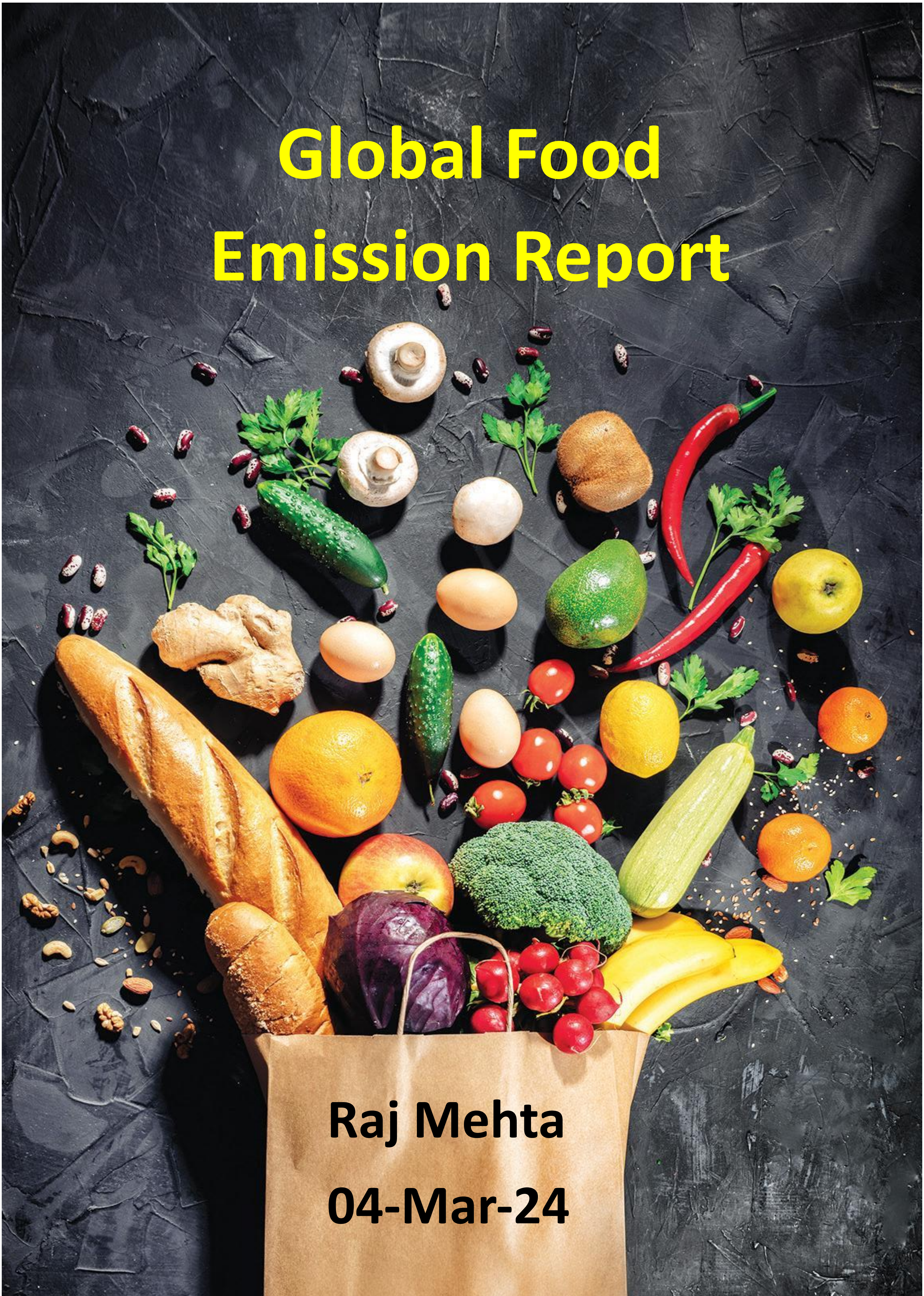

Global Food Emission Report

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04-Mar-24

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Abbreviations

GWP-100	Global Warming Potential over 100 years
AR5	5th Assessment Report from the IPCC
IPCC	Intergovernmental Panel on Climate Change
GHG	Greenhouse Gas Emission
FAO	Food and Agriculture Organization of the United Nations
UN	United Nations
eq	Equivalent
kg	kilogram
LULUC	Land Use and Land Use Change
CO_2	Carbon Dioxide
CH_4	Methane
N_2O	Nitrous Oxide
F-gases	Fluorinated gases
CO_2 eq	carbon dioxide equivalent
Gt	gigatonne, equivalent to 1 billion (10^9) tonnes
EDGAR	Emissions Database for Global Atmospheric Research
GLEAM	Global Livestock Environmental Assessment Model
OWD	Our World in Data

Introduction

The emissions produced by the global food industry are a crucial aspect of the larger conversation surrounding climate change and environmental sustainability. The phenomenon encompasses the greenhouse gas (GHG) emissions generated throughout the entire lifecycle of food production, distribution, consumption, and waste management. As the world's population continues to grow and dietary preferences evolve, the demand for food surges, amplifying the environmental footprint of the food supply chain. According to the Intergovernmental Panel on Climate Change (IPCC), food systems account for approximately one-third of global GHG emissions, making them a significant contributor to anthropogenic climate change[1].

The causes of global food emissions are multifaceted, rooted in the complex interplay of agricultural practices, land use patterns, food processing, transportation logistics, and consumer behaviour. Agriculture itself contributes a substantial portion of these emissions, with activities such as livestock farming, fertilizer application, and deforestation releasing significant amounts of methane, nitrous oxide, and carbon dioxide into the atmosphere. Additionally, inefficiencies across the food supply chain, including food loss, waste, and inefficient transportation, further exacerbate emissions, leading to environmental degradation and climate-related impacts. Thus, understanding the dynamics of global food emissions and their implications across the supply chain is crucial for developing effective mitigation strategies and fostering sustainable food systems for future generations.

In the section 1 and 2 of this report, with the assistance of the Edgar food dataset, valuable insights were drawn into the total global emissions and trends of major greenhouse gases (GHGs). Additionally, we conducted an evaluation of emissions along the food supply chain to pinpoint the major emitting steps where corrective actions should be focused. In section 3, our analysis aimed to determine which food products have a higher environmental impact in terms of CO_2 eq per kg of product and to understand how emissions are distributed within the supply chain of these products. Section 4 summarizes the key findings from the datasets, while section 5 and 6 discusses the obstacles and possible mitigation steps to reduce food related emissions.

Total GHG emissions (including CO_2, CH_4, N_2O and F-gases) are expressed as CO_2 equivalent (CO_2 eq) calculated using the 100-year global warming potential values (GWP -100) used in the IPCC 5th Assessment Report (AR5)[2], with a value of 28 for CH_4 and 265 for N_2O.

1. Global food emissions

The global emissions from Agriculture sector in 2015 was approximately 18 billion tonnes of CO_2 eq. This corresponded to about 34% of the total greenhouse gas emitted that year, making it second-largest contributor to global greenhouse gas emissions after the energy sector (including transport)[3]. The contribution of agriculture related emissions in 1990 corresponded to 44% of the total emissions, indicating a gradual decline on percentage basis, however on an absolute scale the emissions have increased around 11%.

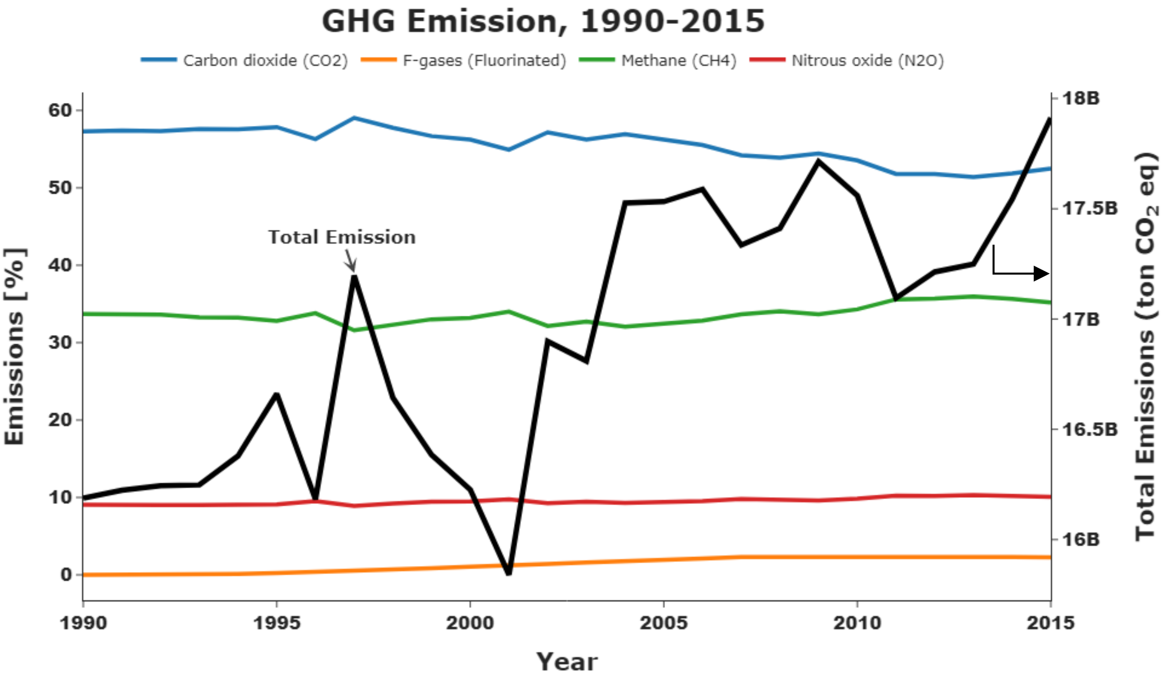

Figure 1: GHG Emission from 1990 to 2015, based on [EDGAR-Food dataset]

Between 1990 and 2015, the composition of global food emissions underwent a notable shift. During this period, the proportion of CO_2 emissions within the total declined from 57.3% in 1990 to 52.5% in 2015, marking a roughly 5% decrease. This trend suggests that the surge in global emissions primarily originates from non-CO_2 greenhouse gases. Specifically, emissions from F-gases surged by 81%, while those from N_2O and CH_4 increased by 23% and 16%, respectively.

This shift can be attributed to various factors. The intensified use of nitrogen-containing fertilizers has led to heightened emissions of N_2O. Likewise, the expansion of livestock farming has contributed to elevated methane emissions. Additionally, the widespread adoption of fluorinated gases (F-gases) in refrigeration, air conditioning, and industrial processes has substantially raised F-gas emissions.

Fluctuations in CO_2 emissions within global food production have been observed over time, influenced by changes in land use, agricultural practices, and food production technologies. Efforts such as reforestation and improved agricultural methods may have reduced CO_2 emissions in certain regions. However, the expansion of agriculture and shifts in consumer preferences and dietary habits have increased emissions elsewhere, impacting the overall carbon footprint of the food sector.

The variability in total food emissions, as evident in figure 1, can be attributed to several factors, including shifts in consumer diets, advancements in agricultural practices, efficient supply chains, or policies aimed at emission reduction. Notably, sharp declines in total food emissions between 1997 and 2001 and again between 2009 and 2011 could be linked to economic downturns, such as the Asian financial crisis in 1997-98 and the global financial crisis in 2007-08. These downturns resulted in decreased consumer spending, reduced industrial activity, and lower transportation of goods, consequently leading to a decline in total food emissions.

In the next section, we will evaluate one level down to understand how the GHGs are distributed across the food supply chain and identify the key emissions steps and their contribution.

2. Food Emission by stage

Addressing GHG emissions from the global food system requires an integrated approach that considers emissions throughout the entire food supply chain. The food lifecycle encompasses eight stages: Land Use and Land Use Change (LULUC), Farm, Processing, Packaging, Transport, Retail, Consumption, and Waste. Each stage significantly contributes to the GHG emissions[3]. The following figure provides a clear depiction of the GHG emission distribution across the different stages of the global food lifecycle.

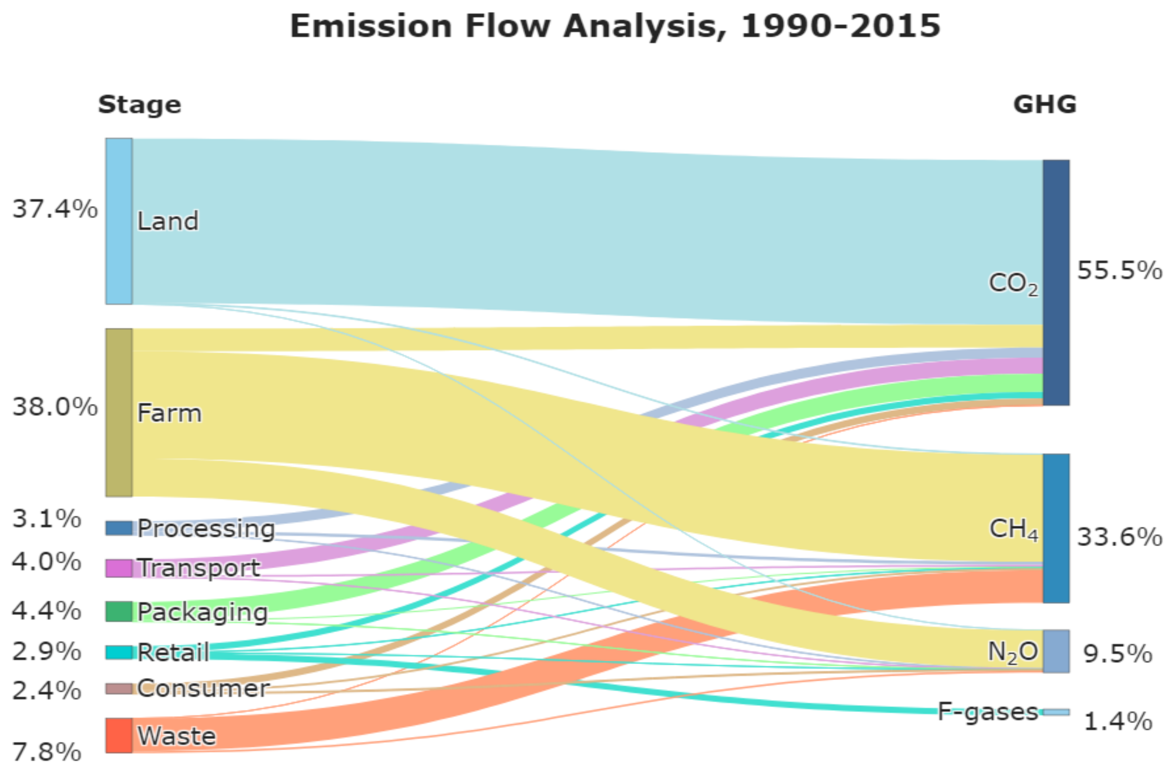

Figure 2: A Sankey plot showing the relation between food stage and the greenhouse gas emission. distribution corresponding to each stage.

The first two stages of the supply chain, Agricultural activities and LULUC (particularly deforestation and forest degradation), contributed to more than 75% of the total food related emission while the rest 25% came from the downstream supply chain activities: processing, distribution, transport, retail and waste management.

An interesting observation from figure 2 is that, the transportation accounts for less than 5% of total supply chain emissions, suggesting limited advantages in advocating for local eating to mitigate food-related emissions. However, transport-related GHG emissions can vary wildly between regions and products, for example, bananas have a high share (>40%) of transport related GHG emissions, according to this dataset.

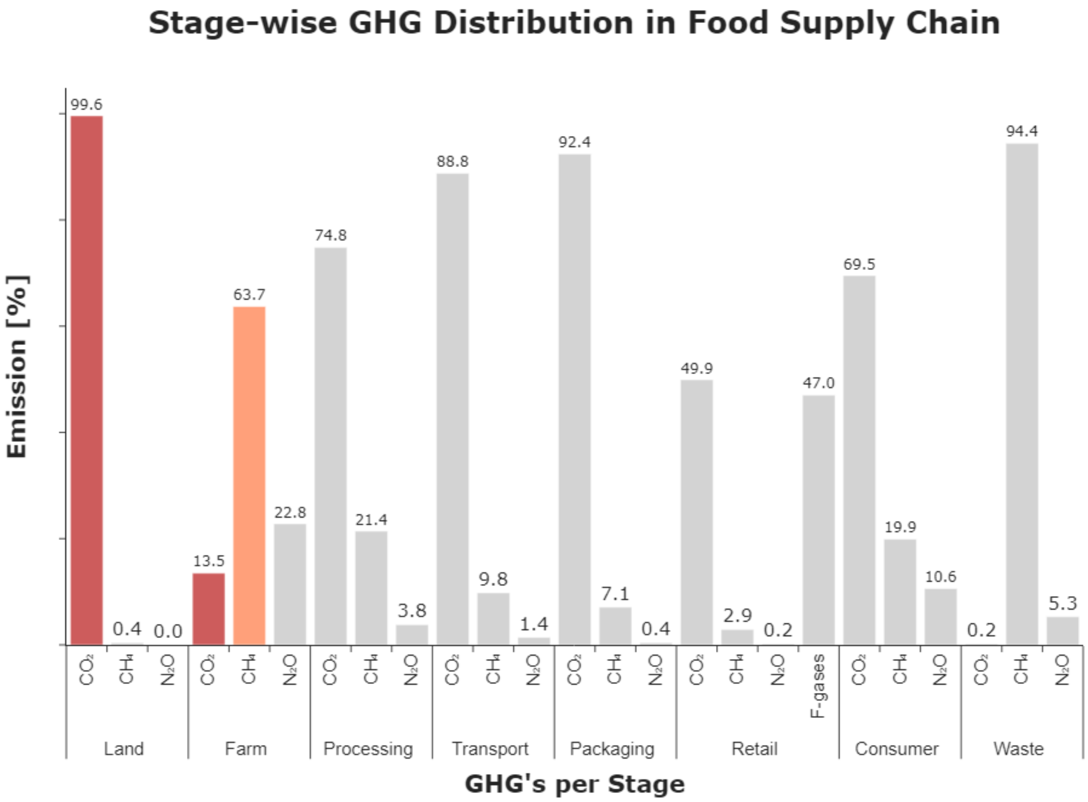

Figure 3: Cumulative distribution of GHGs (from 1990 to 2015) across each stage of the food supply chain

Upon analyzing the distribution of GHGs throughout each stage of the supply chain, it becomes evident that CO_2 emissions make up the majority of land-related emissions. As outlined in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Climate Change and Land (SRCCL), these emissions originate from diverse sources such as alterations in land use, which encompass deforestation, the transformation of forests into agricultural land, and soil degradation[1].

Carbon Dioxide (CO_2 – 99.5%):

1. **Deforestation:**

   When natural landscapes are altered or degraded, carbon stored in vegetation and soils is released into the atmosphere as CO_2. Additionally, poor agricultural practices like tillage can further exacerbate CO_2 emissions from the soil.

   According to data from the Food and Agriculture Organization of the United Nations (UN FAO), we have lost 420 million hectares of forest since 1990 at an average of about 14 million hectares per year[4]. A significant portion of this clearing is driven by agricultural expansion – commodity crop (soy, palm oil, coffee, cocoa etc.) cultivation, pasture land for livestock grazing and small-scale farming[5]. This, as per the IPCC estimates, corresponds to roughly 10-15% of global GHG emissions

   Overall, CO_2 emissions from land-related activities constitute a significant portion of the carbon footprint associated with the global food system, as also seen in figure 1, highlighting the importance of sustainable land management practices in mitigating climate change.

Farm-related emission:

The primary emissions associated with farming activities consist mainly of methane (approximately 64%) and nitrous oxide (around 23%), with carbon dioxide contributing to a lesser extent, approximately 13%. A breakdown of these emissions are explained below:

Methane (CH_4):

1. **Enteric Fermentation:**

   Enteric fermentation is a digestive process unique to ruminant animals, which are a subgroup of livestock known for their specialized digestive systems. These animals, including cattle, buffalo, sheep, and goats, possess a compartment in their stomach called the rumen where fibrous plant feed is digested producing methane as a byproduct.

   On an average:

   - Dairy Cows release 250-300 grams of methane per day per cow[6]
   - Beef cattle release 150-300 grams of methane per day per cow[7]
   - Sheep releases 20-40 grams of methane per day per sheep[8]
   - Goat releases 10-30 grams of methane per day per goat[6]

   The above estimates may vary from facility to facility depending on their diet composition, feed intake, physiology and environmental conditions.

2. **Manure Management:**

   The decomposition of manure by bacteria in anaerobic conditions releases methane This occurs largely in manure storage facilities or anaerobic lagoons. Additionally, during manure spreading on fields, or in open-air manure piles, some methane is also released through aerobic process.

Nitrous Oxide (N_2O):

1. **Soil Management:**

   The use of synthetic fertilizers in agriculture contributes to N_2O emissions. Nitrogen fertilizers undergo processes such as nitrification and denitrification in soils, releasing N_2O into the atmosphere or its run-off from agricultural fields can cause eutrophication in nearby lakes and water bodies, leading to adverse effects on biodiversity and human health.

2. **Manure Management:**

   Similar to CH_4, the decomposition of manure also releases nitrous oxide, particularly if manure is applied to soils as fertilizer.

Carbon Dioxide (CO_2):

1. **Energy Use:**

The combustion of fossil fuels for the purpose of farm operations such as machinery operation, irrigation, heating, and cooling contributes to CO_2 emissions.

2. **Soil Management:**

Intensive agricultural practices, tilling, overgrazing can increase soil erosion and disrupt soil organic carbon structure, releasing CO_2 into the atmosphere.

3. Food Emission by Product

This section presents an examination of the GHG emissions associated with 43 of the most widely consumed food products worldwide. The data is gathered from the series Environmental Impacts of food production, available on the website of Our World in Data (OWD). This data is based on the work published by J. Poore et. al [15]

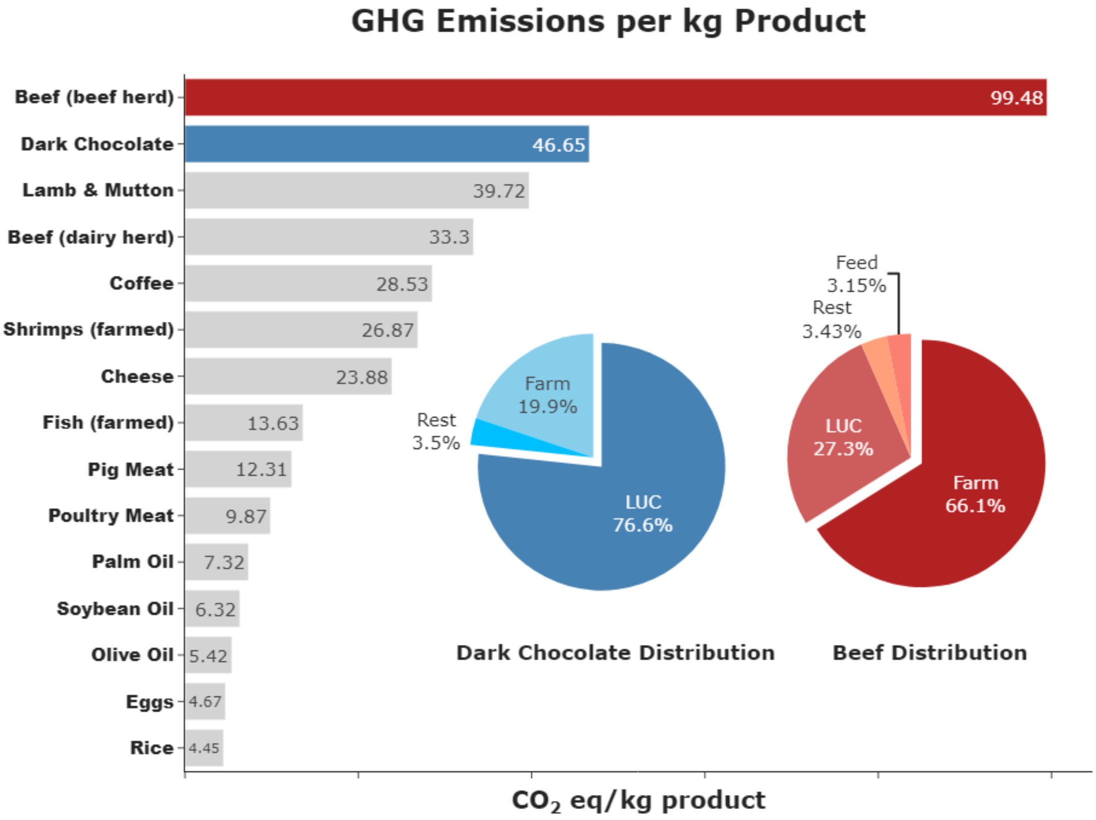

Figure 4: Global average emissions (from Land to Retail) of commonly consumed food products. The pie charts in inset represents the distribution of top two most polluting products i.e. beef (in red) and dark chocolate (in blue)

From figure 4, we notice that beef is the most emission-intensive product among all products under study, with a global average of 99.5 kg CO_2 eq per kg of product. This heightened emission intensity primarily results from factors such as enteric fermentation, occurring during the farm stage, which leads to significant CH_4 emissions. Furthermore, the need for feed inputs like soybeans and corn for livestock often drives deforestation and land conversion, releasing stored CO_2 into the atmosphere[9]. These two factors collectively contribute to roughly 96.5% of the total emissions in the beef supply chain.

Also worthwhile to note, the emission intensity of livestock production varies significantly across countries, species, and production systems due to differences in breeds, management practices, feed quality, and environmental conditions.

Similarly, dark chocolate exhibits significant emissions, primarily from extensive deforestation and land conversion to accommodate cocoa plantations. It's a widely recognized phenomenon that Europe and the USA are major consumers of chocolate products, and their demand significantly influences global cocoa production and associated land use changes. As depicted in Figure 4, approximately 77% of the total greenhouse gas emissions associated with dark chocolate can be attributed to land use change.

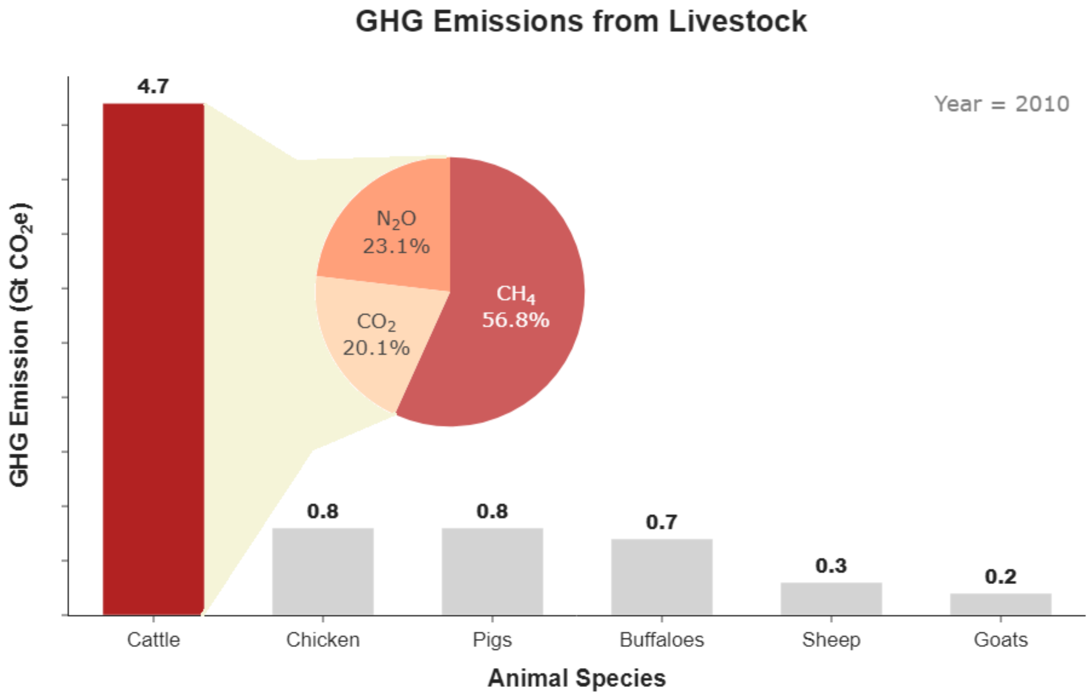

Figure 5: GHG contribution by various livestock, in the year 2010 and the pie chart in inset depicts the distribution of GHGs for the most environmentally polluting animal i.e. Cattle (red)

In 2010, total anthropogenic emissions were estimated to be around 50 Gt CO_2 eq, of which global agricultural emission were about 13 Gt CO_2 eq i.e. roughly 26% of the total [11]. Within agricultural sector, livestock sector contributed about 7.3 Gt CO_2 eq, accounting to ~56% of the total food related emission and about 12-15% of the total anthropogenic emissions.

When assessing the lifecycle emissions of the Livestock sector, it has been observed that [11]:

- CO_2 emission from livestock sector account for 5% of the global CO_2 emissions
- CH_4 emission account for 44% of the total anthropogenic CH_4 emissions
- N_2O emission account for 53% of the total anthropogenic N_2O emissions
- Emissions from F-gases are negligible on global scale

Among all livestock raised for human consumption, cattle are particularly noteworthy for their significant environmental impact, emitting approximately 60-65% of sector emissions, as depicted in figure 5. Livestock, particularly cattle, are raised within three primary production systems: pasture-based systems, feedlot systems, and mixed systems and are primarily farmed for two major commodities: milk and meat.

In terms of commodities, meat production claims the largest share of emissions at 66%, followed by milk and eggs at 30.2% and 3.8%, respectively[12]

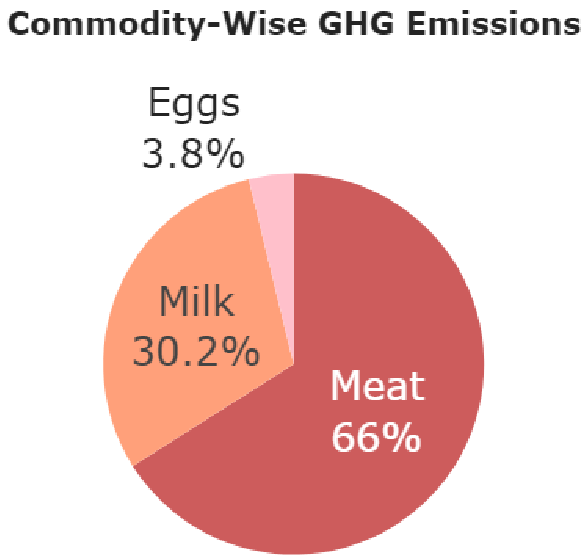

Figure 6: Percentage total emission (year 2010) split across commodities from animals (cattle, buffalo, pig, chicken, sheep & goat)

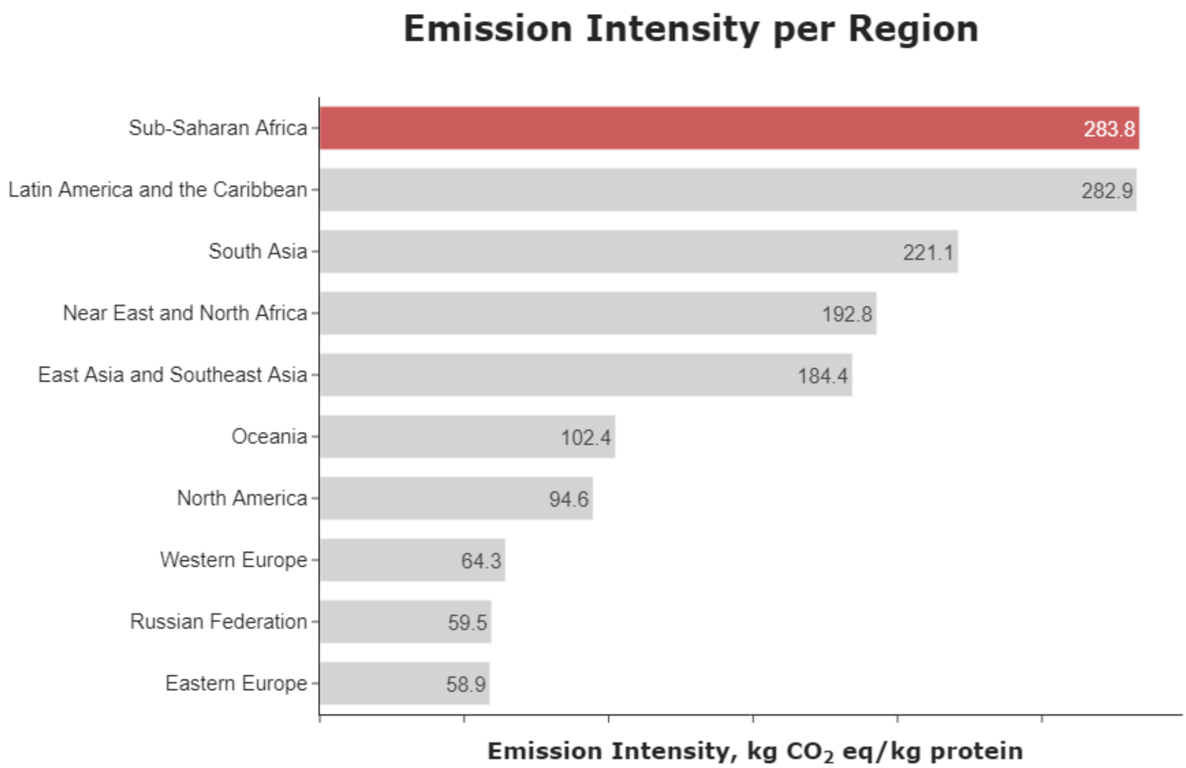

Figure 7: Regional distribution of emissions per kg of animal protein.

As evident from figure 7, countries in regions such as sub-Saharan Africa and South America demonstrate higher emission intensity per kg of protein compared to regions like North America and Europe, where emission intensity tends to be lower. This discrepancy often arises from the varying levels of industrial development, infrastructure, and technological advancements among regions. Well-developed regions like North America typically possess advanced industrial sectors, robust infrastructure, and technologies aimed at reducing emissions. Conversely, less developed regions may lack such resources, leading to reliance on less efficient methods and practices that result in higher emissions.

Additionally, stable governance, stringent environmental regulations, subsidies, access to clean energy, investments, adoption of latest technologies, and promotion of education and learning play pivotal roles in optimizing resources and lowering emissions across regions.

It's important to recognize that while mitigation efforts in these areas can reduce emission intensity, their current contribution to global emissions is relatively low, resulting in limited impact on the global emissions landscape.

4. Conclusions

This report provides an overview of the emissions of the global food system while attempting to answer some critical questions with an aim to identify the focus areas for further actions. From the topics evaluated in this report, some of the key findings of this report are summarized below:

- The emissions from the global food system accounts for roughly one-third of the total GHG emissions. More than 80% of it is contributed by CO_2 and CH_4 alone.
- In the supply chain of a food product from farm to retail, land use (including land use change) and farming practices are the most polluting steps in the entire food supply chain, contributing to roughly 75% of the total food related emissions between 1990 and 2015.
    - CO_2 being the sole driver in land use phase, due to deforestation and forest degradation, while
    - In the farming phase, CH_4 (due to livestock enteric fermentation) and N_2O (due to manure and synthetic fertilizers) accounts for 80% of total emissions
- Food transportation from farm to retail, for most products, contributes less than 5% of the total food-system GHG emission. It is thus important to lay more emphasis on the content of our diets rather than the geographical origin of food.
- Amongst the 43 most common food products consumed by humans, beef had the highest emissions per kg of the food product at 99.5 kg/kg beef. The second highest (dark chocolate) emits less than of it at 46.7 kg/kg dark chocolate.
- On comparing the emissions from various animal species (in 2010), the emissions from cattle were significantly higher (5.7x) than the next polluting animal specie (pigs). This is largely due to CH_4 emissions from enteric fermentation.
- Out of the total livestock emission, about 66% is attributed to the production of meat, while about 30% is for milk production. The rest is for the production of eggs.

A large part of reduction efforts should be channelled towards first two steps by employing better farming practices, educating farmers regarding the use of soil management, crop rotation & fertilizer usage.

5. Challenges

Addressing the complex intersection of food security, a growing global population, and sustainable development poses significant challenges for policymakers, researchers, and communities worldwide.

According to the report, "World Population Prospects 2019: Highlights," published by United Nations Department of Economic and Social Affairs (UN DESA), the global population is expected to reach approximately 10 billion by 2050[13]. Ensuring adequate food production and distribution to meet rising demand with sustainable resource management and minimizing environmental degradation presents a delicate task.

Changing human dietary preference to more plant based diet and occasional to none meat consumption presents a formidable challenge, given the deeply ingrained nature of our eating habits within cultural traditions and social norms. As highlighted in a report by Metabolic titled “Consumer behaviour as a leverage point in the food system”, consumer food decisions have important impacts on the food system through their market demand, sometimes determining what food will be produced and by what methods[14]. Moreover, the marketing strategies employed by the private industry often leverage consumer desires & biases to promote consumption, further complicating efforts to promote sustainable dietary practices. Additionally, consumers lack of interest in analysing environmental concerns of their choices, makes the task at hand even more challenging.

Sustainable development goals must prioritize strategies that enhance agricultural productivity, promote equitable access to nutritious food, and safeguard ecosystems for future generations. Additionally, addressing socio-economic disparities, climate change impacts, and evolving dietary preferences further complicates the pursuit of holistic solutions to these interconnected challenges. Collaboration across sectors and innovative approaches that integrate social, economic, and environmental considerations are essential for navigating the complexities of achieving food security within the context of sustainable development amidst a growing global population.

6. Solutions

Efforts to mitigate the overall GHG footprint of the food supply chain are crucial for addressing climate change and promoting environmental sustainability. Some of the key strategies are listed below:

Improving Agricultural Practices:

Since Land and farm are major source of GHG emissions, implementing sustainable agricultural practices such as precision farming, agroforestry, and conservation agriculture can help reduce GHG emissions from crop and livestock production while enhancing soil health and productivity[1]. Simultaneously, educating farmers about optimizing fertilizer usage, implementing crop rotation practices, and discouraging tilling methods can significantly improve soil health while minimizing emissions and preventing degradation of arable land.

Promoting Plant-Based Diets:

Encouraging dietary shifts towards plant-based diets and reducing meat consumption can significantly reduce GHG emissions associated with livestock farming and feed production[16]. Plant-based diets have been shown to have lower carbon footprints compared to diets high in animal products.

Minimizing Food Loss and Waste:

Food waste ranks as the third-largest contributor to GHG emissions within the food supply chain, see figure 2. Mitigating food loss and waste across the supply chain through initiatives such as improved post-harvest handling, streamlined supply chain logistics, enhanced market access, consumer education programs promoting waste reduction, and donation initiatives can effectively curb GHG emissions linked to food production, transportation, and disposal.

Optimizing Transportation and Distribution:

Improving transportation efficiency, reducing food miles, and optimizing distribution networks can lower GHG emissions from food transportation and logistics. Transitioning to cleaner transportation fuels can help mitigate emissions.

Investing in Renewable Energy:

Transitioning towards renewable energy sources such as solar, wind, and bioenergy in food processing, refrigeration, and other supply chain activities can help decarbonize energy-intensive processes and reduce reliance on fossil fuels.

These efforts, when combined and implemented effectively, can contribute to significant reductions in the overall GHG footprint of the food supply chain, thus advancing climate goals and promoting sustainable food systems for future generations.

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Appendix I : Disclaimer

The analysis carried out in this report, is within the limits and assumptions of the dataset model and thus these numbers will vary in a narrow percentage range, depending on the source of the data used for similar analysis.

There are many things intertwined in the broader context of this topic and a lot of time and resources would be required to make a detailed study from different vantage points – economics of supply and demand, population growth, consumer behaviour, global trade, policy and regulation, etc. Furthermore, within the context of this report and the datasets, it is possible to still drill down and focus on specific food product emissions or regional emissions. Insights from more datasets can be combined to draw a more clear picture of

The dataset and software utilized for this report are based on open-source platforms.

Appendix II : Data Source

Information and knowledge from three datasets were used to complete this report.

1. EDGAR (Emissions Database for Global Atmospheric Research)

EDGAR-Food serves as a comprehensive global emission inventory detailing greenhouse gas emissions stemming from food systems. This data repository encompasses GHG emissions across more than 200 countries, distinguishing emissions by GHG type and specific stage within the food system annually from 1990 to 2015. The dataset categorizes emissions into eight distinct stages of the food supply chain, with Land designated as Stage 1, Farm as Stage 2, and progressing sequentially to Waste as Stage 8.

The original dataset needed cleaning and transformation before it could be used for deeper analytical insights. However, in this instance, this preparatory step was unnecessary as a pre-cleaned file was readily accessible here. Details regarding the methodology applied are available in Crippa et al. (2021), here

A database sample of first five entries is as follows:

	Food System Stage	FS Stage Order	GHG	Country	Year	GHG Emissions	Unit
0	Land	Stage 1	Methane (CH4)	Afghanistan	1990	0.6	metric tons CO2e (GWP-100, AR5)
1	Land	Stage 1	Methane (CH4)	Afghanistan	1991	0.6	metric tons CO2e (GWP-100, AR5)
2	Land	Stage 1	Methane (CH4)	Afghanistan	1992	0.6	metric tons CO2e (GWP-100, AR5)
3	Land	Stage 1	Methane (CH4)	Afghanistan	1993	0.6	metric tons CO2e (GWP-100, AR5)
4	Land	Stage 1	Methane (CH4)	Afghanistan	1994	0.6	metric tons CO2e (GWP-100, AR5)

Below are the questions posed or analysed to derive key insights:

a. What is the trend of total food related GHG emission from 1990 to 2015?
b. What is the primary contributor to the increase in total greenhouse gas emissions, and what does the trend indicate?
c. What is the percentage distribution of GHGs during this period?
d. What is the distribution of GHG emissions among different stages of food life cycle?

2. Environmental Impacts of Food

The information provided in the Environmental Impacts of Food dataset originates from the research conducted by Jospeh Poore and Thomas Nemecek in 2018[15]. This study, regarded as the most extensive meta-analysis of food systems to date, encompasses 43 of the most consumed products, examining their environmental impact from production to the point of sale. Spanning nearly 40,000 farms across 120 countries, the study ensures a comprehensive analysis that avoids bias towards any specific geographic region or income level. Notably, emissions stemming from cooking, refrigeration, and post-consumption food waste within the supply chain are excluded from the study's scope.

A database sample of first five entries is as follows:

	Food product	Land Use Change	Feed	Farm	Processing	Transport	Packaging	Retail	Total from Land to Retail	Total Global Average GHG Emissions per kg	Unit of GHG Emissions
0	Apples	-0.029	0.000	0.225	0.004	0.096	0.044	0.017	0.357	0.43	kg CO2e per kg food produced
1	Bananas	-0.025	0.000	0.266	0.059	0.292	0.065	0.021	0.678	0.86	kg CO2e per kg food produced
2	Barley	0.009	0.000	0.176	0.128	0.035	0.497	0.264	1.109	1.18	kg CO2e per kg food produced
3	Beef (beef herd)	16.278	1.878	39.388	1.269	0.346	0.247	0.164	59.570	99.48	kg CO2e per kg food produced
4	Beef (dairy herd)	0.906	2.508	15.689	1.108	0.424	0.268	0.182	21.085	33.30	kg CO2e per kg food produced

Questions addressed with this dataset are as follows:

a. What is the average global emission per kilogram of food product?
b. What is the percentage distribution of emission across the supply chain, for the two most polluting products on a per kilogram basis?

3. GLEAM (Global Livestock Environmental Assessment Model) Emissions Data

The Global Livestock Environmental Assessment Model is a modelling framework developed within the Animal Production and Health Division of FAO. It simulates the functioning and environmental impacts of livestock production activities. The most relevant characteristics of GLEAM are:

a. It is based on Life Cycle Assessment (LCA) methodologies.
b. It runs in a Geographic Information System (GIS) environment.
c. It covers upstream, on-farm and downstream impacts.
d. The current version of GLEAM (2.0) focuses on the quantification of greenhouse gas emissions related to livestock sector supply chains.

Content in this dataset is from the GLEAM 2.0 public data release. GLEAM 2.0 is the most recent version (as of October 2021) of the Global Livestock Environmental Assessment Model (GLEAM), published in 2018 using data from 2010.

Below you will find a glimpse of the dataset

	Region	Animal species	Production system	Commodity	Emission Intensity (kg CO2e per kg protein)	Production (kg protein)	Total GHG emissions (kg CO2e)	Total CO2 emissions (kg CO2e)	Total CH4 emissions (kg CO2e)	Total N2O emissions (kg CO2e)	...	Feed: fertilizer & crop residues, N2O (kg CO2e)	Feed: applied & deposited manure, N2O (kg CO2e)
0	Global	Cattle	Aggregated	Aggregated	160.3	2.916310e+10	4.674630e+12	9.449299e+11	2.648727e+12	1.080973e+12	...	1.740732e+11	7.419864e+11
1	Global	Cattle	Aggregated	Milk	86.7	1.888089e+10	1.637519e+12	2.756914e+11	9.676442e+11	3.941834e+11	...	7.166208e+10	2.543885e+11
2	Global	Cattle	Aggregated	Meat	295.4	1.028222e+10	3.037111e+12	6.692385e+11	1.681083e+12	6.867892e+11	...	1.024111e+11	4.875979e+11
3	Global	Cattle	Grassland systems	Aggregated	206.3	1.033817e+10	2.133054e+12	5.628062e+11	1.052965e+12	5.172829e+11	...	5.253660e+10	4.267612e+11
4	Global	Cattle	Grassland systems	Milk	95.0	6.940654e+09	6.592844e+11	9.286140e+10	3.713461e+11	1.950770e+11	...	2.156126e+10	1.587838e+11

5 rows × 22 columns

Questions explored using this dataset are as follows:

a. What are the global emissions by different animal species?
b. How are emissions distributed across various regions for the most polluting animal?
c. What is the emission distribution profile for each animal species and its associated greenhouse gas?
d. For which commodity were the animals largely used?
e. Which region has the highest emission intensity (kg CO_2 eq per kg protein)? Why?

Appendix III : Codes

Python libraries and extensions used to derive insights in databases:

- **Pandas** : Data analysis and manipulation tool
- **NumPy** : To work with arrays
- **Plotly** : For appealing data visualization
- **JupySQL** : Jupyter notebook extension to write SQL queries along with Python script.

1. IMPORTING PYTHON LIBRARIES

```
import pandas as pd
import numpy as np
import matplotlib as mpl
import plotly as plt
import plotly.io as pio
import plotly.express as px
import plotly.graph_objects as go
from plotly.subplots import make_subplots
import duckdb as db
```

2. LOADING JUPYSQL (SQL EXTENSION FOR JUPYTER NOTEBOOK)

To write SQL queries in line with Python script

```
%load_ext sql
%sql duckdb://
%config SqlMagic.displaylimit = 10
%config SqlMagic.autopandas = True
```

```
Connecting to 'duckdb://'
```

3. READING EDGAR FOOD DATASET

```
df_edgar = pd.read_csv('EDGARFood.csv')
```

```
df_edgar.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 128700 entries, 0 to 128699
Data columns (total 7 columns):
 #   Column             Non-Null Count   Dtype
---  ------             --------------   -----
 0   Food System Stage  128700 non-null  object
 1   FS Stage Order     128700 non-null  object
 2   GHG                128700 non-null  object
 3   Country            128700 non-null  object
 4   Year               128700 non-null  int64
 5   GHG Emissions      128700 non-null  float64
 6   Unit               128700 non-null  object
```

```
dtypes: float64(1), int64(1), object(5)
memory usage: 6.9+ MB
```

4. TOTAL GHG EMISSION TREND - (FIGURE 1)

```
#Create new dataframe 'edgar_line' that will sum the emissions by year

edgar_line = df_edgar.groupby (by = ['Year']).sum()['GHG Emissions']

edgar_line = edgar_line.reset_index()

edgar_line.head()
```

```
   Year   GHG Emissions
0  1990    1.618755e+10
1  1991    1.622370e+10
2  1992    1.624452e+10
3  1993    1.624781e+10
4  1994    1.637945e+10
```

```
# SQL query to analyze the percentage distribution of GHG's (CO2, CH4, N2O
and F-gases) each year
q3 = """
Select
    Year,
    GHG,
    SUM ( "GHG Emissions" ) as 'Total',
    100 * SUM ( "GHG Emissions" ) / SUM (SUM ( "GHG Emissions" )) over(part
ition by Year) as '%'
From
    df_edgar
Group by
    Year, GHG
Order by
    Year, GHG
"""
# Converting output of above SQL query to pandas dataframe
q3 = %sql {{ q3 }}
q3.head(8)
```

```
Running query in 'duckdb://'

   Year                   GHG         Total          %
0  1990    Carbon dioxide (CO2)  9.270544e+09  57.269578
1  1990  F-gases (Fluorinated)  2.218115e+05   0.001370
2  1990          Methane (CH4)  5.453113e+09  33.687074
3  1990     Nitrous oxide (N2O)  1.463675e+09   9.041978
4  1991    Carbon dioxide (CO2)  9.311716e+09  57.395746
5  1991  F-gases (Fluorinated)  9.814773e+05   0.006050
```

```
6  1991          Methane (CH4)  5.455807e+09  33.628616
7  1991    Nitrous oxide (N2O)  1.455199e+09   8.969588

# Make overlapping line charts (multi Y-axis plot)
fig = make_subplots(specs = [[{"secondary_y":True}]])

# Line chart 1: % distribution of various GHG emissions
fig1 = px.line (
    q3,
    x = 'Year',
    y = '%',
    color = "GHG"
)

fig1.update_traces (line = dict (width = 3.5))

for t in fig1.select_traces():
    fig.add_trace(t, secondary_y = False)

---------------------------------------------------------

# Line chart 2: Total emissions trend from 1990 to 2015 (secondary Y-axis)
fig2 = px.line(
    edgar_line,
    x = "Year",
    y = "GHG Emissions",
    #markers = True
)
fig2.update_traces(
    #marker = dict(
   #     color = "grey",
     #   size = 10),
    line = dict(color = "Black",
               width = 4.5)
                )
fig2.update_layout(
    title = "Global Food Emissions, 1990-2015",
    title_font_size = 25,
    width = 900,
    yaxis = dict(
        title = "GHG Emissions (MT CO2e)",
        title_font_size = 15),
    )
-------------------------------------------------------------
for j in fig2.select_traces():
    fig.add_trace(j, secondary_y = True)

fig.update_layout (title = "<b> GHG Emission, 1990-2015 </b>",
```

```
                   title_x = 0.45,
                   title_font_size = 25,
                   #font = dict(color = "DarkBlue"),
                   xaxis = dict(title = "Year",
                                title_font_size = 20,
                                range = [1990, 2015]),
                   legend = dict(
                       orientation = 'h',
                       x = 0.05,
                       y = 1.1,
                       font = dict(size = 12.5)
                   ),
                   margin = dict(l=50, r=80, t=100, b=80)
                  )
fig.update_xaxes(title_text = "<b> Year </b>" ,
                 title_font_size = 20,
                 tickfont = dict(size = 15,  family = 'Arial Black')
                )
fig.update_yaxes(title_text = "<b> Emissions [%] </b>" ,
                 title_font_size = 20,
                 tickfont = dict(size = 15,  family = 'Arial Black'),
                 secondary_y = False
                )
fig.update_yaxes(title_text = "<b> Total Emissions (ton CO<sub>2</sub> eq)
</b>" ,
                 title_font_size = 20,
                 tickfont = dict(size = 15, family = 'Arial Black'),
                 secondary_y = True
                )
fig.add_annotation(text = "<b> Total Emission </b>",
                   font = dict(size = 15),
                      x = 1997,
                      y = 39,
                      showarrow = True,
                      arrowhead = 3,
                      arrowwidth = 2,
                      align = "right")
fig.show()

pio.write_image(fig, 'GHG_trend.png', width = 1000, height = 600)
```

5. SANKEY PLOT TO ANALYZE THE GHG DISTRIBUTION ACROSS SUPPLY CHAIN (FIGURE 2)

```
link_colors = ['rgb(176, 224, 230)', 'rgb(240, 230, 140)', 'rgb(176, 196, 2
22)', 'rgb(221, 160, 221)', 'rgb(152, 251, 152)',
                'rgb(64, 224, 208)', 'rgb(222, 184, 135)', 'rgb(255, 160, 12
2)', 'rgb(64, 224, 208)', 'rgb(176, 224, 230)', 'rgb(240, 230, 140)', 'rgb(
176, 196, 222)', 'rgb(221, 160, 221)', 'rgb(152, 251, 152)',
                'rgb(64, 224, 208)', 'rgb(222, 184, 135)', 'rgb(255, 160, 12
2)', 'rgb(176, 224, 230)', 'rgb(240, 230, 140)', 'rgb(176, 196, 222)', 'rgb
(221, 160, 221)', 'rgb(152, 251, 152)',
                'rgb(64, 224, 208)', 'rgb(222, 184, 135)', 'rgb(255, 160, 12
2)']

---------------------------------------------------------------------------
--

node_ref = dict(
    label = ["CO<sub>2</sub>", "F-gases", "CH<sub>4</sub>", "N<sub>2</sub>O
",
            "Land", "Farm", "Processing", "Transport", "Packaging", "Retail
", "Consumer", "Waste"], # list of all source nodes
    color = ["#3d6493", "#95ceeb", "#308bbc", "#86aad1", # list of all targ
et node colors
              'rgb(135, 206, 235)', 'rgb(189, 183, 107)', 'rgb(70, 130, 180)
', 'rgb(218, 112, 214)', 'rgb(60, 179, 113)',
                'rgb(0, 206, 209)', 'rgb(188, 143, 143)', 'rgb(255, 99, 71)'
],

 # list of all source colors
    x = [0.9, 0.9, 0.9, 0.9, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05, 0.05
],
    y = [0.3, 0.999, 0.7, 0.9, 0.2, 0.4, 0.6, 0.7, 0.8, 0.9, 0.92, 0.999],
    #pad = 50
                )

link_ref = dict(
    source = [4,5,6,7,8,9,10,11,9,4,5,6,7,8,9,10,11,4,5,6,7,8,9,10,11],
    target = [0,0,0,0,0,0,0,0,1,2,2,2,2,2,2,2,2,3,3,3,3,3,3,3,3],
    value = [1.63842659e+11, 2.25137898e+10, 1.01506384e+10, 1.57765035e+10
, 1.80289417e+10, 6.37215236e+09, 7.21136338e+09, 7.18888257e+07, 6.0103026
3e+09, 6.08796006e+08, 1.06454795e+11, 2.90852906e+09, 1.73819055e+09, 1.39
274312e+09, 3.69802473e+08, 2.06679458e+09, 3.23804654e+10, 8.74212200e+06,
3.80959812e+10, 5.16606457e+08, 2.46781984e+08, 8.13052248e+07, 2.42898945e
+07, 1.09796230e+09, 1.83359537e+09],
    color = link_colors
                ,)
```

```
data = go.Sankey (
    arrangement = "snap",
    node = node_ref,
    link = link_ref
                )
---------------------------------------------------------------------------
--

fig = go.Figure(data)

fig.update_layout(
    height = 600,
    title_text = "<b> Emission Flow Analysis, 1990-2015 </b>",
    title_x = 0.5,
    title_font_size = 25,
    font_size = 20
)
fig.add_annotation(
    x = 0.02,
    y = 1.02,
    text = '<b> Stage </b>',
    showarrow = False,
)
fig.add_annotation(
    x = 0.93,
    y = 1.02,
    text = '<b> GHG </b>',
    showarrow = False,
)

# Land percentage contribution
fig.add_annotation(
    x = -0.05,
    y = 0.85,
    text = "37.4%",
    showarrow = False,
),

# Farm percentage
fig.add_annotation(x = -0.05,
         y = 0.5,
         text = "38.0%",
         showarrow = False
    )

# Processing percentage
```

```python
fig.add_annotation(x = -0.05,
         y = 0.29,
         text = "3.1%",
         showarrow = False,
)

# Transport percentage
fig.add_annotation(x = -0.05,
         y = 0.22,
         text = "4.0%",
         showarrow = False,
)

# Packaging percentage
fig.add_annotation(x = -0.05,
         y = 0.14,
         text = "4.4%",
         showarrow = False,
)

# Retail percentage
fig.add_annotation(x = -0.05,
         y = 0.075,
         text = "2.9%",
         showarrow = False,
)

# Consumer percentage
fig.add_annotation(x = -0.05,
         y = 0.01,
         text = "2.4%",
         showarrow = False,

)

# Waste percentage
fig.add_annotation(x = -0.05,
         y = -0.09,
         text = "7.8%",
         showarrow = False,
    )

# Target side annotations
fig.add_annotation(x = 0.9999, y = 0.75, text = "55.5%",  showarrow = False
)
fig.add_annotation(x = 0.9999, y = 0.26, text = "33.6%",  showarrow = False
)
fig.add_annotation(x = 0.99, y = 0.07, text = "9.5%",  showarrow = False)
```

```
fig.add_annotation(x = 0.99, y = -0.04, text = "1.4%",   showarrow = False)

fig.update_layout(margin = dict(t = 100, b = 100))

fig.show()

# Saving image in directory
pio.write_image(fig, 'Food_System_Sankey.png', width = 1000, height = 700)
```

6. STAGE-WISE GHG DISTRIBUTION (FIGURE 3)

```
#Creating new dataframe by slicing existing df and groupby sum
df3 = df_edgar.groupby ( by = ['Food System Stage', 'FS Stage Order', 'GHG'
] ) . sum() [['GHG Emissions']]

# Create new variable/series to sum emissions grouped by food system stage
tot = df3.groupby(level = 0).sum()

# Divide to find %GHG contribution by stage
df3['% by stage'] = (df3 / tot).mul(100).round(1)

df3 = df3.sort_values('FS Stage Order')

df3 = df3.reset_index()

df3.head()

  Food System Stage FS Stage Order                   GHG  GHG Emissions  \
0              Land        Stage 1  Carbon dioxide (CO2)   1.638427e+11
1              Land        Stage 1         Methane (CH4)   6.087960e+08
2              Land        Stage 1   Nitrous oxide (N2O)   8.742122e+06
3              Farm        Stage 2  Carbon dioxide (CO2)   2.251379e+10
4              Farm        Stage 2         Methane (CH4)   1.064548e+11

   % by stage
0        99.6
1         0.4
2         0.0
3        13.5
4        63.7

# Convert 'GHG' column values, eg: Carbon dioxide (CO2) to CO₂
df3 = df3.replace (to_replace = ['Carbon dioxide (CO2)', 'Methane (CH4)' ,
'Nitrous oxide (N2O)', 'F-gases (Fluorinated)'],
                          value = ["CO\u2082", "CH\u2084", "N\u2082O", 'F-g
ases']
            )
df3.head()

  Food System Stage FS Stage Order  GHG  GHG Emissions  % by stage
0              Land        Stage 1  CO₂   1.638427e+11        99.6
1              Land        Stage 1  CH₄   6.087960e+08         0.4
2              Land        Stage 1  N₂O   8.742122e+06         0.0
3              Farm        Stage 2  CO₂   2.251379e+10        13.5
4              Farm        Stage 2  CH₄   1.064548e+11        63.7

# Plot a hierarchical x-axis bar chart with first axis being supply chain s
tage and second x-axis corresponding to the GHG
```

```
# in that phase.

fig = go.Figure()
clr = ['Lightgrey'] * len(df3['GHG'])
for i, row in df3.iterrows():
    fig.add_trace ( go.Bar (
        x = [  [     row['Food System Stage']     ], [    row['GHG']    ]
],
        y = [  row['% by stage']       ],
        name = row["GHG"], #Legend name
        marker_color = 'Indianred' if row['Food System Stage'] in ['Land',
'Farm'] and row['GHG'] == 'CO\u2082'
        else 'LightSalmon' if row['Food System Stage'] == 'Farm' and row['G
HG'] == 'CH\u2084'
        else clr,
        #text = [f'{i}%' for i in [row['% by stage']]],
        text = row['% by stage'],
        textfont = dict(size = 15),
        showlegend = False,
        textposition = 'outside'
                    ))
    fig.update_layout ( title_text = "<b> Stage-wise GHG Distribution in Fo
od Supply Chain </b> ",
                       title_x = 0.5,
                       title_font_size = 25,
                      xaxis = dict(title_text = "<b> GHG's per Stage </b> "
, title_font_size = 20),
                      yaxis = dict(title_text = "<b> Emission [%] </b> ", t
itle_font_size = 20),
                       margin = dict(t = 90, b = 150)
                      )
    fig.update_xaxes (tickangle = -90,
                      tickfont = dict(size = 15,
                                      family = 'Arial'))
    fig.update_yaxes (showticklabels = False)
fig.show()

pio.write_image(fig, 'GHG_distribution_supplyChain.png', width = 1000, heig
ht = 700)
```

7. LOADING 'ENVIRONMENTAL IMPACTS OF FOOD' DATASET

```
df_pdct = pd.read_csv('Food_Product_Emissions.csv')
df_pdct.info()
df_pdct.head()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 43 entries, 0 to 42
Data columns (total 11 columns):
 #   Column                                    Non-Null Count  Dtype
---  ------                                    --------------  -----
 0   Food product                              43 non-null     object
 1   Land Use Change                           43 non-null     float64
 2   Feed                                      43 non-null     float64
 3   Farm                                      43 non-null     float64
 4   Processing                                43 non-null     float64
 5   Transport                                 43 non-null     float64
 6   Packaging                                 43 non-null     float64
 7   Retail                                    43 non-null     float64
 8   Total from Land to Retail                 43 non-null     float64
 9   Total Global Average GHG Emissions per kg 43 non-null     float64
 10  Unit of GHG Emissions                     43 non-null     object
dtypes: float64(9), object(2)
memory usage: 3.8+ KB

        Food product  Land Use Change   Feed    Farm  Processing  Transport  \
0             Apples           -0.029  0.000   0.225       0.004      0.096
1            Bananas           -0.025  0.000   0.266       0.059      0.292
2             Barley            0.009  0.000   0.176       0.128      0.035
3   Beef (beef herd)           16.278  1.878  39.388       1.269      0.346
4  Beef (dairy herd)            0.906  2.508  15.689       1.108      0.424

   Packaging  Retail  Total from Land to Retail  \
0      0.044   0.017                      0.357
1      0.065   0.021                      0.678
2      0.497   0.264                      1.109
3      0.247   0.164                     59.570
4      0.268   0.182                     21.085

   Total Global Average GHG Emissions per kg         Unit of GHG Emissions
0                                       0.43  kg CO2e per kg food produced
1                                       0.86  kg CO2e per kg food produced
2                                       1.18  kg CO2e per kg food produced
3                                      99.48  kg CO2e per kg food produced
4                                      33.30  kg CO2e per kg food produced
```

```python
# Slicing SQL Query
_p1 = """
    Select
        "Food Product",
        "Total Global Average GHG Emissions per kg"
    From
        df_pdct
    Order by
        "Total Global Average GHG Emissions per kg" DESC
"""
# Query output to dataframe
p1 = %sql {{ _p1 }}
# (optional) Storing Data frame in excel format,
# could be handy for eg. to directly create a dashbaord visualization in Po
werBI
writer = pd.ExcelWriter('sql_output.xlsx')
p1.to_excel(writer, sheet_name='Emissions per product', index=False)
p1.head()
```

```
Running query in 'duckdb://'

        Food product  Total Global Average GHG Emissions per kg
0    Beef (beef herd)                                      99.48
1      Dark Chocolate                                      46.65
2       Lamb & Mutton                                      39.72
3   Beef (dairy herd)                                      33.30
4              Coffee                                      28.53
```

8. PLOTTING GHG EMISSIONS ON PRODUCT BASIS (FIGURE 4)

```
# For this plot , it is better to visualize only top 15 out of 43 products, to avoid clutter on the plot
p1 = p1.head(15)

# Create template
fig = go.Figure() #https://ourworldindata.org/faqs-environmental-impacts-food#on-one-chart-you-previously-showed-a-value-of-99-5-kilograms-co2eq-per-kilogram-of-beef-from-beef-herds-on-another-it-was-shown-as-60-kg-co2eq-per-kilogram-why-were-these-values-different

#----------------------------------------------------------------------
# make subplots with 1 row and 3 columns --> bar chart to go in (1,1) and pie charts in (1,2) and (1,3)

fig = make_subplots(
    rows = 1,
    cols = 3,
    specs = [
        [{'colspan': 3}, {'type': 'domain'}, {'type': 'domain'}]
    ],
    subplot_titles = ["Beef Distribution", "Dark Chocolate Distribution"]
)

#----------------------------------------------------------------------

# Pie Chart 1 : Beef distribution
lbl_beef = ['LUC', 'Farm', 'Feed', 'Rest']
val_beef = ['27.3', '66.12', '3.15', '3.43']
clrs_beef = [ 'IndianRed', 'FireBrick', 'Salmon', 'LightSalmon']

fig.add_trace(
    go.Pie(
        labels = lbl_beef,
        values = val_beef,
        name = "beef",
        direction = 'clockwise',
        showlegend = False,
        marker_colors = clrs_beef,
        textinfo = 'label+percent',
        textfont = dict(size = 15),
        #scalegroup = 'one',
        pull = [0, 0.1, 0, 0] # Pull a slice out
    ),
    row = 1,
    col = 3
)
```

```
# Set the size of pie chart using domain dictionary
fig.update_traces(
    domain = dict(
        x = [0.65, 0.95],
        y = [0.1, 0.8]
    ),
    selector = {'name': 'beef'}
)

#Set the title position of pie chart using x & y position
fig.update_annotations(
    x = 0.825,
    y = 0.15,
    text = "<b> Beef Distribution </b> ",
    selector = {'text': "Beef Distribution"},
    font = dict(size = 17)
)

#---------------------------------------------------------------------------
--

# Pie Chart # 2 : Dark chocolate distribution
lbl_choco = ['LUC', 'Farm', 'Rest']
val_choco = ['76.6', '19.84', '3.5']
clrs_choco = ['SteelBlue', 'SkyBlue', 'DeepSkyBlue']

fig.add_trace(
    go.Pie(
        labels = lbl_choco,
        values = val_choco,
        name = "choco",
        marker_colors = clrs_choco,
        pull = [0.1, 0, 0],
        showlegend = False,
        #scalegroup = 'one',
        textinfo = 'label+percent',
        textfont = dict(size = 15)
    ), 1, 2
)

# Set the size of pie chart using domain dictionary
fig.update_traces(
    domain = dict(
        x = [0.3, 0.6],
        y = [0.1, 0.8]
    ),
```

```
    selector = {'name': 'choco'}
)

#Set the title position of pie chart using x & y position
fig.update_annotations(
    x = 0.475,
    y = 0.15,
    text = "<b> Dark Chocolate Distribution </b>",
    selector = {'text': "Dark Chocolate Distribution"},
    font = dict(size = 17)
)

#-------------------------------------------------------------------------

# Adding Bar chart
clr_bar = ['LightGray'] * len(p1['Food product'])
clr_bar[0] = "FireBrick"
clr_bar[1] = "SteelBlue"

fig.add_trace(
    go.Bar (
        x = p1["Total Global Average GHG Emissions per kg"],
        y = p1["Food product"],
        text = p1["Total Global Average GHG Emissions per kg"],
        textposition = 'inside',
        marker_color = clr_bar,
        #texttemplate = '%'
        textfont = dict(size = 15),
        orientation = 'h'
            )
)

# Update x-axis of bar chart
fig.add_annotation(
    xref = 'paper',
    yref = 'paper',
    x = 0.5,
    y = -0.07,
    align = 'center',
    text = f"<b> CO<sub>2</sub> eq/kg product </b>",
    showarrow = False,
    font = dict(size=20)
)
#-------------------------------------------------------------------------

# Layout / figure level modifications
fig.update_layout(
```

```
    width = 980,
    height = 750,
    autosize = True,
    showlegend = False,
    title = '<b>GHG Emissions per kg Product</b>',
    titlefont = dict(size = 25),
    title_x = 0.5,
    xaxis = dict(showticklabels = False),
    yaxis = dict(categoryorder = 'total ascending'),
    margin = dict(l = 100, r = 100, t = 70, b = 0)
)

fig.update_yaxes( tickfont = dict(size = 15,  family = 'Arial Black') )

fig.show()

pio.write_image(fig, 'Emissions per product.png', width = 1000, height = 70
0)
```

9. LOADING GLEAM DATASET

```
# Gleam2.0_data_from_2010
df_gleam = pd.read_csv('GLEAM_LivestockEmissions.csv')
df_gleam.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 583 entries, 0 to 582
Data columns (total 22 columns):
 #   Column                                        Non-Null Count  Dtype  
---  ------                                        --------------  -----  
 0   Region                                        583 non-null    objec
t
 1   Animal species                                583 non-null    objec
t
 2   Production system                             583 non-null    objec
t
 3   Commodity                                     583 non-null    objec
t
 4   Emission Intensity (kg CO2e per kg protein)   583 non-null    float
64
 5   Production (kg protein)                       543 non-null    float
64
 6   Total GHG emissions (kg CO2e)                 543 non-null    float
64
 7   Total CO2 emissions (kg CO2e)                 543 non-null    float
64
 8   Total CH4 emissions (kg CO2e)                 543 non-null    float
64
 9   Total N2O emissions (kg CO2e)                 543 non-null    float
64
 10  Feed, CO2 (kg CO2e)                           543 non-null    float
64
 11  Feed, CH4 (kg CO2e)                           96 non-null     float
64
 12  Feed: fertilizer & crop residues, N2O (kg CO2e)  543 non-null    float
64
 13  Feed: applied & deposited manure, N2O (kg CO2e)  543 non-null    float
64
 14  LUC: soy & palm, CO2 (kg CO2e)                440 non-null    float
64
 15  LUC: pasture expansion, CO2 (kg CO2e)         8 non-null      float
64
 16  Enteric fermentation, CH4 (kg CO2e)           425 non-null    float
64
 17  Manure management, CH4 (kg CO2e)              543 non-null    float
64
 18  Manure management, N2O (kg CO2e)              528 non-null    float
```

```
64
 19  Direct energy, CO2 (kg CO2e)                     503 non-null    float
64
 20  Indirect energy, CO2 (kg CO2e)                   512 non-null    float
64
 21  Postfarm, CO2 (kg CO2e)                          491 non-null    float
64
dtypes: float64(18), object(4)
memory usage: 100.3+ KB
```

```
#SQL query to filter columns
_g1 = """
Select
    Region,
    "Animal species",
    "Production system",
    Commodity,
    "Total GHG emissions (kg CO2e)",
    "Total CO2 emissions (kg CO2e)",
    "Total CH4 emissions (kg CO2e)",
    "Total N2O emissions (kg CO2e)"
From
    df_gleam
where
    Region = 'Global' AND
    "Production system" != 'Aggregated' AND
    "Commodity" != 'Aggregated'
"""
g1 = %sql {{ _g1 }}
g1.head(2)
```

```
Running query in 'duckdb://'

   Region Animal species   Production system Commodity  \
0  Global         Cattle  Grassland systems      Milk
1  Global         Cattle  Grassland systems      Meat

   Total GHG emissions (kg CO2e)  Total CO2 emissions (kg CO2e)  \
0                   6.592844e+11                   9.286140e+10
1                   1.473770e+12                   4.699448e+11

   Total CH4 emissions (kg CO2e)  Total N2O emissions (kg CO2e)
0                   3.713461e+11                   1.950770e+11
1                   6.816191e+11                   3.222059e+11
```

```
# Filter the dataframe on 'global' region and eliminate all production syst
em and commodity with 'aggregated' values
# (since aggregated value is the aggregate of milk and meat and hence is a
```

```
duplicate record)

_g2 = """
select
    *
From
    g1
where
    Region = 'Global' AND
    "Production system" != 'Aggregated' AND
    "Commodity" != 'Aggregated'
"""

g2 = %sql {{ _g2 }}
```

```
Running query in 'duckdb://'
```

```
# Select necessary columns
_g2 = """
Select
    "Animal species",
    SUM("Total GHG emissions (kg CO2e)") as "Total GHG emissions (kg CO2e)"
,
    SUM("Total CO2 emissions (kg CO2e)") as "Total CO2 emissions (kg CO2e)"
,
    Sum("Total CH4 emissions (kg CO2e)") as "Total CH4 emissions (kg CO2e)"
,
    Sum("Total N2O emissions (kg CO2e)") as "Total N2O emissions (kg CO2e)"
From
    g1
Group by
    "Animal species"
"""
# Convert query output to dataframe
g2 = %sql {{ _g2 }}

# Python operation to convert unit from kg CO2 eq to Gt CO2 eq
g2['Total GHG emissions (kg CO2e)'] = g2['Total GHG emissions (kg CO2e)']*1
0**(-12)
g2['Total CO2 emissions (kg CO2e)'] = g2['Total CO2 emissions (kg CO2e)']*1
0**(-12)
g2['Total CH4 emissions (kg CO2e)'] = g2['Total CH4 emissions (kg CO2e)']*1
0**(-12)
g2['Total N2O emissions (kg CO2e)'] = g2['Total N2O emissions (kg CO2e)']*1
0**(-12)

# Renaming columns with new units
g2.rename(columns = {'Total GHG emissions (kg CO2e)': 'Total GHG emissions
```

```
(Gt CO\u2082 eq)',
          'Total CO2 emissions (kg CO2e)': 'Total CO\u2082 emissions (Gt CO
\u2082 eq)',
          'Total CH4 emissions (kg CO2e)': 'Total CH\u2084 emissions (Gt CO
\u2082 eq)',
          'Total N2O emissions (kg CO2e)': 'Total N\u2082O emissions (Gt CO
\u2082 eq)',},
          inplace = True
         )

g2 = g2.round(1)

g2.head()
```

```
Running query in 'duckdb://'

  Animal species  Total GHG emissions (Gt CO₂ eq)  \
0         Cattle                              4.7
1          Sheep                              0.3
2          Goats                              0.2
3           Pigs                              0.8
4      Buffaloes                              0.7

   Total CO₂ emissions (Gt CO₂ eq)  Total CH₄ emissions (Gt CO₂ eq)  \
0                              0.9                              2.6
1                              0.0                              0.2
2                              0.0                              0.1
3                              0.4                              0.3
4                              0.1                              0.4

   Total N₂O emissions (Gt CO₂ eq)
0                              1.1
1                              0.1
2                              0.0
3                              0.2
4                              0.2
```

10. PLOTTING LIVESTOCK EMISSION (FIGURE 5)

```
#col = g3.columns[1:5]

clr = ["lightgrey"] * len(g2['Animal species'])
clr[0] = "FireBrick"

fig1 = px.bar(
    g2,
    x =  "Animal species",
    y = "Total GHG emissions (Gt CO\u2082 eq)",
    text = [f'{i}' for i in g2["Total GHG emissions (Gt CO\u2082 eq)"]],
    #text_auto = '.2s'
)

fig1.update_traces(width = 0.6,
                 marker_color = clr,
                  textposition = 'outside',
                  textfont = dict(
                      size = 16,
                      family = 'Arial Black'
                  )
                 )

l = [ 'CO<sub>2</sub>', 'N<sub>2</sub>O','CH<sub>4</sub>']
v = [ '20.1', '23.1','56.7']
clrs = [ "PeachPuff", "LightSalmon","IndianRed"]

fig2 = go.Figure()

fig2.add_trace(
    go.Pie(
        labels = l,
        values = v,
        marker_colors = clrs,
        direction = 'counterclockwise',
        textinfo = 'label+percent',
        textfont = dict(size = 17),
        #title = "GHG Distribution for Cattle",
        #title_font_size = 17
    )
)
fig2.update_traces(domain = dict(x = [0.1, 0.65],
                                 y = [0.35, 0.85]
                                )
                  )

for data in fig1.data:
```

```
    fig2.add_trace(data)

fig2.update_layout(showlegend = False,
                   width = 900,
                   title = "<b> GHG Emissions from Livestock",
                   title_font_size = 25,
                   title_font_family = 'Arial',
                   title_x = 0.5,
                   margin = dict(t=60)
                 )

fig2.update_xaxes(categoryorder = 'total descending',
                  title = "<b> Animal Species </b>",
                  title_font_size = 20,
                  title_font_family = 'Arial',
                  tickfont = dict(size = 17,
                                  family = 'Arial'
                                 ),
)

fig2.update_yaxes(title = "<b> GHG Emission (Gt CO<sub>2</sub>e) </b>",
                  title_font_size = 20,
                  showticklabels = False,
                  title_font_family = 'Arial'
)

fig2.add_annotation(text = "Year = 2010",
                    x = 'Goats',
                    y = 4.7,
                    showarrow = False,
                    font = dict(size = 18,
                                color = 'Grey'
                               )
)

fig2.show()

pio.write_image(fig2, 'Emissions_from_livestock.png', width = 1000, height
= 650)
```

```
_livestock_sankey = """
select
   Region,
   "Production system",
   Commodity,
   SUM("Total GHG emissions (kg CO2e)") as 'Total GHG'
From
    df_gleam
where
    Region = 'Global' AND
    "Production system" != 'Aggregated' AND
    "Commodity" != 'Aggregated'
Group by
    Region,
   "Production system",
   Commodity
Order by
    "Total GHG" DESC
"""
livestock_sankey = %sql {{ _livestock_sankey }}

livestock_sankey.head()
```

```
Running query in 'duckdb://'

   Region  Production system Commodity     Total GHG
0  Global      Mixed systems      Meat  1.784406e+12
1  Global  Grassland systems      Meat  1.718533e+12
2  Global      Mixed systems      Milk  1.452717e+12
3  Global  Grassland systems      Milk  8.152560e+11
4  Global           Broilers      Meat  4.436656e+11
```

```
# SQL query to select required columns
_commodity = """
Select
    Commodity,
    SUM("Total GHG") as Total
From
    livestock_sankey
Group by
    Commodity
"""
commodity = %sql {{_commodity}}

# Python script to add percentage column
commodity['%'] = commodity['Total'].apply(lambda x: 100*x/(commodity['Total
```

```
'].sum())).round(1)
```

```
commodity.head()
```

```
Running query in 'duckdb://'
```

```
  Commodity         Total     %
0      Meat  4.970073e+12  66.1
1      Milk  2.267973e+12  30.2
2      Eggs  2.834679e+11   3.8
```

12. COMMODITY-WISE GHG DISTRIBUTION PLOT (FIGURE 6)

```
fig = go.Figure()

clrs = [ 'IndianRed', 'LightSalmon', 'Pink']

fig.add_trace(go.Pie(
    labels = commodity['Commodity'],
    values = commodity['%'],
    marker_colors = clrs,
    direction = 'clockwise',
    #hole = 0.5,
    textinfo = 'label+percent',
    textfont = dict(size = 25)
))

fig.update_traces(domain = dict(x = [0, 0.95], y = [0.05, 0.95]))
fig.update_layout(showlegend = False,
                  title_text = "<b> Commodity-Wise GHG Emissions </b>",
                  title_x = 0.5,
                  title_font_size = 20,
                  margin = dict(t = 150))

fig.show()

pio.write_image(fig, 'Commodity emission.png')
```

13. EMISSION INTENSITY PLOT (FIGURE 7)

```
df_intensity = df_gleam[['Region',
                         'Emission Intensity (kg CO2e per kg protein)'
                        ]].loc[(df_gleam['Region']!='Global') &
                             (df_gleam['Animal species'] == 'Cattle') &
                             (df_gleam['Production system'] == 'Aggregated'
) &
                             (df_gleam['Commodity'] == 'Aggregated')
                            ].sort_values(by = 'Emission Intensity (kg CO2e
per kg protein)', ascending = False)

clr = ['Lightgray',] * len(df_intensity['Region'])
clr[0] = 'IndianRed'

fig = go.Figure()
fig.add_trace(go.Bar (
    x = df_intensity["Emission Intensity (kg CO2e per kg protein)"],
    y = df_intensity["Region"],
    marker_color = clr,
    text = df_intensity["Emission Intensity (kg CO2e per kg protein)"],
    textposition = 'inside',
    textfont = dict(size = 15, family = 'Arial'),
    orientation = 'h'
))
fig.update_layout(title_text = "<b> Emission Intensity per Region </b>",
                  title_x = 0.5,
                  title_font_size = 25,
                  xaxis = dict(showticklabels = False,
                               title = '<b> Emission Intensity, kg CO<sub>2
</sub> eq/kg protein</b>',
                               title_font = dict(size = 17)
                              ),
                  yaxis = dict(categoryorder = 'total ascending',
                               title = None,
                               tickfont = dict(size = 15)
                              ),
                  width =950,
                  margin=dict(l=0, r=140, t=80, b=80),
                  uniformtext = dict(minsize=13, mode = 'show'),
                  bargap=0.3,
                  #title_font_color="Blue"
                 )
fig.update_yaxes(tickfont = dict(size = 15, family = 'Arial'))
fig.show()

pio.write_image(fig, 'Emissions Intensity per Region.png', width = 1000, he
ight = 600)
```


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