404NotFound

Inter IIT TechMeet Bootcamp

Optimizing carbon emissions in supply chain

Table of contents

Industry Selection

Healthcare

- Healthcare organizations prioritize **immediate patient care**, which can detract from long-term sustainability goals.
- The healthcare sector is **heavily regulated**, which can create hurdles for implementing innovative sustainability measures.
- The focus tends to be on regulatory compliance and **maintaining safety standards rather than pioneering new sustainable practices.**

E-Commerce

- E-commerce's focus on fast delivery and convenience often increases emissions due to expedited shipping and returns.
- **Reliance on third-party logistics limits control over emissions reduction, making sustainability efforts challenging.**
- In a competitive market, cost-cutting and speed often take priority over sustainability.

Agriculture

- In agriculture, emissions are tied to supply chain practices, allowing for targeted interventions to reduce carbon footprints.
- It aligns with SDGs, particularly **SDG 13 (Climate Action) and SDG 2 (Zero Hunger)**, contributing to environmental sustainability and food security.
- Practices like organic farming, reducing chemical inputs, and improving biodiversity lower emissions and promote a healthier ecosystem.

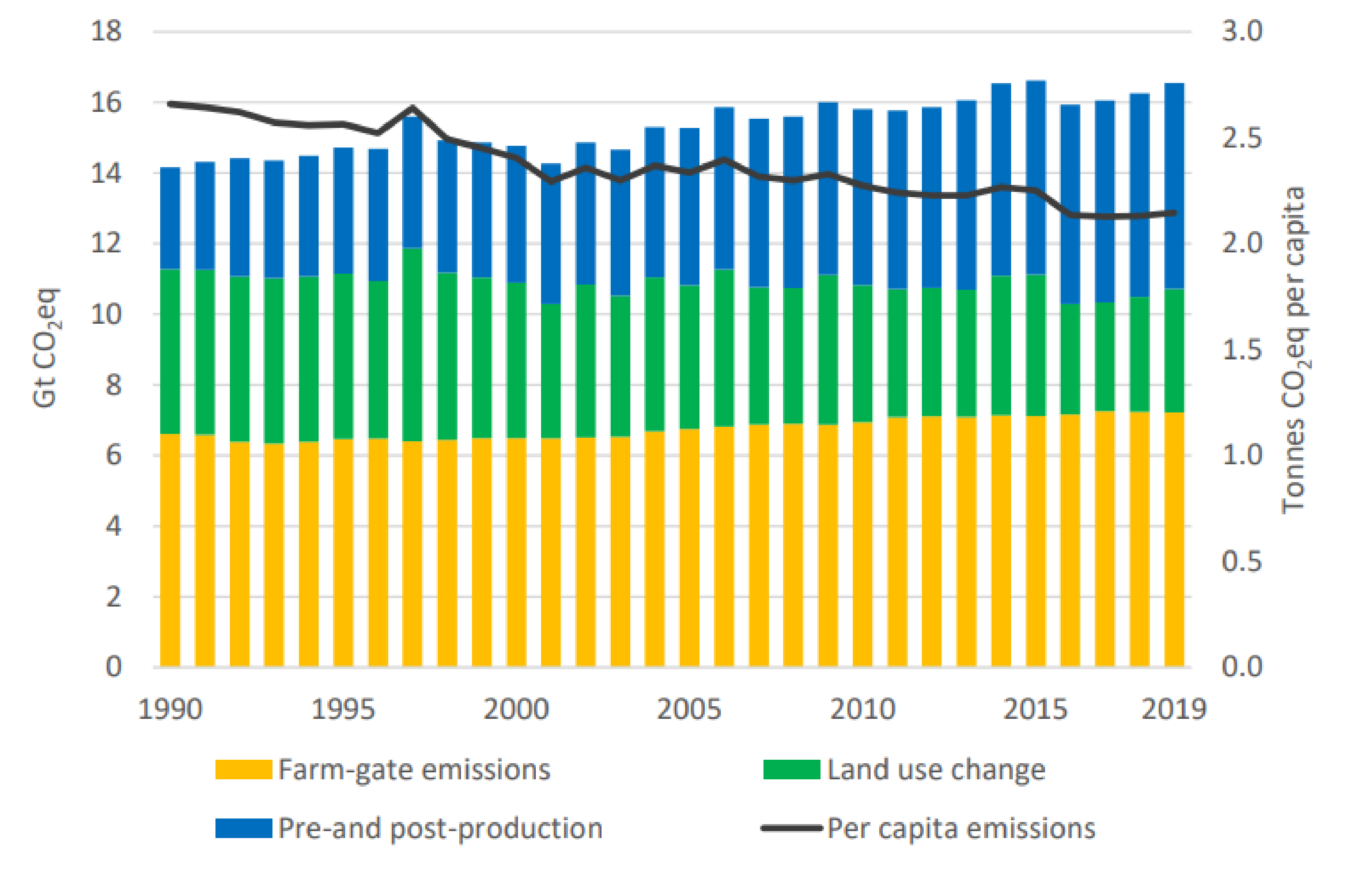
Conclusion

- Thus, agriculture seems to be the best option over healthcare and e-commerce due to its **direct impact on carbon emissions** and opportunities for targeted interventions.
- Unlike healthcare, with its regulatory constraints, and e-commerce's reliance on third-party logistics, **agriculture offers the most potential for long-term, scalable carbon reduction and environmental impact**.

Industry Selection

Why Agriculture?

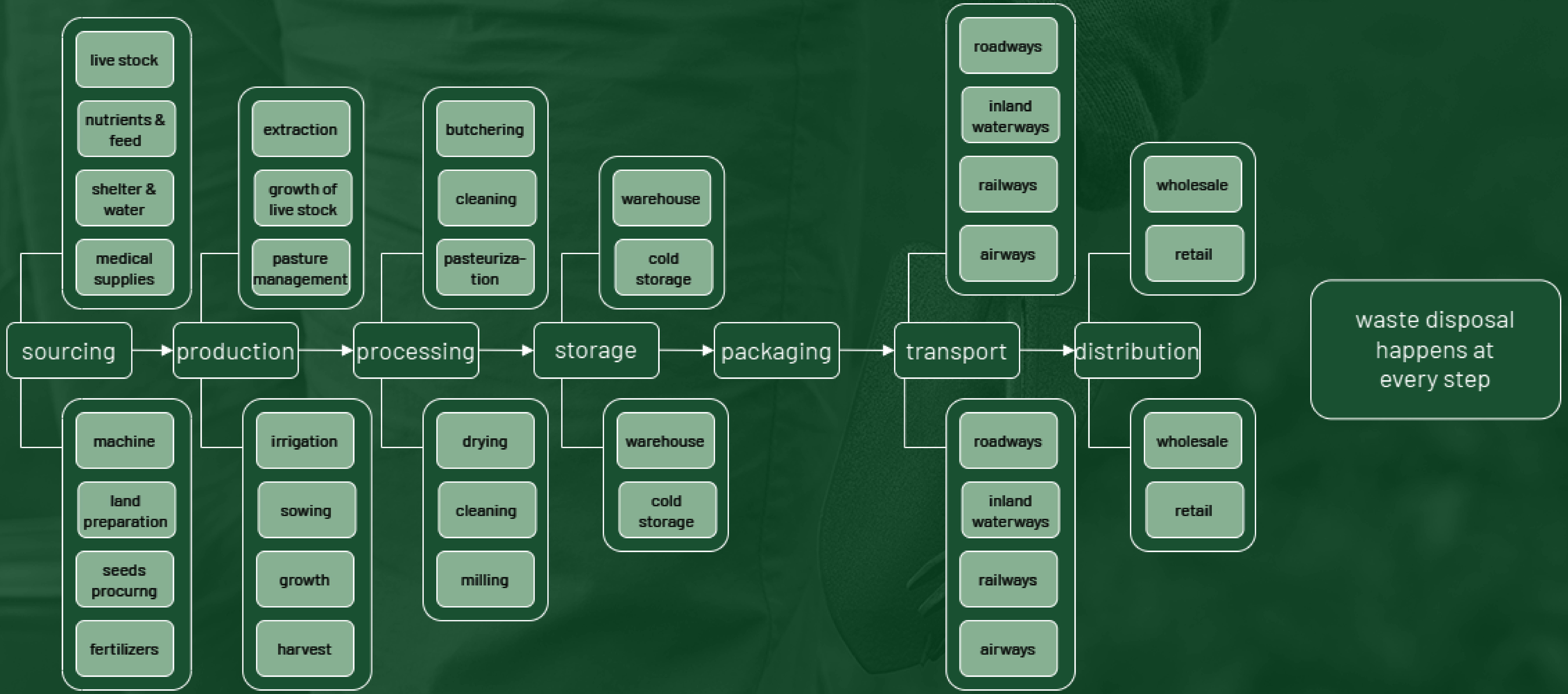
- Agriculture is a promising sector for carbon emission reductions due to its significant contribution to global emissions and **direct control over supply chain practices**.
- Agriculture is a major source of methane (53%) and nitrous oxide (78%) emissions.



Key reasons agriculture offers potential for carbon emission reductions:

- **Supply chain impact**: In 2019, farm-gate activities produced 7 billion tonnes CO2eq, while pre/post-production processes added 6 billion tonnes CO2eq, **offering multiple intervention points.**
- **Emission trends and per capita reductions**: Though agri-food system emissions grew by 16% between 1990 and 2019, per capita emissions **fell from 2.7 to 2.1 tonnes CO2eq**. This indicates that despite rising total emissions due to population growth and industrialization, **better practices have reduced the per capita impact**, showing the **potential for further reductions**.
- **Regional opportunities**: In Africa and South America, agri-food systems represent over 70% of total emissions, **providing a focus for impactful regional strategies.**

Supply Chain Analysis



Supply Chain Analysis

To simplify the agricultural supply chain analysis, we categorize it into three parts: pre-production, farm gate, and post-production. This framework highlights the distinct contributions to overall emissions, enabling targeted strategies for carbon reduction at each stage. By addressing emissions in these areas, we can enhance sustainability efforts effectively.

Pre-Production

- **Sourcing materials**: Pre-production includes acquiring essential raw materials, impacting **emissions through resource extraction**.
- **Land use**: The **conversion of land for agriculture** affects carbon storage and greenhouse gas emissions.

Farm Gate

- **Irrigation**: Effective water management is vital for crop growth and **impacts emissions**.
- **Sowing**: Proper planting is crucial for successful crop development and efficiency.
- **Crop and livestock growth**: Cultivation and livestock raising are **major contributors** to greenhouse gas emissions.
- **Harvesting and extraction**: Harvesting methods influence emissions and resource efficiency.
- **Pasture management**: Effective pasture management **enhances carbon sequestration** and environmental outcomes.

Post-Production

- **Processing**: Energy-intensive, adding to CO2 emissions.
- **Storage**: Refrigeration and storage generate significant emissions.
- **Packaging**: Packaging materials, especially plastics, contribute to greenhouse gases.
- **Transport**: Road and air transport are major sources of CO2.
- **Distribution**: Inefficient logistics increase fuel consumption and emissions.

*Waste disposal happens at each step

Pre-Production

Land Preparation

- Soil **removes** about **25%** of the world's fossil-fuel emissions each year. The **carbon sink capacity** of the world's agricultural and degraded soils is **50 to 66%**
- This means our soil can hold **42 to 78 Gts more carbon. 133 Bts** of carbon — about 8% of total organic soil carbon — has been lost from the top 2 metres of soil since the advent of agriculture some 12,000 years ago

Manure & Fertilizers

- Manure and synthetic fertilizers emit the equivalent of **2.6 Gts of carbon per year**.
- Production and use of food security account for **5% of GHG emissions**. Synthetic N fertilizer supply chain was emitted an estimated emissions of **1.13 GtCO_2e in 2018**, representing 10.6% of agricultural emissions and **2.1% of global GHG emissions**.
- Emissions from the fertilizer sector could be **reduced** by as much as **80% by 2050**.

Land Use Change (LUC)

- Land use change (LUC) from agricultural expansion is a major source of **anthropogenic greenhouse gas (GHG) emissions**.
- Emissions from tropical peat fires were **204 Mt CO_2eq yr–1 in 2018**. CO_2 emissions from **deforestation in 2020 was 2.9 Gt CO_2eq**.
- Companies and individuals are making land-use decisions at least partially directed at reducing GHGs

Post-Production

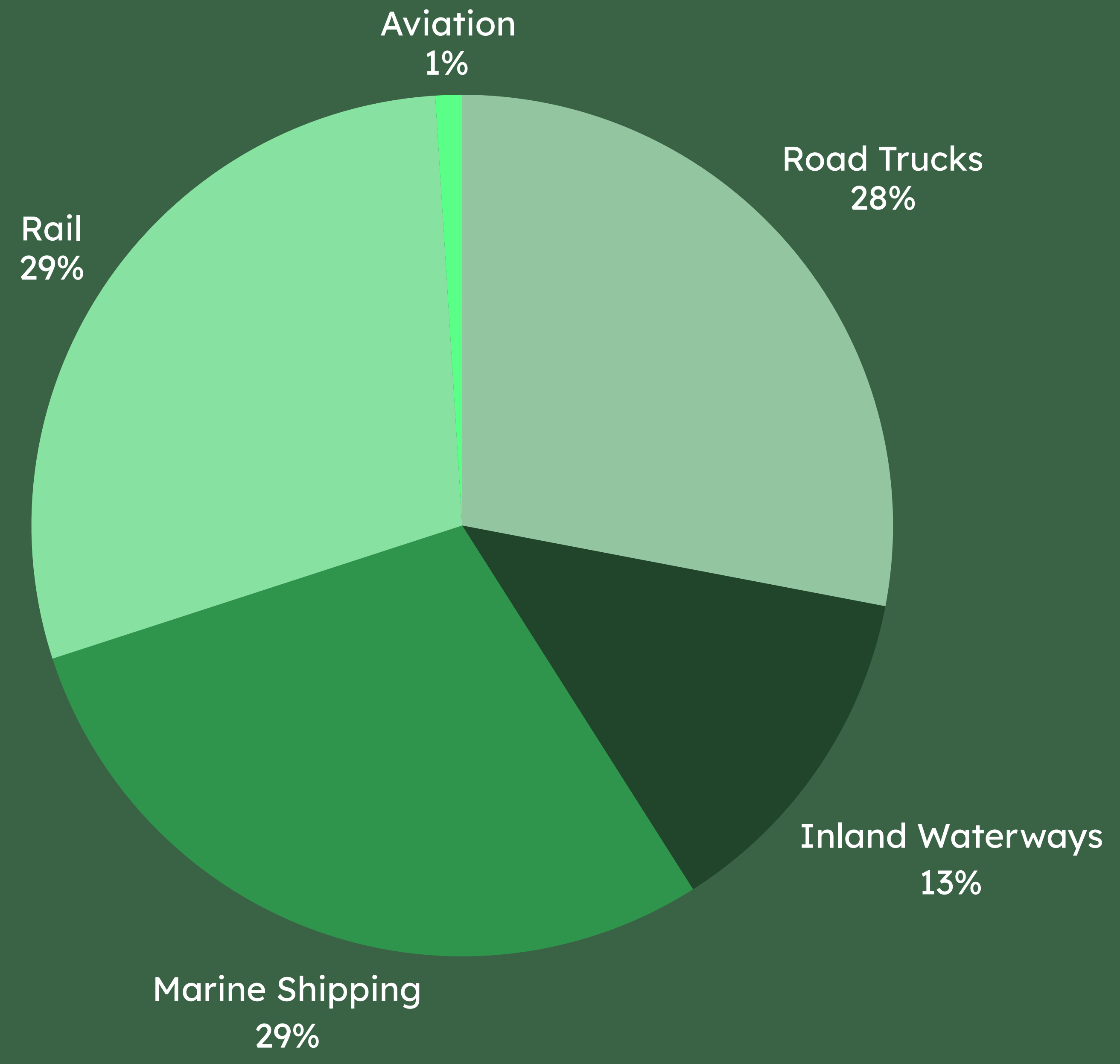
Problems

- Carbon emissions in the post-production phase of the food supply chain, including **processing, storage, packaging, and transportation**, significantly contribute to global greenhouse gases.
- The post-production sector is responsible for producing **9,800–16,900 million tonnes of CO2 annually**, a figure expected to rise to **30% of global emissions by 2050**.
- Food wastage in storage and transport exacerbates this, with **67 million tons of food** wasted yearly in India, leading to **INR 920 billion** in potential economic losses. Reducing such inefficiencies can dramatically cut emissions and resource use.
- Furthermore, **methane emissions** from food waste decomposition and **carbon dioxide** from transportation and refrigeration of perishable goods further compound environmental impacts.
- For instance, food production consumes **10% of the U.S. energy budget**, and reducing waste by just **15%** could feed **25 million people for a year**, also significantly cutting carbon emissions.
- Addressing post-production inefficiencies in handling, storage, and transport will not only improve supply chain efficiency but will also reduce emissions across the board.

Post-Production

Problems

- The current global food system generates significant emissions from transportation, nearly **one-fifth** of the total food system emissions.
- Food transportation covers **22 trillion tonne-kilometres per year**, with various transport modes contributing differently to emissions.
- Rail accounts for **29% of global food transport** with low energy intensity, while road trucks contribute **28%** but have much **higher energy demands**.
- Although international shipping and aviation play smaller roles, they still contribute significantly to global emissions due to their **high energy intensity**.



Global Food Transport by Mass (%)

Solution - Regenerative Agriculture

Regenerative agriculture is an adaptive farming approach applying practically proven and science-based practices, focused on soil and crop health aimed at yield resilience and a positive impact on carbon, water, and biodiversity.

Smaller CO2e Emissions

The farming thrives on **significantly less use of farming machineries**, leading to reduction in direct CO2e emissions. Additionally, **decline in use of synthetic fertilizers** also lowers the emissions.
Improved soil health also **increases carbon sequestration**.

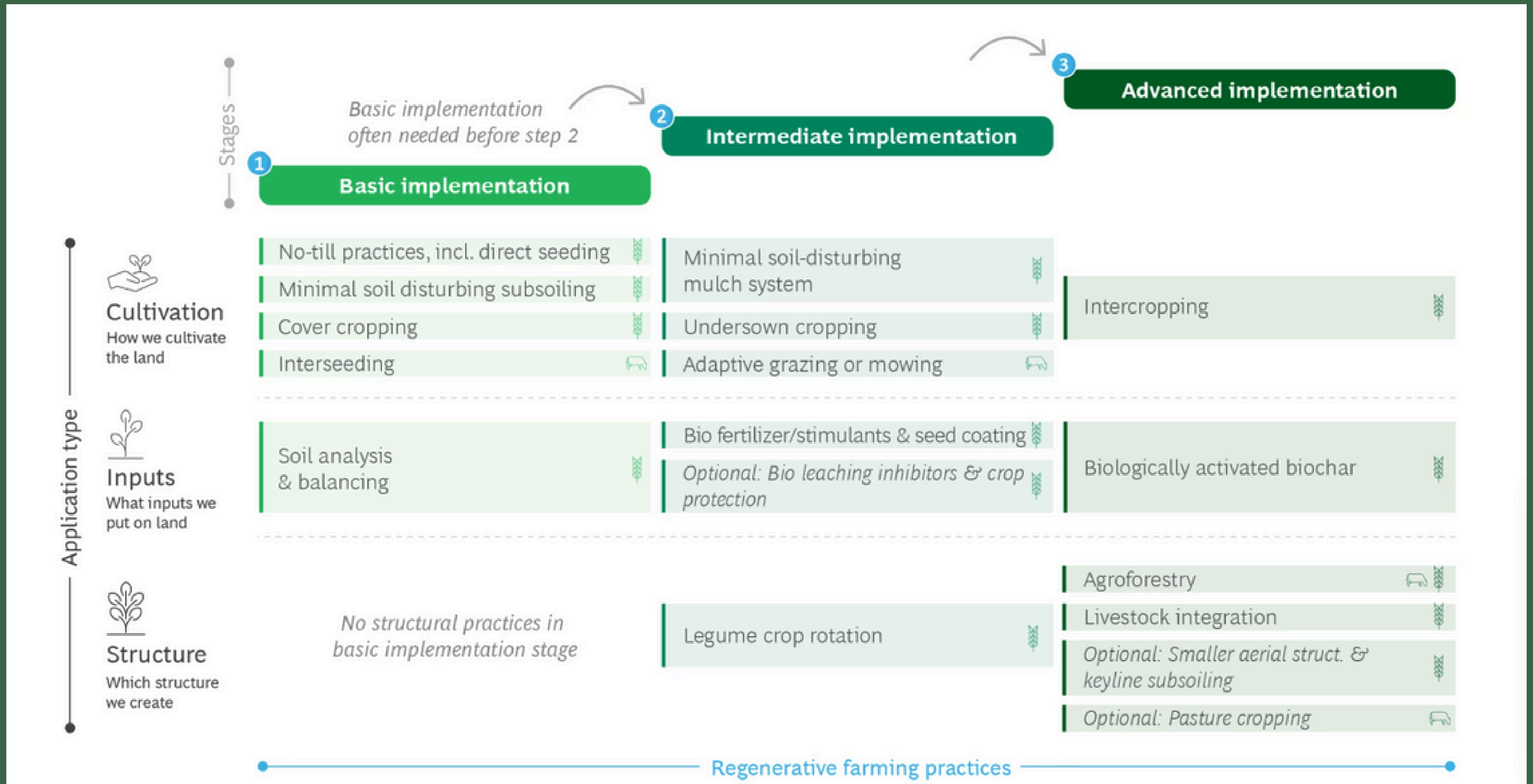
Greater Biodiversity

Reducing the use of synthetic fertilizers, and adopting techniques such as **no-till farming, greater coverage of the soil, and more diverse crops**—can provide a substantially healthier ecosystem for a wide variety of animals and **promote a wide variety of microorganisms**.

Better Water Management

Regenerative agriculture helps lessen the runoff that causes water pollution and eutrophication. Since, t**he soil health improves**, its capacity to hold water increases, thus **reducing the need for irrigation**, surface water puddling, lowering the risk of crop damage and soil erosion.

Implementation & Expected Profits

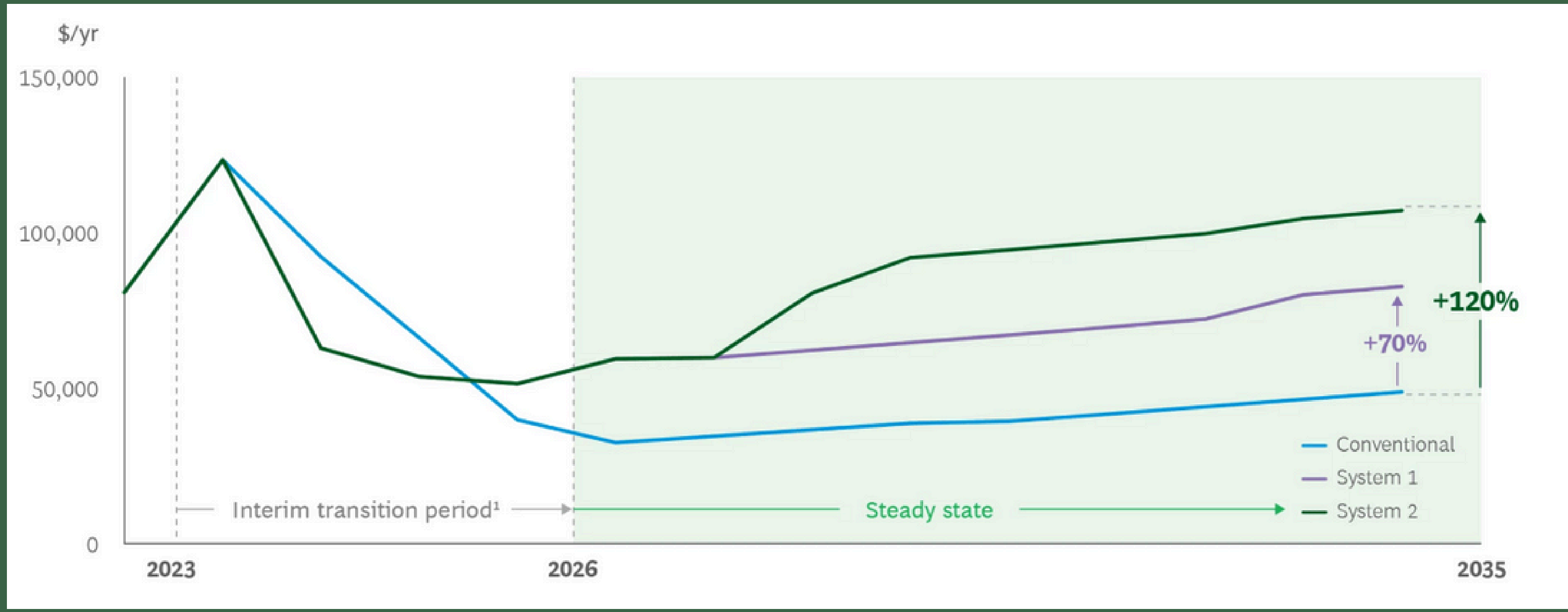


+70%

Profit increase in transition from conventional system to system 1

+120%

Profit increase in transition from system 1 to system 2



Annual profit by farming system for an average 780 acre wheat farm in a state in the United States

Risks Involved

- Farmers **lack technical and financial assistance** in terms of starting capital and resources to make a successful transition.
- An **initial decline in profits** is expected due to added costs of new seeds for intercropping and new machinery.
- Individual farms may require **different regenerative practices**, depending on context and past practices with regard to variables as climate and soil type.

*This analysis is done for developed nations

Regenerative Fertilization - Biochar

The three most-potent agricultural GHGs associated with soil nutrient-climate feedback loops are **CO_2, N_2O and CH_4**. The combination of manure and mineral fertilizer had the highest **CO_2 (74%) and N_2O (89%)** emissions. Either manure or fertilizer alone increased CO_2 and N_2O emissions. Manure application also raised CH_4 emissions.

Crop

- **The greatest reduction in CO_2 emissions (– 19%) : corn cultivation, followed by wheat and fallow fields.**
- Wheat was the best crop for reduction of CH_4 and N_2O.

Soil

- **The greatest CO_2 (– 38%), N_2O (– 72%) and CH_4 (– 40%) emission reductions were for coarse, followed by medium, then fine textured.**
- The strongest CO_2 and N_2O emission reductions were for alkaline soils (37% and 60%), followed by neutral, then acidic soils.

C:N Ratio

- For high C:N ratio (C:N > 10), fertilizer or manure should be avoided, in favor of biochar. Yet integrated biochar and fertilizer should be avoided for soils with low C:N ratio(C:N <=10).
- **For C:N > 10; notable reductions of CO_2(35%), N_2O(60%) and CH_4(31%) were seen.**

Key Points

- Inputs of biochar and manure, can curb emission rates of **CO_2 by 14.4–28.3%, N_2O by 19.7% and CH_4 by 32.9%, while also boosting overall crop productivity**
- Economic Impact - Biochar was applied at 10,000 kg/ha, and the resultant yields increased from 2900 kg/ha to 11,004 kg ha−1. The **net return** for this process was up to **$4953 ha−1**

Risks

- High biochar inputs were proportional to either mitigation or exacerbation of GHGs emissions.
- It has crop specific and soil specific responses.
- The results might differ with region as this study is confined to some continents to achieve a balanced analysis.

Farm-Gate / Production

Irrigation & Tractor Use (On Farm Energy Use)

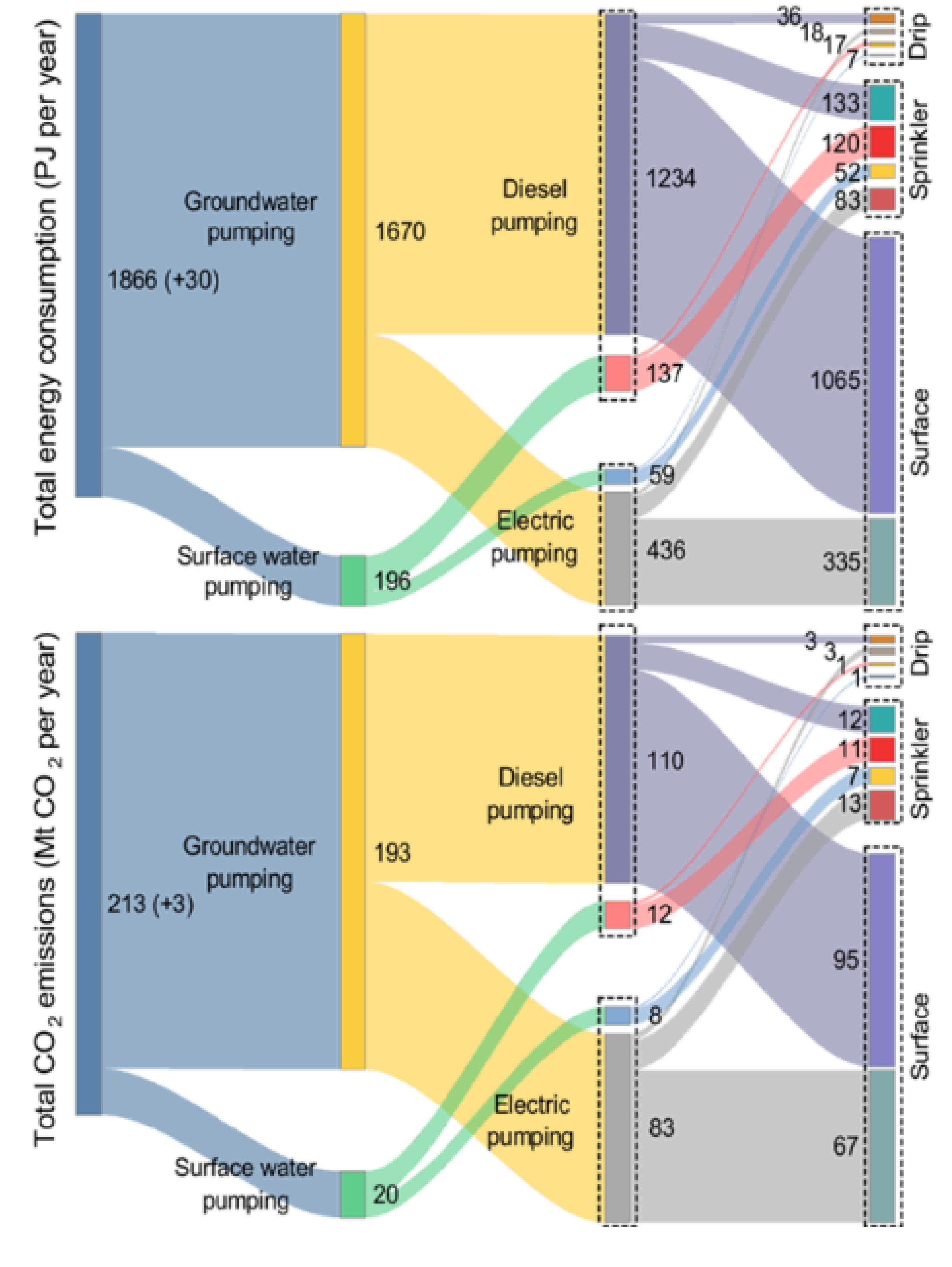
<u>~537 MtCO_2e, at cost savings of ~$229/t$CO_2$e</u>

- Irrigation in agriculture contributes to significant CO_2 emissions (**216 million metric tons**) and energy consumption (**1,896 petajoules**), representing **15% of greenhouse gas emissions**. Groundwater pumping, though only used in 40% of irrigated agriculture, accounts for **89% of energy consumption**.

- Low-carbon irrigation methods, such as gravity-fed and basic drip systems(using plastic tubing), can significantly reduce energy consumption. However, **global CO2 emissions may decrease by only 55%** due to varying feasibility in different countries.

- Electric tractors powered by renewable energy can lower emissions and costs. **Declining battery costs** could enhance tractor **affordability by 2030**.
- Current machinery has a long lifespan, impeding technology adoption.

- Dependence on government policy and funding can create uncertainty in implementation.
- The typical lifetime of a tractor is **more than 20 years.**



Solving Rice Cultivation

~496 $MtCO_2e$, at cost savings of ~$53/$tCO_2e$

The issue of how much water to use in rice production & Microbes that feed off decaying plant matter in these fields produce the greenhouse gas methane. Solution: Laser Land Levelling & Dry Direct Seeding in Agriculture

- Laser Land Levelling: Expanding this technology **in low- and middle-income** regions can revolutionize water management. It enhances precision in leveling fields, allowing for **more efficient water usage and better crop yields**. Notably, it significantly reduces methane emissions from flooded rice fields, sometimes nearly eliminating methane production entirely.

- Water-Focused Policy: Water scarcity has driven the adoption of water-saving technologies, especially in countries like India and China. Market pricing for water could further promote this practice by improving the economic case for water management innovations.

- Dry Direct Seeding: Involves sowing seeds directly into dry rice paddies, cutting the duration of field flooding by a month. This decreases the activity of methane-producing microorganisms, **reducing methane emissions by around 45% per hectare**. Additionally, it offers **cost savings** by reducing labor for transplanting and managing flooded fields.

- Support for Expansion: **In low- and middle-income regions**, local advisory networks and research institutions could play key roles in expanding these technologies through **education and diffusion.** **Input manufacturers' support** will be critical for ensuring the availability and affordability of necessary tools and technologies.

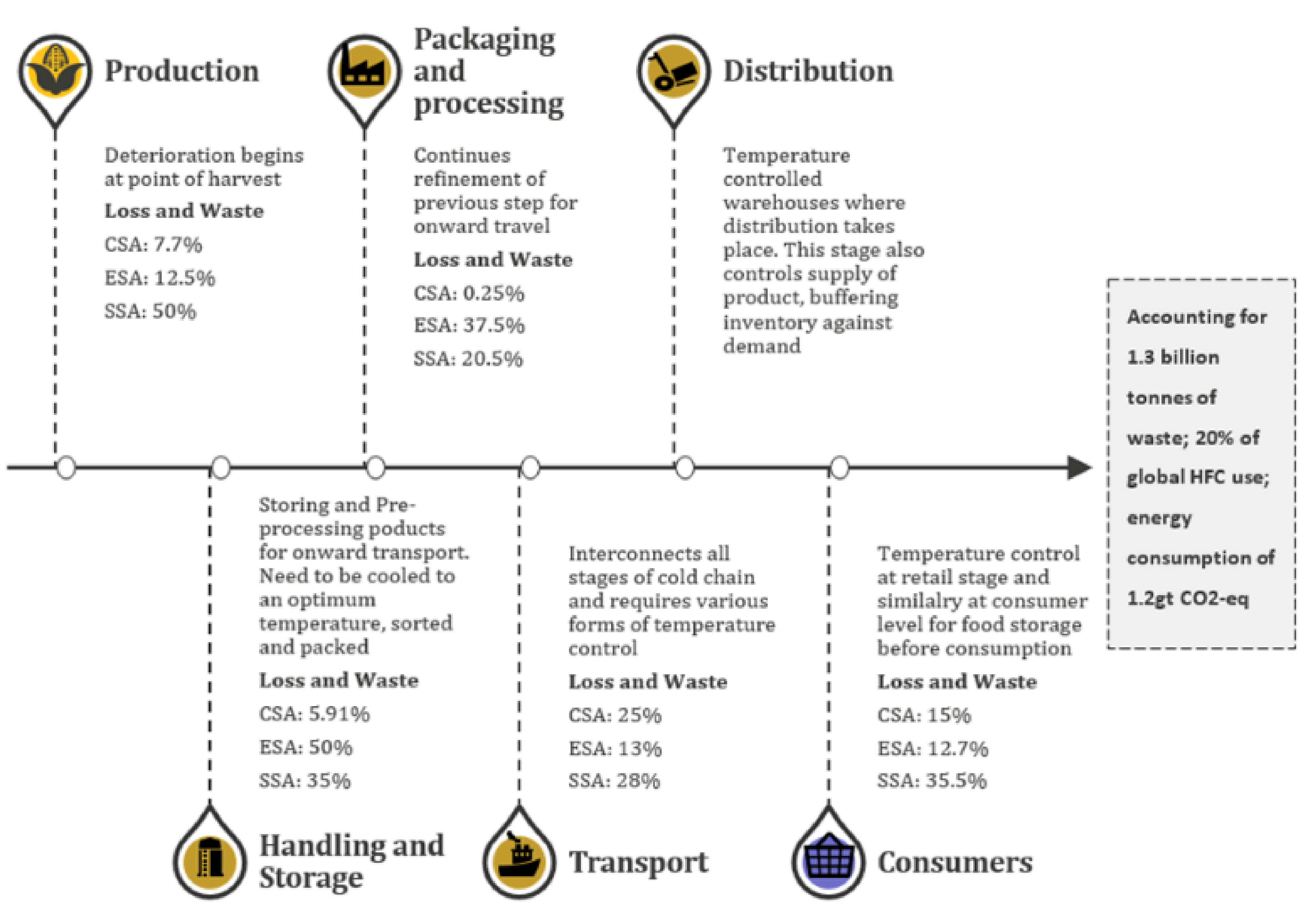
Risks Involved:

- **High Initial Investment**: Laser levelling technology has significant upfront costs, which may be a barrier for smallholder farmers.
- **Training Needs**: Proper implementation of these practices requires extensive farmer education and support to ensure effectiveness.
- **Limited Access to Technology**: In lower-income regions, access to the technology and inputs required for dry direct seeding and laser levelling may be restricted, slowing adoption.

Solution - Digital Twin

A digital twin is a virtual representation of an object or system designed to reflect a physical object accurately. It spans the object's lifecycle, is updated from real-time data and uses simulation, machine learning and reasoning to help make decisions to reduce emissions and food wastage in distribution networks. .

- The food retail sector generates approximately **0.3 gigatonnes of CO2 annually**, while the **UK** reports **366 kilotonnes of food waste** due to inefficiencies like poor shelf management.
- DT optimizes these processes by **tracking delivery vehicles**, **food inventory**, and environmental factors such as temperature and weather **in real-time**, thus reducing spoilage and emissions. By **simulating the cold chain**, DT can enhance shipping conditions and extend the shelf life of perishable items through sensitivity analysis.
- For example, DTs could **reroute products based on inventory levels**, sending food to retailers with lower stocks rather than nearby stores likely to incur spoilage.
- Moreover, DTs can **predict supply chain disruptions** and recommend preventative actions. Expanding DT networks to include food redistribution systems, like community kitchens, would further mitigate waste and improve food security.
- While DTs are already used in logistics and manufacturing, their application in agriculture is growing, promising improved efficiency, reduced emissions, and cost control for **companies like Cargill and ADM**.



Value Chain Loss and Waste| CSA: Central and Southern Asia; ESA: Eastern and South-Eastern Asia; SSA: Sub-Saharan Africa | Source data: Boston Consulting Group (BCG)

Implementation & Feasability

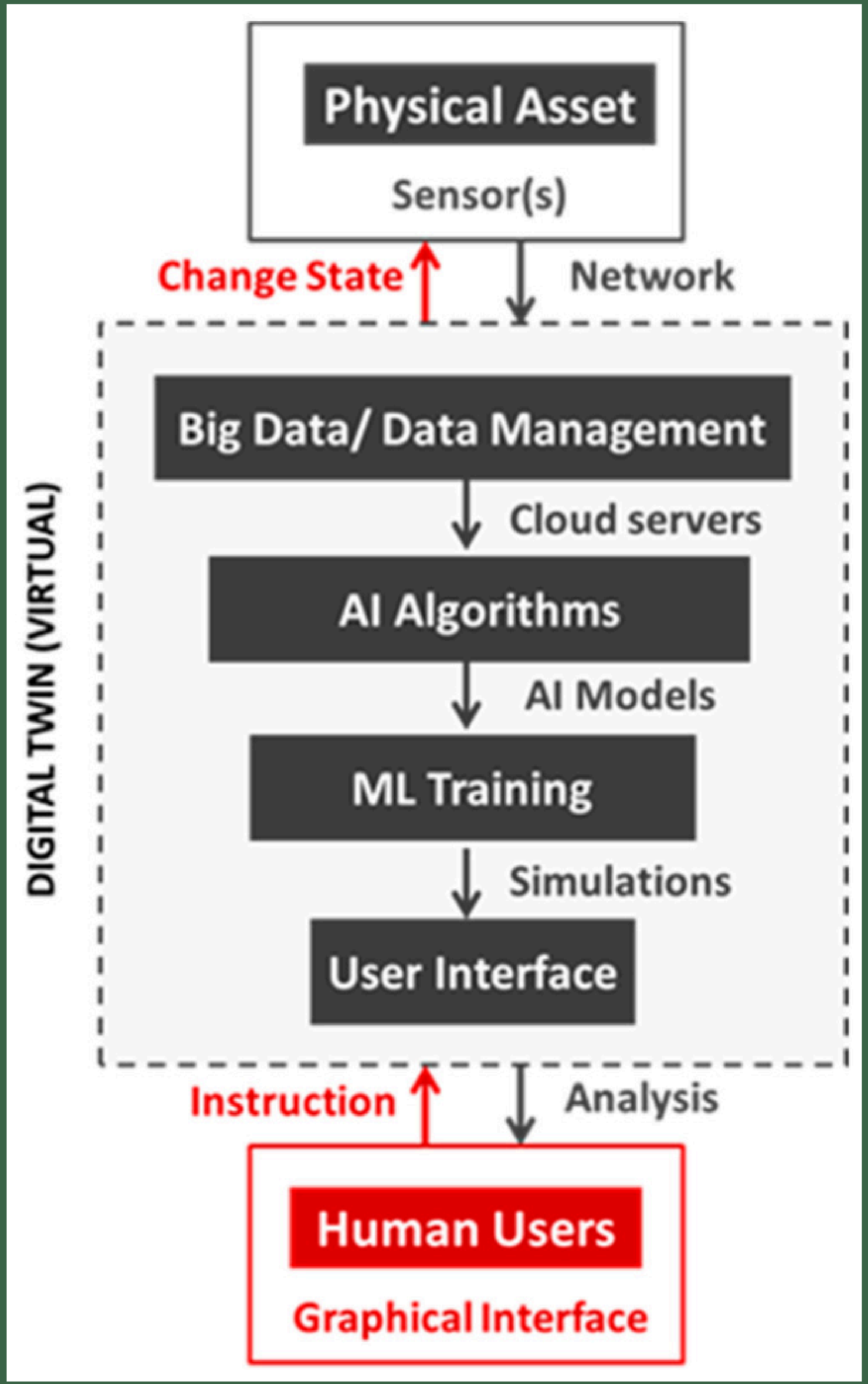
- For large firms, however, this technology will not only help reduce emissions but also allow them to stay competitive by cutting down supply chain costs and improving operational efficiency. By automating supply chain decisions, companies can **reduce costs by 10%** and **inventory levels by up to 25%**. This translates to fewer emissions from storage, transportation, and spoilage.

- **Real-time monitoring** can predict production overruns and enable timely adjustments, reducing carbon-intensive activities like excess transportation or storage. Successful implementation of digital twins could lead to **15% reductions in operating costs** and a **6% increase in EBIT** for agricultural companies.

- For instance, a digital twin of global corn exposure could integrate climate data (e.g., "rainfall is the highest in 25 years"), news insights (e.g., "flooding reports have increased 60-fold"), and satellite information (e.g., "1 million hectares of corn are affected") to help companies anticipate supply chain disruptions. While exact emissions reductions depend on factors like crop type and region, digital twinning holds **great potential for reducing food wastage emissions**.

Risks Involved:

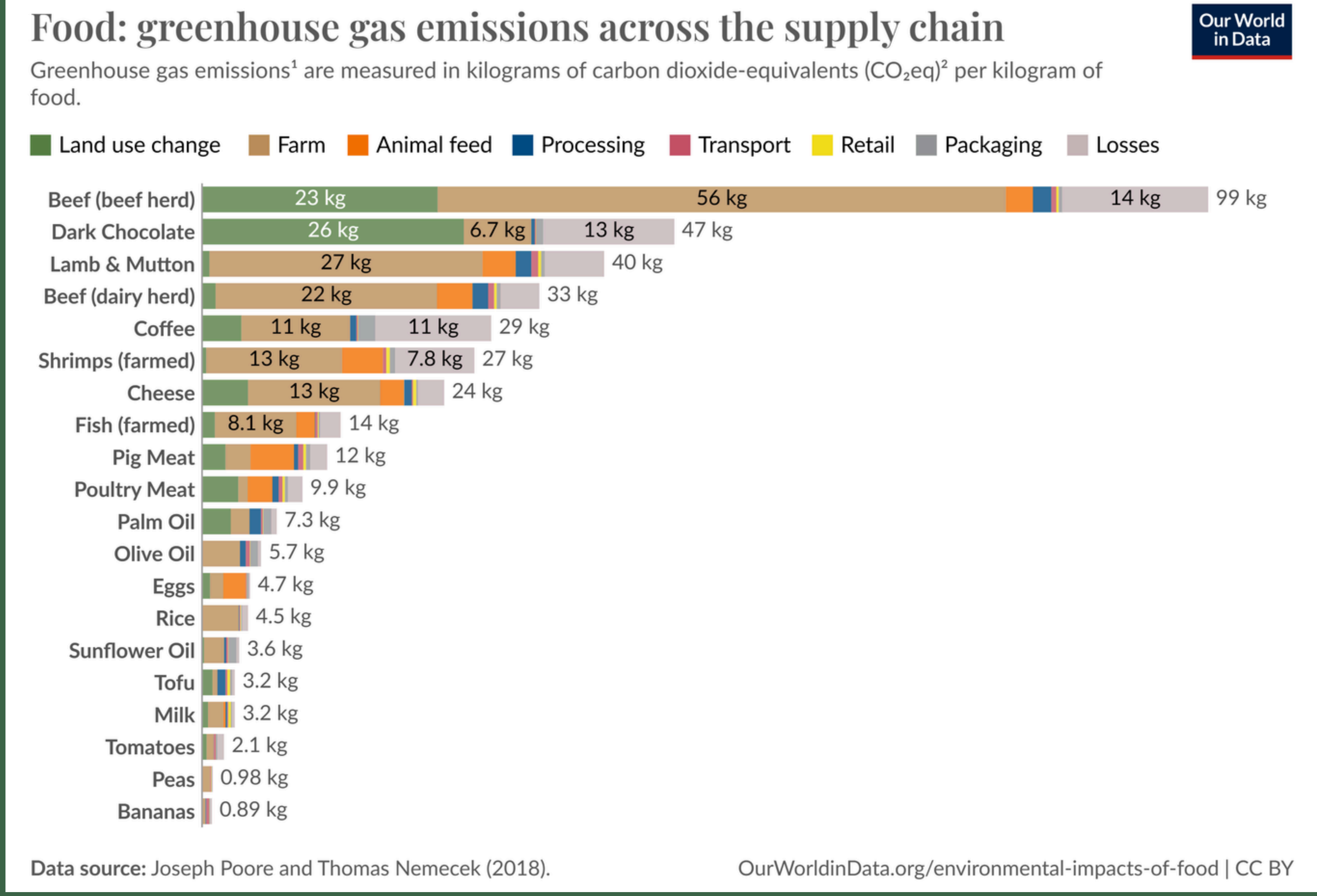
- There's insufficient proof of digital twins' impact on performance and profits.
- Resistance to transition from traditional practices, incurring costs for new technology, and labor adjustments.



Enteric Fermentation / Feed Processing

livestock, particularly cattle, produce significant methane emissions through digestion, contributing to climate change. With 1.5 billion cattle generating over 231 billion pounds of methane annually

- Researchers have found that **37% of methane emissions** from human activity are the direct result of our livestock and agricultural practices.
- Mechanical Processing: **Steam flaking** enhances starch digestibility, improving feed efficiency and reducing methane emissions by **up to 15%.**
- Plant-Based Alternatives: Investment in **plant-based products and lab-grown meat** could reduce reliance on animal farming and associated emissions.
- Seaweed Feed Additives: Adding **Asparagopsis taxiformis** to cattle feed can **lower methane emissions by 98% with a 0.20% daily addition**.
- Other aquaculture products such as **Asparagopsis armata**, reducing their methane emissions **by 67% with only a 1% seaweed mix.**



Risks Involved

- Steam Flaking is not very cost effective. Although the addition of aquaculture is cost effective but it may require a policy-push.
- **Market Acceptance and Adoption**: Consumer skepticism towards plant-based and lab-grown alternatives can hinder market growth, while slow farmer adoption of new feed additives may reduce overall effectiveness.
- **Regulatory and Environmental Challenges**: New feed and genetic modification may face regulatory hurdles, and increased demand for seaweed could threaten local ecosystems

Food Transport & Storage

Inefficient cold chains and high energy consumption in food transport and storage, driven by fossil fuels and HFCs, result in significant greenhouse gas emissions and food wastage.

- Shift to Rail, Waterways, and Electrification in Food Transport:

1. Shifting domestic food transport from road to rail and inland waterways can significantly reduce carbon emissions, as rail (**8–10 MJ t−1 km−1**) and waterways (**20–30 MJ t−1 km−1**) are much more energy-efficient than road trucks (**70–80 MJ t−1 km−1**).
2. Governments can invest in **expanding rail networks** and **optimizing routes** to reduce reliance on road transport.
3. Additionally, **using electric or hybrid trucks** for short-haul deliveries, improving logistics efficiency, and optimizing routes can further cut emissions from road transport.

- Promote Energy-Efficient, Low-Emission Cold Chain Technologies:

1. Current cold chains rely heavily on fossil fuels and Hydrofluorocarbons (HFCs), which have a global warming potential **23,000 times higher than CO2**.
2. Shifting to **low-emission technologies**, such as biogas- or solar-powered cooling, can significantly reduce emissions. Innovations like **evaporative cooling systems** for farm-level storage, **low-GWP refrigerants**, and variable-speed compressors offer efficient alternatives.
3. **Major companies like Dow Chemical and PepsiCo** are already committing to **HFC-free products**, demonstrating that low-emission solutions are viable and scalable.

Risks Involved:

- **High Initial Costs**: Significant upfront investments may deter small producers from adopting energy-efficient technologies.
- **Infrastructure Limitations**: Lack of necessary infrastructure can hinder the implementation of new cold storage and transport systems.
- **Training Needs**: Workforce training for new technologies may lead to temporary productivity losses.

Impact Analysis & Conclusions

The darker the colour, the more preferable and impactful the solution is on the basis of combination of reduction in costs and CO2e emissions.

On farm energy use reduction in irrigation & transportation

Regenerative agriculture and biochar

Solving rice cultivation

Digital twinning

Feed processing & enteric fermentation

Food transport & cold storage

Resources & References

- https://ourworldindata.org/grapher/food-emissions-supply-chain
- https://global.noharm.org/media/4370/download?inline=1
- https://blog.sevensenders.com/en/ecommerce-carbon-footprint-study-2022
- https://openknowledge.fao.org/server/api/core/bitstreams/ffb21ed0-05dd-46b1-b16c-50c9d47a6676/content
- https://ecocart.io/reduce-business-carbon-footprint/
- https://earth.org/online-shopping-and-its-environmental-impact/
- https://www.generationim.com/our-thinking/insights/the-carbon-footprint-of-retail-ecommerce-vs-bricks-mortar/
- https://www.emerald.com/insight/content/doi/10.1108/IMDS-09-2016-0383/full/pdf?title=modelling-and-optimisation-of-indian-traditional-agriculture-supply-chain-to-reduce-post-harvest-loss-and-cosub2sub-emission
- https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/the-promise-and-challenge-of-multi-client-fulfillment-for-e-commerce
- https://www.mckinsey.com/industries/agriculture/our-insights/agriculture-supply-chain-optimization-and-value-creation#/
- https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions
- https://openknowledge.fao.org/server/api/core/bitstreams/cc09fbbc-eb1d-436b-a88a-bed42a1f12f3/content
- https://openknowledge.fao.org/server/api/core/bitstreams/3b36953e-5689-480b-9280-71e4ab73646a/content/i3437e01.pdf
- https://ntrs.nasa.gov/api/citations/20220005764/downloads/EContrerasMencosPreandPostESSDReprint.pdf
- https://www.fao.org/faostat/en/#data/GN
- https://ourworldindata.org/emissions-by-sector
- https://iopscience.iop.org/article/10.1088/1748-9326/ac018e
- https://www.sciencedirect.com/science/article/pii/S1877050922024115
- https://research.wri.org/wrr-food/course/reduce-greenhouse-gas-emissions-agricultural-production-synthesis
- https://www.iitg.ac.in/pdf/8f3bd270a51d185b30cb93e6648c9914.pdf
- https://www.mckinsey.com/industries/agriculture/our-insights/how-advanced-analytics-can-address-agricultural-supply-chain-shocks

Thankyou!

404NotFound

- Arpit Ranjan
- Lakshita Agarwalla
- Madhav Goel
- Poorvi Panjwani