the wine supply-chain. *Environmental management.* 2012;49: 1247-1258.
4. IPCC. Special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. 2014;Geneva.
5. Foley, J.A., Ramankutty, N., Brauman, K.A., Gerber, J.S., Johnston, J.M., Lobell, D.K., Field, C.B., and Ericksen, P.H. Global agricultural yields: Past trends, future prospects. Sci. 2014; 305(5683): 570-575.
6. Tubiello, F. N., Salvatore, M., Rossi, S., Ferrara, A., Fitton, N., Smith, P. The FAOSTAT database of greenhouse gas emissions from agriculture. *Environ Resea Let.* 2013;8(1): 015009.
7. MIT Energy Initiative. Cambridge, MA, https://energy.mit.edu/wpcontent/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf. 2018.
8. Liu, C., Cutforth, H., Chai, Q., & Gan, Y. Farming tactics to reduce the carbon footprint of crop cultivation in semiarid areas. A review. *Agron For Sustai Devel.*2016; 36: 1-16.
9. Pragna, P., Chauhan, S. S., Sejian, V., Leury, B. J., Dunshea, F. R. Climate change and goat production: Enteric methane emission and its mitigation. *Anim.*2018; 8(12): 235.
10. Fynn, R. W. S., Bonyongo, M. C. The adoption of holistic management practices among commercial cattle farmers in semi-arid Botswana. *Jour of Environmental Manage.*2011; 92(9), 1990-1997. doi: 10.1016/j.jenvman.2011.03.012.
11. Robertson, G. P., Groffman, P. M., Swinton, S. M. Nitrogen transformations. In Soil microbiology, ecology and biochemistry. *AcademPress*. 2017; 433-467.
12. Kremen, C., Iles, A., & Bacon, C. Diversified farming systems: an agroecological, systems-based alternative to modern industrial agriculture. *Ecolo and Society.*2012; 17(4).
13. Capra, F. The web of life: *A new scientific understanding of living systems. Anchor* 1997.
14. Bruvoll, A., Larsen, B. M. Greenhouse gas emissions in Norway: do carbon taxes work?. In *Environmental taxation in Prac.*2017; 545-557.
15. Bisht, A., Kamboj, N., Kamboj, V.,Bisht, A. A review on the role of emerging anthropogenic activities in environmental degradation and emphasis on their mitigation. *Archives of Agricuand Environmental Sci.*2020; 5(3):419-425.
16. Brummett, R. N., Karlen, D. L. Carbon footprint of soil management: A review. *Jour of Soil and Water Conser* . 2013; 68(1): 16-24.
17. Smil, V. Fritz Haber, Carl Bosch. *Enriching the Earth:and the Transforof World Food Produ. MIT press.*2004.
18. FAO. The future of food and agriculture: Trends and challenges. Food and Agriculture Organization of the United Nations. 2017
19. Africa Centre for Holistic Management. (n.d.). Our work. https://achmonline.org/our-work/
20. Chen, Shanshan, Amelia-Elena Rotaru, Fanghua Liu, Jo Philips, Trevor L. Woodard, Kelly P. Nevin, Derek R. Lovley. Carbon cloth stimulates direct interspecies electron transfer in syntrophic co-cultures.*Biores Tech.* 2014; 173; 82-86.
21. Snyder, C. S., Bruulsema, T. W., Jensen, T. L. Fixen, P. E. Review of greenhouse gas emissions from crop production systems and fertilizer management effects. *Agric, Eco andEnviro,* 2009; 133(3-4): 247-266.
22. Jat, R. A., Sapkota, T. B., Singh, R. G., Gupta, R., Jat, M. L., Kumar, M. Seven years of conservation agriculture in a rice-wheat rotation of Eastern Gangetic Plains of South Asia: yield trends and economic profitability. *Field Cro Rese.* 2014;164:199-210.
23. Tirol-Padre, A., Tran, D. H., Hoang, T. N., Hau, D. V., Ngan, T. T., An, L. V & Sander, B. O. Measuring GHG emissions from

rice production in Quang Nam Province (Central Vietnam): Emission factors for different landscapes and water management practices. *Land Use and Clim Change Interac in Central Vietnam.*2017;103-121.

24. Garg, V., Smith, R. F., Garg, H. P. Renewable energy for sustainable agriculture. *InternJourof Ener and Enviro Engine.*2013; 4(1): 23.
25. Chel, A., & Kaushik, G. Renewable energy for sustainable agriculture. *Agro for SustainDevelopt*. 2011; 31: 91-118.
26. Kumar, P., Singh, M., Singh, R., Kumar, V. Changes in soil quality indicators under different crop rotations in a long-term experiment in subtropical India. *Arch of Agroand Soil Sc*i.2015;61(2): 151-167.
27. Pandey, R. K., Maranville, J. W.,Admou, A. Tropical wheat response to irrigation and nitrogen in a Sahelian environment. I. Grain yield, yield component,s, and water use efficiency. *Euro Jourof Agro.* 2001.15(12):93-105
28. Sykes, A. J., Topp, C. F., Wilson, R. M., Reid, G., Rees, R. M. A comparison of farm-level greenhouse gas calculators in their application on beef production systems. *Jour of Cleaner Produc.* 2017;164:398-409.
29. Li, Q., Wang, Y., Zhang, C., Wang, E. Carbon footprint of agricultural production systems: A review. *InterJourof Agricultural Sustainabi.*2021; 19(1): 1-16.
30. Abdalla, M., Hastings, A., Helmy, M., Prescher, A., Osborne, B., Lanigan, G Jones, M. B. Assessing the combined use of reduced tillage and cover crops for mitigating greenhouse gas emissions from arable ecosystem. *Geoderma,* 2014;223:9-20.
31. Robertson, G. P., Paul, E. A., & Harwood, R. R. Greenhouse gases in intensive agriculture: contributions of individual gases to the radiative forcing of the atmosphere. *Sci.* 2000; 289(5486): 1922-1925.
32. Ogle, S. M., Olander, L., Wollenberg, L., Rosenstock, T., Tubiello, F., Paustian, K. Smith, P. Reducing greenhouse gas emissions and adapting agricultural management for climate change in developing countries: providing the basis for action. *Global Change Bio.* 2014; 20(1): 1-6.
33. Dalal, R. C., Allen, D. E., Livesley, S. J., Richards, G., Evans, D. R. Soil greenhouse gas fluxes and stock changes in grazed pasture systems: A methodology comparison. *Soil Bioand Biochem.* 2013; 58:44-54.
34. Liska, A. J., Cassman, K. G., Gao, X. The role of soil management in mitigating greenhouse gas emissions from corn production systems. *Soil Sci Society of Amer Jour.*2018; 82(6):1456-1468.
35. Kihara, J., Nyamai, A. J., Njoroge, S. M., Franzluebbers, A. J., Shepherd, K. D., Mairura, F. Soil organic carbon dynamics and stocks under different farming systems in the Central Highlands of Kenya. *Agricul, Ecosysand Enviro.*2016; 235: 284-293.
36. Lizaso, J. I., Verhagen, J., Basso, B. An overview of APSIM, a model designed for farming systems simulation. *Europ Jour of Agro.*2016; 76, 8-22.
37. Gupta, D. K., Bhatia, A., Kumar, A., Das, T. K., Jain, N., Tomer, R. & Pathak, H. Mitigation of greenhouse gas emission from rice–wheat system of the Indo-Gangetic plains: Through tillage, irrigation and fertilizer management. *Agricul, Ecosys and Enviro,* 2016; 230: 1-9.
38. Hiloidhari, M., Vijay, V., Banerjee, R., Baruah, D. C., Rao, A. B. Energy-carbon-water footprint of sugarcane bioenergy: A district-level life cycle assessment in the state of Maharashtra, India. *Renewand Sustain EnerRev.* 2021; 151: 111583.
39. Basavalingaiah, K., Ramesha, Y. M., Paramesh, V., Rajanna, G. A., Jat, S. L., Dhar Misra, S., Elansary, H. O. Energy budgeting, data envelopment analysis and greenhouse gas emission from rice production system: A case study from puddled transplanted rice and direct-seeded rice system of Karnataka, India. *Sustainabi.*2020; 12(16): 6439.
40. Sharma, P. K., Singh, A. K., Dubey, S. K., & Singh, V. K. Conservation agriculture and its effect on soil fertility and crop productivity: A case study from northern India. *Jour of Clean Produc.*2018; 195: 883-893.
41. Brentrup, F., Küsters, J., Kuhlmann, H., & Lammel, J. Environmental impact assessment of agricultural production systems using the life cycle assessment methodology: I. Theoretical concept of a LCA method tailored to crop production. *Euro Jourof Agro.* 2004; 20(3):247-264.

42. Latunussa, C. E. L. Life cycle assessment (LCA) of food and beverage packaging. 2011.
43. Janzen, H. H., Angers, D. A., Boehm, M., Bolinder, M., Desjardins, R. L., Dyer, J., Wang, H. A proposed approach to estimate and reduce net greenhouse gas emissions from whole farms. *Canadi Jour of Soil Science*.2006; 86(3): 401-418.
44. Gkisakis, V. D., Volakakis, N., Kosmas, E., Kabourakis, E. M. Developing a decision support tool for evaluating the environmental performance of olive production in terms of energy use and greenhouse gas emissions. *Sustain Producand Consum.*2020; 24:156-168.
45. Gosnell, H., Grimm, K., & Goldstein, B. E. A half century of Holistic Management: what does the evidence reveal?. *Agricul and Human Val.*2020; 37, 849-867.
46. Karwacka, M., Ciurzyńska, A., Lenart, A., Janowicz, M. Sustainable development in the agri-food sector in terms of the carbon footprint: A Review. *Sustainabi.*2020; 12(16): 6463.
47. Bouwman, A. F., Lee, D. S., van der Hoek, K. W., Daroudi, H., Kroeze, C., Heuberger, P. S. C. Greenhouse gas emissions from dairy farming in the United States and Europe: A modeling study with the Global Dairy Environmental Assessment Tool. J*our of Clea Produc.*2017; 148:525-534.
48. Tedeschi, L. O., Abdalla, A. L., Álvarez, C., Anuga, S. W., Arango, J., Beauchemin, K. A., Kebreab, E. Quantification of methane emitted by ruminants: a review of methods. *Jour of AniSci.* 2022; 100(7):197
49. Rondoni, A., Grasso, S. Consumers behaviour towards carbon footprint labels on food: A review of the literature and discussion of industry implications. *Jour of CleaProdu*2021; 301: 127031.
50. J.W. Shennan, M.E. Johnston, and J.M. Shepherd. *Agrofor Sustai Develo.* 2019;39(1):1-28,
51. Schönleben, M., Mentschel, J., Střelec, L. Towards smart dairy nutrition: Improving sustainability and economics of dairy production. *Czech Jourof AniSci*2020; 65(5):153-161.
52. Costa, M. P., Chadwick, D., Saget, S., Rees, R. M., Williams, M., Styles, D. Representing crop rotations in life cycle assessment: a review of legume LCA studies. *The Inter Jourof Life Cycle Assess.*2020; 25: 1942-1956.
53. Haruna, S. I., & Nkongolo, N. V. Influence of cover crop, tillage, and crop rotation management on soil nutrients. *Agricul.*2020; 10(6): 225.
54. De Vries, S.C., Dolman, M.J.J.S., Van der Werf., M.C.M. Carbon Footprinting of Agriculture: A Review of Approaches and Opportunities. *Agricule, Ecosys and Enviro.* 2016; 232:61-78
55. Marks, A. B. Carbon Farming Our Way Out of Climate Change. *Denv. L. Rev.*2019; 97:497.
56. Shepherd, J.M., Johnston, M.E., & Shennan, J.W. The Carbon Footprint of Agriculture: A Review of Methods and Sources. *Enviro Sci andPoli.*2017; 93: 1-13.
57. Balafoutis, A., Beck, B., Fountas, S., Vangeyte, J., Van der Wal, T., Soto, I Eory, V. Precision agriculture technologies positively contributing to GHG emissions mitigation, farm productivity and economics. *Sustainab.* 2017; 9(8): 1339.
58. Yue, T., Liu, H., Long, R., Chen, H., Gan, X., Liu, J. Research trends and hotspots related to global carbon footprint based on bibliometric analysis: 2007–2018. *EnvironSci and PolluRese* 2020; 27: 17671-17691.
59. Mishra, A. K., Sinha, D. D., Grover, D., Roohi, Mishra, S., Tyagi, R Sharma, S. Regenerative Agriculture as Climate Smart Solution to Improve Soil Health and Crop Productivity Thereby Catalysing Farmers' Livelihood and Sustainability. In Towards Sustainable Natural Resources: Monitoring and Managing Ecosystem Biodiversity. *Cham: Springer International Publishing*. 2022:295-309.
60. A.M. Arshad, K.A. Malik, M.A. Qureshi. J*our of IntegraAgricu*l;15(3):477-493, 2016.
61. Herrero, M., Thornton, P. K., Notenbaert, A. M., Wood, S., Msangi, S., Freeman, H. A., Jones, P. G. Drivers of change in crop-livestock systems and their potential impacts on agro-ecosystems services and human well-being to 2030. *AgriculSyst.*2013.
62. Gomes, S., Nogueira, M., Ferreira, M., Gregorio, M. J., Graça, P., Jewell, J., Breda, J. Consumer attitudes toward food

and nutritional labeling: implications for policymakers and practitioners on a national level. *Jour of Food Produs Marke.* 2020; 26(7):470-485.

63. Palazzo, J., Geyer, R., & Suh, S. A review of methods for characterizing the environmental consequences of actions in life cycle assessment. *Journof Industrial Ecolo.*2020; 24(4): 815-829.
64. Kjaer, L. L., Pagoropoulos, A., Schmidt, J. H., McAloone, T. C. Challenges when evaluating product/service-systems through life cycle assessment. *Jour of CleaProduc.*2016; 120:95-104.
65. Clark, Casey. Biogeochemical Tracers of Change in Pacific Walruses Past and Present. *University of Alaska Fairbanks,* 2019.
66. Cooreman-Algoed, Margot, Sophie Huysveld, Carl Lachat, Jo Dewulf. How to integrate nutritional recommendations and environmental policy targets at the meal level: A university canteen example.*Sustain Product and Consumpti* 2020:21: 120-131.
67. Stylianou, K.S., and Miller, S.A. A review of life cycle assessment (LCA) applications in the food-energy-water (FEW) nexus. *Jou of Clean Product.*2017; 171: 1354-1367.
68. Matos, P. ESG and responsible institutional investing around the world: A critical review. 2020
69. MacLeod, C. J., Brandt, A. J., Collins, K., Moller, H., Manhire, J. Behavioural insights for improved uptake of agricultural sustainability assessment tools. *Peo and Nat.*2022; 4(2): 428-444.
70. Mekonnen, M. M., Hoekstra, A. Y. The green, blue and grey water footprint of farm animal products. *Wa Resou Rese*. 2012; 48(9): 5506-5518.
71. Poore, J., & Nemecek, T. Reducing food's environmental impacts through better production practices. *Scie,* 2018;360 (6392):987-992.
72. Mbow, C., & van der Velde, M.Reducing agricultural greenhouse gas emissions: A review of mitigation options. *Environme Resea Lett.* 2020;15(5): 055002.
73. Tubiello, F. N., Van Ittersum, M. K. Options for mitigation of greenhouse gas emissions in agriculture: A review. *Mitigat and Adapta Strates for Global Chan.* 2010;15(5):503-536.
74. Smith, P., Martino, D., Cai, X., Gwary, D., Janzen, H. J., Kumar, P., Zurek, M. Greenhouse gas mitigation in agriculture. Philosophical Transactions of the Royal Society B: *BiologScien.* 2008;363(1507) :789-813.
75. Carlson, B. R., Carpenter-Boggs, L. A., Higgins, S. S., Nelson, R., Stöckle, C. O., Weddell, J. Development of a web application for estimating carbon footprints of organic farms. *Computand Electronin Agricult.*2017; 142: 211-223.
76. Padhan, N., Islary, M., Gupta, A. K. Climate Finance at International and National Level: Needs, Drivers and Sources. In Hydro-Meteorological Extremes and Disasters. *Springer NatuSingap*;2022: 33-43.
77. Mor, S., Madan, S., Prasad, K. D. Artificial intelligence and carbon footprints: Roadmap for Indian agriculture. *Strategic Change.*2021; 30(3), 269-280.
78. Al-Mansour, F., & Jejcic, V. A model calculation of the carbon footprint of dairy production in the UK. *Jour of CleanProduct.*2019; 221: 1178-1187.
79. Grant, N., Hawkes, A., Napp, T., & Gambhir, A. The appropriate use of reference scenarios in mitigation analysis. *NatCliChan.*2020; 10(7): 605-610.
80. Green, A., Lewis, K. A., Tzilivakis, J., and Warner, D. J. Agricultural climate change mitigation: carbon calculators as a guide for decision making. *Interna Jour of AgriculSustaina.*2017;15(6): 645-661.