Food loss and waste in India:

GHG emissions and value chain insights

NIFTEM
KUNDLI

Tetra Pak®
PROTECTS WHAT'S GOOD

CONTENTS

i. Preface

Food loss and waste (FLW) poses major challenges within global food systems. According to FAO (2023), 13% of food is lost after harvest before it reaches retail shelves, while an additional 19% is wasted in households, supermarkets, and restaurants. Beyond reducing food availability, these losses represent loss of vital resources – land, water, and energy – and contribute 8-10% of global anthropogenic greenhouse gas emissions, amounting to over a trillion dollars in economic losses each year.
In India, where post-harvest losses are particularly high for perishable commodities, research on FLW and its environmental implications remains limited and is often staggered.

This study seeks to bridge part of that gap by estimating the GHG emissions associated with losses in apple, orange, and milk value chains. The results highlight the striking contrast between fruit and dairy products: although milk experiences smaller losses in the supply chain, its associated GHG emissions are far higher because of the inherently greater GHG intensity of livestock production.

As post-harvest losses continue to undermine food security in India, improving supply chain efficiency, strengthening agribusiness, and investing in modern processing – particularly at or near farm gates – are crucial steps for reducing such losses. Equally important are continued research, cross-sector collaboration, and policies that prioritize sustainable food systems.

This study aims to bring out strategies that can contribute to a more resilient, resource-efficient, and climate-smart food system. We also acknowledge Tetra Pak's support with this study.

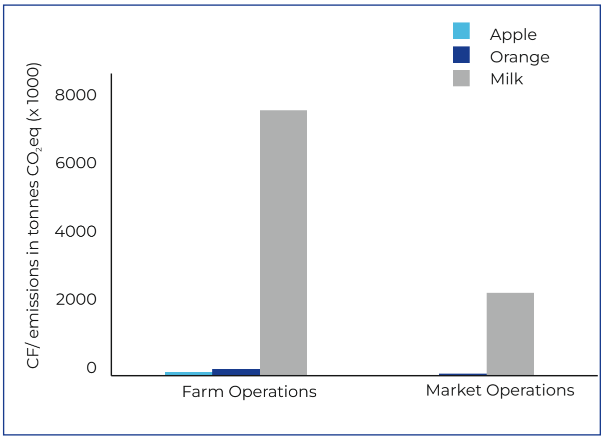
Dr Harinder Singh Oberoi
Director, NIFTEM-K

ii. Executive summary

Food loss and waste (FLW) represent a major inefficiency in global food systems in terms of large amounts of food that never reaches the people. It is either lost or wasted while traveling through the various stages of the supply chain. **According to FAO (2023), 13% of food produced is lost after harvest and before it reaches store shelves[1], while 19% is wasted in our homes, supermarkets and restaurants[2].** Food losses also represent a waste of land, water and energy resources used in the production and supply chain of food in addition to the associated GHG emissions. **Global FLW contributes to 8-10% of total anthropogenic GHG emissions[3,4], and results in over $1 trillion financial losses yearly[5].**

Food loss and waste research across the globe is patchy while in India, it is scarce. The existing data on FLW and associated greenhouse gas (GHG) emissions are not comparable due to different methodology of estimations. Therefore, a standardized approach needs to be formulated to overcome these challenges. The present study attempted to measure (using secondary data) the greenhouse gas (GHG) emissions associated with the losses in fruits (apple and orange) and dairy (milk) value chain. **The total GHG emissions (Farm and Market Operations) associated with the lost apples, oranges and milk were found to be 56,416; 1,62,867; 91,25,219 tonnes CO_2eq respectively (Fig. 1). This implies that the emissions from the losses of milk were ~ 162 times and 56 times higher than that of the losses of apples and the oranges respectively.** However, the percentage losses in the milk value chain were 11 and 9 times lower as compared to the losses in the apple and orange

Figure 1: GHG emissions (in tonnes CO_2eq) associated with the losses in Farm and Market Operations for apple, orange and milk value chain.



value chain respectively. This is due to higher GHG intensity of livestock products as compared to the plant derived products. In the case of milk, the transport is the second major emission hot spot after milking/ harvesting. This means that **transport related emissions are important for the dairy sector.**

As post-harvest losses remain a significant challenge in India, particularly for perishable commodities such as fruits and dairy, it is challenging to ensure food security for all. To manage the FLW issues in India, a strong strategy to formalize the supply chain of food commodities, strengthening of agribusiness sector and building up of an advanced level processing sector is essential. Technological advancements at the GHG hot spots, identified in this study, are strongly suggested to reduce the post-harvest losses. **Processing of commodities close to farm gate is proposed as one of the strategies to reduce the losses as well as associated GHG emissions.**

More research and analysis is needed to give specific insights on the losses of different commodities and associated burden on the natural resources[6]. Putting the agenda of FLW and its associated emissions on priority, promoting partnerships and collaboration to manage FLW, raising awareness about the FLW and its associated emissions, supporting policy environments for sustainable food systems and formalized supply chains can help in reducing the food loss and waste in a larger context. A multi-disciplinary approach with stronger partnership among stakeholders needs to be adopted to embed sustainability in food systems.

Synopsis

This document summarizes a NIFTEM study on Food Loss and Waste (FLW) in India, examining apples, oranges, and milk to measure losses across the supply chain and their impact on GHG emissions. While fruits face high physical losses due to poor handling, storage, and transport, milk despite low physical loss levels, drives massive emissions because of its methane intensity. The report highlights FLW has both food security & climate impact issues, linking it to key UN Sustainable Development Goals (SDGs) and provides recommendations in the problem areas at each step of the value chain, reflecting where focus is required.

SDGs: Reducing food loss and waste is vital for achieving the SDGs - especially SDG 12.3, while also supporting food security (SDG 2), climate action (SDG 13), and innovation in infrastructure (SDG 9). For India, since fruits and vegetables form the largest share of FLW and animal-based diets are set to double by 2050, tackling FLW is critical to cut emissions and ensure sustainable growth.

Methodology

The study in the report examined apples, oranges, and milk, using government data for production and NABCONS for loss rates. Since India-specific emission data was only available for milk, international studies were used for apples and oranges. Losses at each stage of the supply chain were converted into greenhouse gas emissions using the formula Emissions = Emission Factor × Losses, with results shown in tonnes of CO.

Key insights with data points

Global food loss and waste scenario:
Around 2.5 billion tonnes of food (~40% of production) is lost/ wasted annually, including 1.3 billion tonnes wasted at various stages (about one-third of production). Of this, 1.2 billion tonnes are lost on farms. Food loss and waste (FLW) contribute 8–10% of global GHG emissions and accounts for 30% of global emissions in 2022, marking a 10% increase since 2000. Nearly 30% of farmland globally is used to grow food that never gets eaten. Consumer-level waste is ~19% of food available at shops, restaurants, and homes, while 13% is lost in the supply chain before reaching consumers. In wealthier regions (Europe, North America, Industrialized Asia), 58% of losses occur on farms, whereas in poorer regions 54% of losses happen post-harvest due to weak storage and supply chains.

India food loss and waste scenario:

Between 30-40% of fruits & vegetables are lost between harvest and consumption. Commodity-level study results show:

- Apples: 9.5% production loss, 56,000 tCO eq emissions
- Oranges: 7.7% production loss, 1,62,000 tCO_2eq emissions
- Milk: 0.87% production loss, but a massive 91.25 million tCO_2eq emissions (162× apples, 56× oranges), due to methane from cows

In India, fruits experience high quantity losses and demonstrate lower emissions, while milk experiences lower losses in terms of quantity and yet demonstrate higher emissions.

Commodity-wise challenges and suggested mitigation strategies

APPLE

Challenges:
Rough harvesting & handling damage, losses in manual sorting/ grading, high transport losses over long distances, cold stores dependent on diesel gensets.

Mitigation strategies:
Better harvesting tools & farmer training, automated grading & improved packaging, refrigerated containers (reefer) logistics/ cold chain, renewable energy use in controlled atmosphere stores.

ORANGE

Challenges:
High losses in manual sorting/ grading, no on-farm storage (most farmers in open fields), damage in loose transport & overfilling, limited cold storage use by traders.

Mitigation strategies:
Mechanical graders & farmer capacity building, on-farm storage sheds & pack houses, scientific packaging & reefer vans, wider cold storage access & processing units.

MILK

Challenges:
Milking losses from spillage & poor hygiene, transport leakages in cans & small vehicles, high GHG footprint from enteric fermentation, processing/ retail spoilage from poor storage.

Mitigation strategies:
Portable milking machines & clean containers, village collection/ chilling centers, insulated tankers & cold chain expansion, renewable energy use in dairies, training/ capacity building for hygienic handling.

Conclusion

India's efforts to reduce food loss and waste must focus on building structured and efficient supply chains, supported by technology and farmer training. Standardizing the dairy value chain can greatly improve productivity while lowering emissions, while greater investment in agribusiness, food processing, and cold-chain infrastructure, particularly empowering women farmers can enhance incomes through value-added products. Above all, stronger collaboration between government, industry, and research bodies will be essential to drive coordinated action and achieve meaningful progress.

iii. Need for reducing FLW (including its role in GHG emissions) and role of evidence-based decision making

Highlights

- Food loss and waste research across the globe is patchy while in India, it is scarce. The existing data on food losses and associated greenhouse gas (GHG) emissions are not comparable due to different methodology of estimations. Therefore, a standardized approach must be formulated to overcome these challenges.
- The present study attempts to measure the volume of losses and associated greenhouse gas (GHG) emissions for fruits (apple and orange) and dairy (milk) value chain. **The GHG emissions associated with the losses of milk were the highest (Fig. 1) followed by orange and apple.** The total emissions (Farm and Market Operations) for the lost apples, oranges and milk were 56,416; 1,62,867; 91,25,219 tonnes CO_2eq respectively. This implies that the **emissions from the milk losses are ~ 162 times more than that of the apple and 56 times higher than that of the oranges.** However, the percentage losses in the milk value chain were 11 and 9 times lower as compared to the losses in the apple and orange value chain respectively. This is due to higher GHG intensity of livestock products as compared to the plant derived products.
- To manage the food loss and waste issues in India, a strong strategy to formalize the supply chain of food commodities, strengthening of agribusiness sector and building up of an advanced level processing sector is essential. A roadmap to fill the gaps at critical loss points in the value chain has to be in place as per the present findings. In this study, technological advancements are strongly suggested at hot spots to bridge the existing gaps. The processing of commodities close to farm gate is proposed as one of the strategies to reduce the losses as well as associated GHG emissions.
- A multi-disciplinary approach with stronger partnership among stakeholders needs to be adopted to embed sustainability in food systems. The food loss and waste topic and associated climate impacts needs to be prioritized in research. This will support decision making and help in developing the technological solutions for the resources wasted along the value chain.

1. Introduction

As per the United Nations (UN), the world's population is going to be 9.7 billion by 2050. This implies that there will be a need for more food to feed this growing number of people. However, it should also be comprehended that there is no food shortage globally at present. The world produces enough food to feed everyone on the planet. However, there are issues with accessibility, affordability, food losses etc. which leads to existing food insecurity at different places around the world. FAO estimated that nearly 30 percent of the world's agricultural land is used to produce food that is ultimately never consumed by people. **Each year approximately one-third (almost 1.3 billion tonnes) of the edible part of food is lost or wasted.** Out of this, 19% of food available to consumers is wasted, at the retail, food service and household levels. This is in addition to the estimated 13% of the world's food that is lost in the supply chain from post-harvest up to and excluding retail.

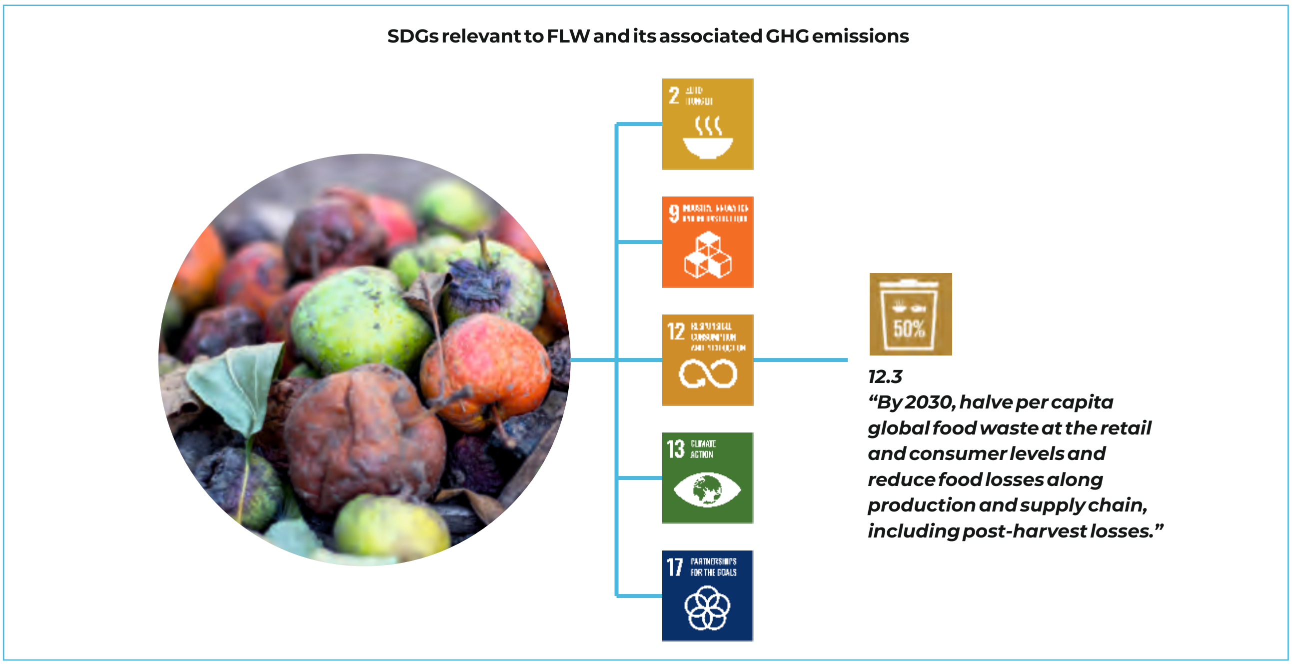
The term "Food Loss" and "Food Waste" can be technically separated. **"Food Waste"** (FW) is defined as food and the associated inedible parts removed from the human food supply chain. "Removed from the human food supply chain" means it can undergo: co/ anaerobic digestion; compost/ aerobic digestion; land application; controlled combustion; sewer; litter/ discards/ refuse; or landfill. **"Food Loss"** is defined as all the crop and livestock human-edible commodity quantities that, directly or indirectly, completely exit the post-harvest/slaughter production/ supply chain by being discarded, incinerated or otherwise, and do not re-enter in any other utilization (such as animal feed, industrial use, etc.), up to, and excluding, the retail level. Losses that occur during storage, transport and processing are all included. Losses include the commodity as a whole with its non-edible parts decrease in edible mass at the production, post-harvest and processing stages of the food chain.

FLW has become a significant issue from an economic as well as an environmental perspective. The wasted resources also corresponds to 20 percent of freshwater consumption. The latest dimension emerging from the FLW is associated greenhouse gas (GHG) emissions. Food losses also represent a waste of land, water and energy resources used in the production of food apart from associated GHG emissions. **Global food loss and waste contributes to 8-10% of total anthropogenic GHG emissions and would be the third largest GHG emitter if it were a country**. GHG emissions from FLW have two major sources: the emissions during the production (including storage, processing, distribution and consumption) of food that is lost or wasted, and the emissions from FLW management (that is, waste management). Crop production leads to GHG emissions due to different inputs and farm management practices. The post-harvest stages such as storage, transportation and distribution also lead to GHG emissions due to energy requirements for different operations. It is estimated that **total FLW is over 2.5 billion tonnes that is close to 40% of all food produced,** compared to the commonly cited 33%. Nearly **1.2 billion tonnes of this food is lost on farms,** during and after harvest. Despite higher on-farm mechanization, high- and middle-income countries in Europe, North America and Industrialized Asia, with only 37% of the global population, contribute 58% of global harvest loss (368 million tonnes). On the other hand, low-income countries with 63% of the population have a 54% share of global post-harvest farm-stage loss (291 million tonnes). This highlights that the action to tackle FLW needs to be prioritized globally not in specific regions.

FAO has identified FLW prevention and reduction as its key pathway in transforming agrifood systems. **In 2022, global agrifood systems' emissions were 16.2 billion tonnes of carbon dioxide equivalent (CO_2eq), which is equivalent to 30.5% of total GHG emissions** and representing an increase of 10% since 2000. Therefore, a significant amount of GHG emissions resulting from food loss and waste in the agrifood systems can be avoided by reducing FLW. It can directly support food security at global, regional and national levels. The lower income countries are struggling to meet the pace of economic prosperity. With food security, they will be able to improve their performance on the index of Human Development Indicators such as life expectancy, infant mortality rate, maternal mortality rate, health and nutrition etc.

The UN's 2030 Agenda for Sustainable development has been supported by FAO. There are 17 Sustainable Development Goals (SDGs) and 169 targets. The food loss and waste is directly linked to Goal 12 - "Ensure sustainable consumption and production patterns". It has been stated clearly in the 12.3 target as "By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses." The other relevant SDGs with respect to FLW and associated emissions would be SDG 2 (End hunger, achieve food security and improved nutrition and promote sustainable agriculture), SDG 9 (Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation), SDG 13 (Take urgent action to combat climate change and its impacts) and SDG 17 (Strengthen the means of implementation and revitalize the global partnership for sustainable development) (Fig. 2).

Figure 2: Sustainable Development Goals (SDGs) 2030 related to Food Loss and Waste (FLW) and associated Greenhouse Gas (GHG) Emissions.



The cereals, fruits and vegetables, and roots and tubers comprise 80 per cent of the total food waste globally despite their production percentage being 70. The fruits and vegetables' waste comprised 42 per cent of all the FLW in 2011. Another study reported that **fruits and vegetables contributed almost half of the total FLW.** It has also been stated that developing economies have the largest increases in associated GHG emissions primarily due to the increasing losses in fruits and vegetables. The situation is further complicated by a shift in trend towards animal-based diets in future which would increase resource consumption and associated GHG emissions. In India particularly, animal products are projected to increase by 100% by 2050. Also, the GHG emission intensity per calorie of animal products in India is three times (3.19 G CO_2eq/ kcal) higher than China (0.96 G CO_2eq/ kcal).

Indian Economic Survey 2024-2025 mentioned about FLW and associated emissions, and stated that dietary preferences also impact emissions. Despite abundant production, an estimated 30-40% of fruits and vegetables are lost between harvest and consumption. Thus, there is an emphasis on identifying the levels of losses in the food supply chain and its reduction. Two studies were conducted by ICAR-CIPHET (2005-07 and 2012) to estimate the levels of post-harvest losses in India. After that, a third study titled “Study to Determine Post-Harvest Losses in India” was undertaken by NABARD Consultancy Services (NABCONS) in 2022. The special focus of this study was on the post-harvest losses of 54 commodities including perishables such as fruits and vegetables and dairy items like milk, meat and eggs etc. Food losses and consequent environmental impacts such as GHG emissions are expected to be very high in India. However, there is a need for – and a dearth of – studies reporting environmental impacts including GHG emissions associated with food loss in India. Evidence with respect to the associated environmental cost holds immense value in framing the context specific mitigation/ adaptation strategies. The important aspect to be considered here is the opportunity and challenge in carrying out the FLW related studies. The topic requires immediate attention in the light of the fact that food loss and waste has not been clearly defined or delineated.

Therefore, this study is aimed to estimate the GHG emissions for the fruit and dairy supply chain in India. The commodities have been chosen based on their predominant usage in Indian diet as well as their contribution to the country's economy. It should be clarified here that the present study has worked on the value chain of the raw items i.e. apples, oranges and raw milk. The processed and packaged products made from these commodities are not part of this work.

2. Objectives

This study attempts to address this gap by:

- Estimating the environmental impacts associated with losses at different stages of a dairy (milk) and a fruit value chain (apples and oranges) in India in terms of GHG emissions.
- Identification of hot spots of GHG emissions to prioritize the mitigation/ adaptation strategies.

3. Methodology

Selection of commodities

India as one of the fastest growing economies in the world has taken conscious steps in the food sector. It has attempted to increase its production in many commodities such as milk from the dairy sector and fruits and vegetables from horticultural crops. These commodities have a significant contribution in the Indian economy and provide a livelihood option as well as help to meet the nutritional needs of the population. **India is the world's largest producer of milk** contributing over 24% of global production. **In 2023-24, India produced 239.3 million tonnes of milk, with per capita availability reaching 471 grams/day. India is among the top 5 global producers of apples** having a significant share in terms of commodity consumption, export and processing in India. They are major horticultural crops primarily grown in Jammu and Kashmir, Himachal Pradesh, and Uttarakhand contributing significantly to the economy of hill states. **India is the third largest producer of oranges in the world,** with major production in the states of Maharashtra, Madhya Pradesh, and the Northeast. Hence, apple, orange and milk were selected for this research study. These items vitally contribute to the country's economy. This study does not take into account the processed and packaged products of the three commodities.

Data search and data extraction

The production data for the fruits was taken from Horticultural Statistics (2021). The milk production data was taken from Basic Animal Husbandry Statistics. The data for rate of loss was taken from NABCONS report (2022).

The scientific studies were systematically reviewed and the studies of carbon footprint estimation via Life Cycle Assessment (LCA) approach for each commodity were screened. To the best of our knowledge, no studies were present on the estimation of carbon footprint of apples and oranges in the Indian scenario. Therefore, the emission factors for apples and oranges were taken from the studies of Longo et al. (2016) and Bell et al. (2020) carried in other regions of the world. For raw milk, the emission factors have been taken from a study by Garg et al. (2018) on GHG emissions from milk production in the Indian context. The studies relevant to milk, apple and orange were selected in a manner so that they cover the GHG emissions from all the main post-harvest stages of the supply chain.

GHG emission calculations

Based on the emission factors, the losses derived from the NABCONS study were used to calculate the emissions associated with the losses of commodities at each stage. For the calculation of emissions after harvesting, the emission factors of post-harvest stages were applied to the stages of collection, sorting/ grading, packaging, farm level storage and transport from farm to market channels. The emissions of final users of Market Operations such as wholesalers, retailers and processors were also calculated using the emission factors of studies referred (Table 4). The following formula was used for GHG emission calculations:

GHG emissions (in tonnes CO_2eq) =
Emission factor for the stage considered x Losses in tonnes
OR
CF^i loss = CEF^i x F^i loss

where CF^i loss is carbon emission associated with food loss of the ith item in tonnes and CEF^i is the carbon emission factor (carbon emission per unit weight of food in t Co_2eq/ t or kg Co_2eq/ kg). F^i loss is the loss of the amount of commodity in tonnes. (Kashyap and Agarwal, 2021). The GHGs associated with the losses of commodities are reported in tonnes CO_2eq.

Table 1: Annual production of apple, orange and milk

Commodity	Quantity produced (in tonnes)	Reference
Apple	22,76,000	Department of Agriculture and Farmers' Welfare (MoA&FW), 2020-21
Orange	62,19,400	Department of Agriculture and Farmers' Welfare (MoA&FW), 2020-21
Milk (FPCM)	22,37,44,565	DAHD, GoI, 2023-24

Note: Milk production in tonnes was 239,299,000 for the year 2023-24 as per DAHD, GoI. It was converted to Fat and Protein Corrected Milk (FPCM).

Table 2: Stage wise loss at national level (NABCONS 2022)

S.No.		Apple	Orange	Milk
Farm Operations (%)				
1.	Harvesting	3.55	1.12	0.25
2.	Collection	0.01	0.23	0.08
3.	Sorting/grading	3.61	1.92	
4.	Packaging	0.02	0.35	
5.	Farm level storage	0.05	0.98	
6.	Transport	0.62	0.93	0.21
Market Operations (%)				
7.	Godown/cold store	0.01	0.04	
8.	Wholesalers	0.39	0.58	
9.	Retailers	0.17	0.63	0.05
10.	Processing unit	0.16	0.02	0.17
11.	Transport	0.91	0.91	0.12
Total loss %		**9.51**	**7.71**	**0.87**

Note: The NABCONS study provides the stage wise percentage loss of the apple, orange and milk given in Table 2. By multiplying the percentage value with quantity produced in tonnes given in Table 1, the losses in tonnes were calculated for each stage. For the harvesting stage, the quantity produced in tonnes given in Table 1 was used. But for the stages after harvesting, the quantity in tonnes was used after subtracting the losses of the previous stage. This is one aspect of mass balancing exercise. To understand when losses are occurring at one stage, it is rational that for the next stage the amount available will be after deducting the losses. For Market Operations, the percentage of quantity available in different channels such as godowns, wholesalers, retailers etc as given in NABCONS study has been used. For calculation of emissions for the transport stage of market level operations, the total quantity of losses was estimated after adding the wholesalers and retailers' values as they have tie-ups with transporters to send further to other retailers and processing units.

Table 3: Carbon footprint/emission factor/Global Warming Potential (GWP) of the commodities

Commodity	GWP in kg CO_2eq/ tonnes)	Source
Apple	612	Longo et.al (2016)
Orange	560	Bell et.al (2020)
Milk	5,800	Garg et.al (2018)

Table 4: Stage wise emission factors

Supply chain stages	Description	Stage wise carbon footprint GWP in kg CO_2eq/tonne		
		Apple	Orange	Milk
Harvest	The emission factor of the harvesting stage has emissions resulting from cultivating the commodities including machines management, pruning, land management, fertilization, irrigation, thinning, anti-parasitic treatment, harvest.	124.66	250	5,684
Post-harvest	The emission factor of this stage is used to calculate the emissions associated with the losses of on -farm stages of "collection, sorting/ grading, packaging, farm level storage and transportation."	255.57	150	116
Transportation to final users	The emission factor of this stage was used to calculate the emissions associated with the losses of Market Operations.	225.58	160	116

For calculating the emissions associated with the losses in each stage, the emission factors were added for subsequent stages. This implies that for calculating the emissions of post-harvest stages, the emission factor of "cultivation process" will also be added. Likewise, for the calculation of the last stage i.e. "Transport to Final Users," the emission factors of all previous stages was added. Therefore, stage wise emission factors used in this study are given in Table 5.

Table 5: Emission factors used in the present study for each stage

Stage considered	Stage wise carbon footprint - GWP in kg CO_2eq/tonne		
	Apple	Orange	Milk
Harvest/cultivation	125	150	5,684
Post-harvest	380 (harvesting and post-harvesting post-harvesting combined)	400 (harvesting and post-harvesting combined)	5,800 (harvesting and post-harvesting combined)
Transportation to final users	612 (harvesting, post-harvesting and transportation combined)	560 (harvesting, post-harvesting and transportation combined)	5,800 (harvesting and post-harvesting combined)

As mentioned earlier, the emission factor of the previous stage has been added to the next stage. It is because the volume of a commodity (apples, oranges and raw milk) lost at a particular stage has utilized the resources at that stage as well as the previous stages before reaching the next stage of the supply chain. Therefore, when calculating the amount of emissions for the stages of post-harvest, the emission factor of harvesting is added. Likewise, for transportation stage, the emission factor of previous two stages, i.e. harvest and post-harvest has been taken into account.

4. Key insights

APPLE

There is a total loss of 9.51% across the value chain of apples in India. In Farm Operations, **the highest losses are reported in sorting and grading (3.61%) followed by harvesting (3.55%) operations** (Figure 3). This is attributed to **improper and rough handling, hand pressing, harvesting of immature and over mature fruits, and improper collecting material by laborers** resulting in physical damage, bruising and cracking in fruits. According to NABCONS (2022), physical damage of fruit as well as dropping of fruit was observed in apples. The loss volumes occurring at farm level operations are significant and require immediate attention in terms of providing technological solutions. The manpower must be equipped well to handle the harvested apples. The losses in packaging and farm level storages are less as the best fruits are screened at the stage of sorting/grading only. The transport stage of Farm Operations consists of transporting the apples from farm to the different channels of Market Operations.

Figure 3: Loss of apples in tonnes from Farm and Market Operations

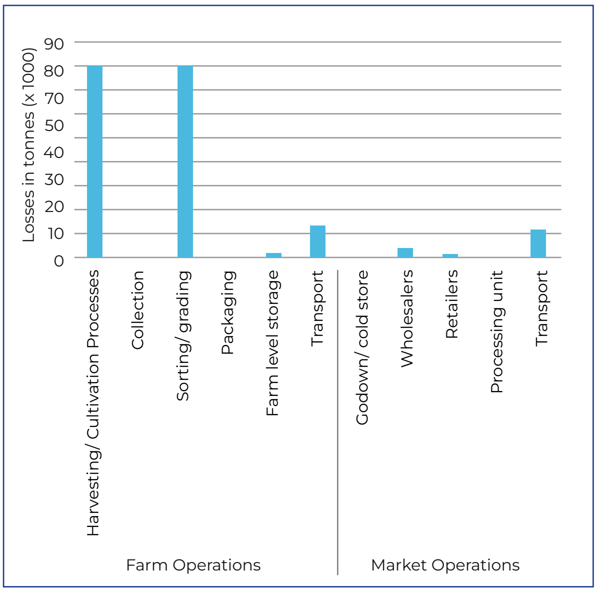


Figure 3 also depicts that godowns/ cold stores have very less losses as compared to other market channels such as wholesalers, retailers and transport. It is mainly because the godowns/ cold stores are used in India for the storage purposes only and the apples are transported to wholesalers and big retailers from the storage points. The losses at wholesalers could be due to the perishability of apples. According to another study conducted in 2021, due to the standards maintained by the retail chains/ brand owners, the daily dump of 7-10% has been reported which is unavoidable. The transport losses of Market Operations are high because apple is getting distributed to a wide range of locations. The losses are calculated from the starting point up-to the destinations. The destinations are local cities, cities from other states as well as the export sites. Therefore, the transport losses in Market Operations are large because they cover the regional, national and international export points.

In the apple value chain there are two types of primary processors in India- 1. Controlled Atmosphere (CA) stores, 2. Pack houses. CA storages have been established by a few private players in major apple producing Indian states like J&K, Himachal Pradesh and Uttarakhand. After harvest, the fruits are procured directly from the farm by CA store operators and later sold through a network of dealers which are mainly wholesalers and big retailers. Cold chain players stock produce in controlled atmosphere storages. The transportation from field to storage point and from storage point to distributors is carried out in ambient trucks and reefer vans. The average time period for which the apples are stocked in the cold storages are between 3-6 months. The second channel for apples after harvest is the pack house. The pack house is a building with other facilities where fruits are packed prior to transportation or distribution to shops. Pack houses help in preparing fruits for storage, transportation and distribution while maintaining the quality and value. The apple packing house is a combination of building and other facilities such as machinery, equipment, personnel, and procedures which assist converting harvested fruits into acceptable market-ready packages. This process involves cleaning, waxing, grading, sizing and final packing. Washing, color sorting, grading, and packing line account for 5 to 10 MT per hour capacity. The fruit is brought by farmers after harvesting and is sorted into 3-4 grades, of which the best quality i.e., Grade A is selected for CA storage and other grades are sold in the fresh market. Although CA stores in the regions are typically designed for apples, 30.4% stores reported to have stored other commodities during off-season in order to earn additional revenues. The CA store owners reported that they are facing the problem of irregular electricity supply (in some months, the power cut is more than 6-7 hours) and therefore, are forced to install diesel generators for power-backup which increases the operational costs. The power consumption of CA stores is relatively higher than the normal cold stores. The packaging of apples is done in wooden boxes and corrugated fibre boxes (CFB).

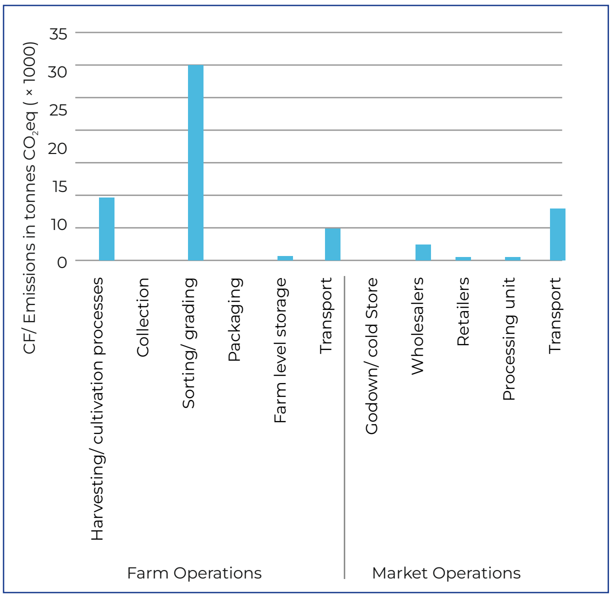
The GHG emissions (tonnes CO_2eq) resulting from the loss of apples during sorting/ grading processes were found to be the highest followed by the harvesting stage. The emissions in tonnes CO_2eq of the apples lost in different

Table 6: GHG emissions associated with losses of apples in India

Farm Operations				
Stage name	**Stage wise apples (in tonnes)**	**Losses as per NABCONS % (in tonnes)**	**Stage wise carbon footprint GWP in kg CO_2eq/ tonne**	**Carbon footprint/ GWP in tonne CO_2eq of the lost apples**
Harvesting/ cultivation processes	22,76,000	80,798	125	10,072
Collection	21,95,202	219	380	83
Sorting/ grading	21,94,983	79,239	380	30,130
Packaging	21,15,744	423	380	161
Farm level storage	21,15,320	1,058	380	402
Transport	21,14,263	13,108	386	5,065
Total quantity of Apples available for Market Ops	21,01,154			
Total CO_2eq (in tonnes) of apples lost in Farm Ops	45,914			
Market Operations				
Godown/ cold store	3,78,628	38	612	23
Wholesalers	8,83,535	3,446	612	2,109
Retailers	4,66,666	793	612	486
Processing unit	3,72,535	596	612	365
Transport	13,50,202	12,287	612	752
Total CO_2eq (in tonnes) of apples lost in Market Ops	10,502			
Overall CO_2eq (in tonnes) of lost apples	**56,416**			

stages of Market Operations are comparatively less than the stages of Farm Operations. As mentioned above, the cold storages/ pack houses have erratic electricity supply and depend upon diesel generator sets for operations. The emissions from use of DG sets are not reflected in Figure 4. Though the electricity supplied to these cold storages may have a higher carbon footprint otherwise. The emissions associated with the transport of these commodities are based on the distances of local and national markets. It doesn't cover the export of these commodities which might also have a significant carbon footprint.

Figure 4: Carbon footprint/emissions in tonnes CO_2eq of apples lost in Farm and Market Operations



ORANGE

The total losses of oranges in India across the value chain are 7.71%. Figure 5 depicts that **the highest losses are in the sorting/ grading stage of Farm Operations.** It is because this operation is one of the most important operations after harvesting and is being done manually on the field. During this operation, washing and sorting of fruits is done and the fruits unfit for consumption are removed. Fruit discarded during the operation accounted for losses. Since the oranges at this stage are screened properly for injuries and other defects, the losses reported are high. The oranges checked after this stage only go to the packaging, storage and transportation channels. Also at this point, a coating of edible wax is provided to the citrus fruits after washing to avoid further losses. **The major causes of losses observed during harvesting were improper and rough handling, hand pressing, harvesting of immature and over mature fruits, and improper collecting material by labourers** resulting in physical damage, bruising and cracking in fruits. Since the oranges are harvested manually without proper care and

Figure 5: Loss of oranges in tonnes from Farm & Market Operations

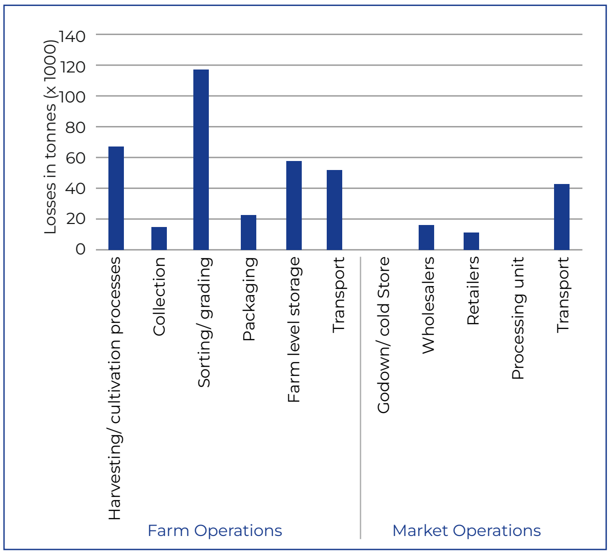


Table 7: GHG emissions associated with loss of oranges in India

Farm Operations				
Stage name	**Stage wise oranges in tonnes**	**Losses in tonnes as per NABCONS %**	**Stage wise carbon footprint - GWP in kg CO_2eq/tonne**	**Carbon footprint/GWP in tonne CO_2eq of lost oranges**
Harvesting/cultivation	62,19,400	69,657	250	17,414
Collection	61,49,743	14,144	400	5,658
Sorting/grading	61,35,598	1,17,803	400	47,121
Packaging	60,17,795	21,062	400	8,425
Farm level storage	59,96,732	58,768	400	23,507
Transport	59,37,965	55,223	400	22,089
Total quantity of oranges available for Market Ops	58,82,741			
Total CO_2eq (in tonnes) of oranges lost in Farm Ops	1,24,215			

Market Operations				
Godown/ cold store	50,0033	200	560	112
Wholesalers	26,43,116	15,330	560	8,585
Retailers	19,00,714	11,974	560	6,707
Processing unit	83,8879	168	560	94
Transport	45,43,829	41,349	560	23,155
Total CO_2eq (in tonnes) of oranges lost in Market Ops	38,652			
Overall CO_2eq (in tonnes) of oranges lost	**1,62,867**			

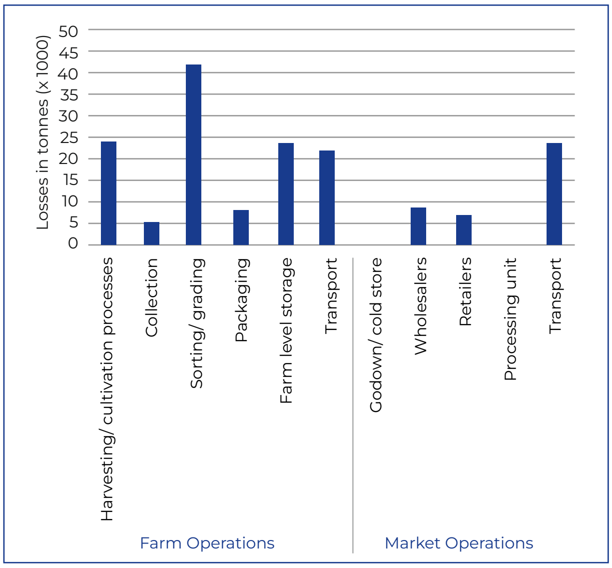
safety measures, the losses are more. In the collection stage, collection of oranges was done manually by farmers in plastic trays or jute bags or plastic katta bags or bamboo baskets. The collection of oranges is done either by using baskets and carrying them on head or by directly loading in the vehicles present between the trees. Kinnow in Punjab are collected by using a plastic sheet in the field while oranges in Madhya Pradesh were collected using crates. The causes of losses included either improper handling or unavoidable weather conditions during the operation.

The citrus fruits are majorly packed in crates and plastic perforated sacs. It is also observed that many farmers were not packaging citrus fruit and were transporting it in loose form from the field. Overfilling of fruits in boxes/ overloading during transport were the major reasons for pressing/ abrasion of fruits leading to bruising and spoilage. Rough handling such as throwing of fruits in crates by the packers and mishandling during stacking led to damage to the fruits during packaging. The farm level storage of oranges shows a loss of around 0.98%. This loss can be avoided with proper measures as this is the storage of fruits at the field for a few hours before transportation to the respective destination. Another study conducted in 2021, indicated that in orange growing states, only 6% of the total surveyed farmers owned on-farm storage infrastructure like sheds while 94% of the farmers do not have any on-farm storage for storage and sorting grading activities, which means very large number of growers undertake these operations in open conditions. Such farmers, if given storage facilities near to their farms can aid in reducing the post-harvest losses. The transport operations in farms involve transporting the oranges to different market channels. Transportation of fruits was done by various types of fleet such as tempo trucks, tractors and trolleys, Tata ACE trucks etc. to

various destinations such as markets in the same district and different districts/ states. Losses were observed during the transportation owing to physical damage due to stacking, vibration/ impact/ bruising during the journey and subsequent rotting of the oranges. As mentioned above, there is a significant transportation of oranges from farms in loose form, it is also increasing the losses at this stage. At the market level, losses were mainly observed due to injury of fruit during loading and unloading, pressing/ abrasion of fruits during transportation, and over-ripening (physiological loss). The operations are done manually at the wholesalers and retailers level. The losses during handling, marketing, and storage are observed at the wholesaler and levels of retailers. The transportation of oranges in Market Operations consist of distributing the fruit in various cities across India and also to the export sites. Here in this transportation of market channels, physical damage due to improper stacking, impact during the journey and subsequent rotting of the fruit were the major causes observed. Of late, fruits are transported in reefer vans, especially by organized players. It is also important to mention that 63% of the wholesalers and traders do not use cold stores for storing oranges & kinnows. Most of them resell it in short durations. It was found that 87% of the kinnow/ mandarin/ orange sales are in local markets as compared to the 18% sales in distant markets.

The GHG emissions associated with the sorting/ grading stage were found to be the highest followed by farm level storage (Figure 6). In Market Operations, the wholesalers, retailers and transport have significant emissions.

Figure 6: Carbon footprint/emissions in tonnes CO_2eq of oranges lost in Farm and Market Operations



The highest emissions are from the transport in market channels, which is corresponding to the fact that the oranges are transported to far-off places in the country. The cold stores/ godowns have no major losses (0.04%) therefore the emissions associated with those losses are also not major. As per MoFPI (2021), there are 18 cold storages in Punjab, 6 in Madhya Pradesh, 1 in Rajasthan and 19 in Maharashtra. Also there are 70 pack houses in Punjab and 30 pack houses in Rajasthan. Also the states of Madhya Pradesh and Maharashtra have 1 and 6 pack houses respectively. These units operating in above states might have high carbon footprint and GHG emissions otherwise depending upon the source of energy mix supply. In the present study, they are not being reflected as emissions related to losses have been focused. The oranges would also have emissions from export which are not considered here.

MILK

Figure 7 shows that **the losses in harvesting (0.25%) were the highest followed by transport (0.21%) stages of Farm Operations.** Harvesting/ milking is being done manually by the majority of the farmers. Some of the bigger farmers have portable milking machines in the sample surveyed. **The losses range from small spillages due to the milking activity, which included striping of milk outside the container (bucket), the milk falling due to mishandling while milking as well as spoilage of milk due to unclean udder or mastitic milk.** On some rare occasions, it was also observed that while milking, the cow kicked the bucket in which the milk was stored leading to losses to the farmers. Mostly, small-scale farmers have old buckets/ containers, which were distorted or broken, thus leading to more losses during milking. The harvesting/ milking losses in tonnes is around 5,59,361. It is the highest amount of loss if compared both in Farm Operations as well as Market Operations. After milking/ harvesting, milk was collected in large steel/ aluminum cans either for delivery to the neighboring areas or for transport to the cooperative units. Losses in such cases were mainly due to spillage of the milk while transferring it to the cans. Due to the short shelf life of milk, it was transported on the same day. **The transport stage of Farm Operations has losses of 4,68,314 tonnes (second highest after harvesting/ milking).** Some farmers transported their own produce while in other cases, the processor/ aggregator/ cooperatives collected milk from their farms. Milk was transported by farmers on bikes in steel cans. The milk was lost due to mishandling of milk, which led to spillage. A certain quantity of milk was also wasted due to leakages.

In Market Operations, retailers have 0.05% losses, processing units have 0.17% losses and transport of Market Operations have 0.12% losses. At retailer level, post-harvest losses during handling, marketing and storage were observed. Post-harvest losses during the storage and marketing for milk were caused by spillage during loading/ unloading or improper packaging. At the retailer's level, packaged milk was spoiled and loose milk collected from various small farmers/ dairies got curdled due to improper storage/ higher temperature. The figure 7 shows that processing units' losses of milk amounts to 2,50,709 tonnes (highest in Market Operations). At this level, the storage carried out in the processing units was captured. The post-harvest losses observed were mostly attributed to mishandling and spillages/ leakages. Transportation of milk in Market Operations is mainly done in tempos, trucks, insulated containers and tankers. In most cases, the milk is being transported to nearby areas. The duration of the journey ranged from a few minutes (45-50 minutes) to a few hours (8-10 hours). The far off distances are covered by insulated tankers and containers. Very small losses due to spillage while loading/ unloading or leakage in the milk container were observed.

Figure 7: Loss of milk in tonnes in Farm and Market Operations

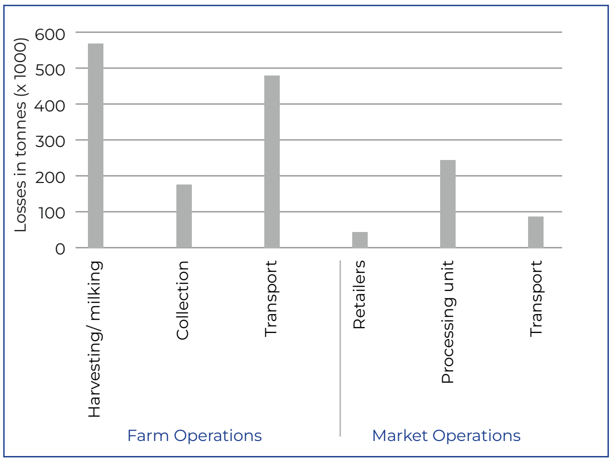


Table 8: GHG emissions associated with loss of milk in India

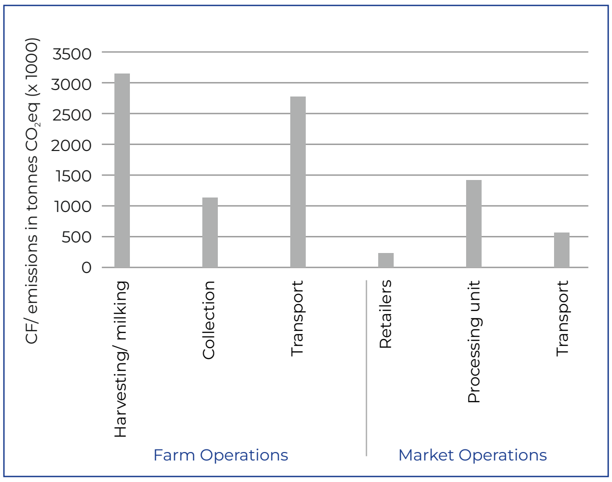
Farm Operations				
Stage name	**Stage wise milk in tonnes**	**Losses in tonnes as per NABCONS %**	**Stage wise carbon footprint - GWP in kg CO_2eq/tonne**	**Carbon footprint/GWP in tonne CO_2eq of lost milk**
Harvesting/ milking processes	22,37,44,565	5,59,361	5,684	31,79,410
Collection	22,31,85,204	1,78,548	5,800	10,35,579
Sorting/grading	NA	NA	NA	NA
Packaging	NA	NA	NA	NA
Farm level storage	NA	NA	NA	NA
Transport	22,30,06,655	4,68,314	5,800	27,16,221
Total quantity of milk available for Market Ops	22,35,38,341			

Market Operations				
Godown/cold store	NA	NA	NA	NA
Wholesalers	NA	NA	NA	NA
Retailers	7,50,39,929	37,520	5,800	2,17,616
Processing unit	14,74,76,159	2,50,709	5,800	14,54,115
Transport	7,50,39,929	90,048	5,800	5,22,278
Total CO_2eq (in tonnes) of milk lost in Market Ops	21,94,009			
Overall CO_2eq (in tonnes) of milk lost	**91,25,219**			

Figure 8 depicts the emissions associated with the losses of milk in the milk value chain in India. The emissions of Farm Operations are corresponding to the losses shown in Figure 7. **The highest emissions are reported from the milking stage.** Here also the emission factor of the milking stage is added up to the subsequent post-harvest stages. Thus the resulting emissions from stages such as transport of farm level operations, processing units, and collection are also significant.

It is important to mention here that the emission factor of milk is very high because it includes emissions from enteric fermentation and manure management (N_2O and CH_4). Therefore, due to emissions of gases such as methane (CH_4), having higher global warming potential, the resultant

Figure 8: Carbon footprint/emissions in tonnes CO_2eq of milk lost in Farm and Market Operations



emission factor is also high. The methane emissions are due to the digestive processes of ruminants such as cows. Transportation of milk is a significant GHG emitter after the harvesting/ milking stage as the large volumes of milk are transported and distributed to local as well as distant sites.

GHG emission hot spots in the apple, orange and milk value chain and mitigation strategies

The emissions associated with the various stages of the commodities studied are given in descending order as follows:

Apple	Orange	Milk
Sorting/grading	Sorting/grading	Harvesting/milking
Harvesting/cultivation	Farm level storage	Transport (Farm Operations)
Transport (Market Operations)	Transport (Market Operations)	Processing unit
Transport (Farm Operations)	Transport (Farm Operations)	Collection
Wholesalers	Harvesting/cultivation	Transport (Market Operations)
Retailers	Wholesalers	Retailers
Farm level storage	Packaging	
Processing unit	Retailers	
Packaging	Collection	
Collection	Godown/cold store	
Godown/cold store	Processing unit	

A sustainable and resilient food system can only be achieved when issue-specific mitigation strategies are formulated. The challenges in the supply chain can be due to inefficiencies such as inadequate infrastructure, logistical challenges, limited technology adoption, lack of technical skills, and restricted market access. Mitigating the GHG emissions from the value chain of the studied commodities in India involves a coherent set of strategies. These mitigation strategies in view of the above identified hot spots are discussed as follows:

Farm level: In the present study, sorting/ grading is the largest emission hot spot for apples and oranges. These can be averted by the use of automated grading machines. The government can support the introduction of technology in farms. Training and capacity building programs can be conducted for better use of advanced technology. Industry should come forward to support the government by supplying and acclimatizing the farmers with new generation farm level interventions. Farmers should be ready to adopt the change and consumers should be made well aware of the updated range of products available in the market.

Transport level: The supply of raw commodities to the closest market is an essential part of a robust value chain. In the case of raw milk, transport is the second major emission hot spot after milking/ harvesting. This means that transport related emissions are of high significance for the dairy sector. To target the reduction of these emissions, cold chain infrastructure needs to be strengthened and a fleet with lower emissions needs to be targeted. The private players can be made partners via PPP projects. The consumers will be benefitted when the markets are close by and healthier options will be made available at fair prices.

Storage level: Farm level storage is the second highest emission hot spot for oranges. Emissions from loss of food at farm level can be mitigated via storage facilities. In addition to this, processing facilities near the farm can also be a strategy to mitigate the losses and thereby associated emissions. The government can aid in providing the necessary infrastructure for the same. Private players may be encouraged to venture in with the support of government departments and agencies. Seasonal items such as oranges are consumed within specific months of the year. With better scientific storage and processing, shelf life can be increased. **Processed and packaged products give more options to the consumers at large.**

Packaging and processing level: In these operations, use of renewable energy, optimizing energy use, and choosing biodegradable or recyclable packaging materials go a long way. However, from the perspective of this study, the emissions associated with the losses can be reduced when stakeholders such as government and private industry work in tandem. The government can ease the setting up of processing units at the required locations. The smoothening of regulatory processes when it comes to inviting the private players is a major step. **New packaging and processing sites in the value chain of apples, oranges and milk will create a bigger market for Indian processed products** in India as well as abroad.

Institutional level: The timely introduction of technology at each stage of the value chain with appropriate equipment and know-how to implement, has to be kept in priority. The government can sensitize the market players about the urgency of taking businesses into less polluting ways. The international organizations like FAO, UNEP, WRI etc. have been very vocal and supportive about FLW related work across the globe with special focus on the developing countries. They fund projects in resource deficient countries so that they can streamline their supply chain and meet their SDGs while mitigating the emissions and reducing the FLW.

5. Limitations of the study

There are certain limitations of this study which are discussed as follows:

- This study is based on secondary research. The production data and the loss data used here is taken from official websites/ reports of GoI. The latest data on food loss is from the NABCONS (2022) report. There is no updated data after that.
- The present study has focused on the value chain of the raw items i.e. apple, orange and milk. The processed and packaged products made from these commodities have not been discussed in this report.
- The findings of the existing studies are fragmented. There is a huge research gap wherein the challenges come from having no uniform system boundaries, absence of country specific emission factors and other relevant information with respect to the supply chain stages.
- There are no specific studies of estimating the carbon footprint of apples and oranges in the Indian scenario. Therefore, the emission factors of studies carried in other regions for apples and oranges were taken.
- The emissions associated with the transport sector of these commodities are based on the distances of local and national markets. However, the export of these commodities might also have a significant carbon footprint/ emissions which needs to be accounted for.

6. Recommendations and the way forward

The FLW topic is under-researched. The studies done are insufficiently examined; the data and results are not comparable. **There is a big gap between the policy initiatives and the on-ground interventions** which makes food loss and waste an upcoming point of discussion. It is essential for all stakeholders to enable the existing system of operations in the value chain to be more advanced and conducive for achieving the economic and environmental goals. The study done in the present context had focused on fresh commodities. Though the findings of the work are oriented towards a larger picture of supporting the entire value chain of the selected commodities. It was found during the research work that losses are high in the supply chain because there is no robust system in place which can avert or divert the losses into opportunities for the processing sector. If and when the processing facilities are aligned with the growers and traders, there can be a variety of options for the consumers. The processing operations give the leverage of high quality products to the market. The higher income countries have strengthened their processing sector which reflects in their statistics. They have lower levels of undernourishment cases and their farmers are more prosperous because of the increased income generated via tie ups with the processing units. Thus, with this brief background, this report provides the key recommendations discussed as follows:

Formalization of supply chains

FLW and its associated emissions can be minimized by formalization of supply chains. The supply chains in developed countries are more organized as compared to the developing countries. The evidence to this is reported in the structural differences in FLW streams and food value chains between higher income countries and lower middle-income countries. **The formalized supply chains can reduce post-harvest losses and can optimize agricultural productivity and potentially increase the incomes of small-scale food producers and associated value-chain actors.**

Clear guidelines and standardized methods of operations in the supply chain lead to less amount of losses. There can be interventions at the meso, micro and macro level for the supply chain formalization. The stages of the supply chain can be individually targeted for minimum

losses. For example - at storage and processing stages, there can be technological interventions such as better equipment, or for harvesting, there can be proper training and better collaboration among various actors of the supply chain. The direction of a macro level intervention in the formalization of the supply chain has to come from the government authorities. Though the solutions to fill the deficiency in the supply chain of food products have to be gathered from the consensus of all stakeholders. The producers, transporters and processors have to be given a sustainable platform. The proper channels in the supply chain enhance the efficiency as well as make it a profitable ecosystem for the people involved. For example, in India, there are success stories of cooperatives such as Amul, Nandini and Verka. Once the supply chain is formalized and established, it is better for the milkmen and other participants. The adoption of processing methods and integrating them in the value chain of milk can empower the communities sustaining on the small amount of earnings. Similarly, the supply chains for other ranges of products such as apple juice, orange juice, fruit jams and jelly etc. can be created. The more organized the supply chain, the higher are the prospects of minimizing the losses and thus the resultant net emissions.

Key market trends and insights

The concept of mindful consumption is gaining momentum. To continue with the above example of milk, it has been reported in the 2024 study of Global Dairy Platform (GDP) that higher income countries have higher levels of milk yield and low price per liter as compared to lower income countries where yield levels are low but the price per liter is higher. This calls for a transformation in the dairy sector of developing and low income countries. Discussions around the sustainable transformation, however, largely focus on its links with two global public goods: the environment, greenhouse gas emissions in particular, and human health.

According to the present study, **the GHG emissions of the milk value chain are much higher than the fruits value chain.** This scenario indicates that the milk value chain must be standardized. As the largest producer of milk, India should be a trendsetter among developing countries and should focus on strengthening its dairy sector. The GDP report also gives the information that 70 percent of the population in South Asia is living on dairy farms and 90 percent of that population is informal. This means there has been a wide neglect of dairy farms in the region. The present study has highlighted that reducing losses in the value chain and channel-izing food items to a more organized processing sector will benefit the national economy.

Promotion of agribusiness industrial development

It has not been emphasized less that development of agribusinesses is vital for the economy. The flourishing of agribusiness will create opportunities for all the sections of society, the most important one is touching the grassroots level people. The organizations at international level are also advancing their efforts to meet the development of this sector in particular. As per the latest industrial brief 2025 by UNIDO (United Nations Industrial Development Organization), **the value of food processing in some developed countries even surpasses that of primary production** due to the extensive scale of downstream processing and value-addition activities. For instance, in Norway, food processing contributes around 50 per cent more to GDP than primary food production. In contrast, in developing countries, the processed food to primary food production ratio is approximately 0.3 percent, reflecting low levels of industrialization in the food sector and the associated limited capacities of food processing.

The food processing sector is supposed to ease the burden on marginal farmers of emerging economies like India. Thus, **the transformation of existing informal agricultural and food processing facilities into formal agribusinesses should be encouraged.** This can be addressed by providing incentives and support for business development through one-stop shop, cluster development and professionalization programs. The steps taken for the development of the Indian food processing industry will have larger implications including removing the gender biases by empowering the women who are the major stakeholders in farming and economy as a whole. The availability of better quality processed food items can save women time in the kitchen and get them involved in more paid work. The ready to eat items can also be stored for longer durations after processing and thus enhances the reach up to far off places which otherwise would be lost due to perishability of raw items. The cold chain and infrastructure development in the agri-businesses can reduce food losses. There is a scope of empowering the farmers through training programs. The tech-advancements and latest scientific tips can be communicated to the growers in an easy way. That shall increase the possibility of effectively managing the issue of FLW. **The creation of a developed food processing system in India will also support the goal of zero hunger, fight the undernourishment and food security issues.**

Building a network of institutions, companies and government bodies for guiding research and drafting the methodology for future course of actions

Despite the limitations, the present study has highlighted the importance of considering FLW and its associated emissions on an immediate basis. The scale and magnitude of the issue can be carefully examined and thus opens up the ways to handle it scientifically. As a key member of various international bodies, India has to report on its SDGs and climate actions. Therefore, a network of institutions, government agencies and corporate organizations can do the needful. There has to be a joint effort from all stakeholders to prepare the structure of future actions. More research and analysis is required to give specific insights. The targeted approach to reduce the FLW and its associated emissions requires fostering multi-actor partnerships and developing strategies to manage it. Putting the agenda of FLW and its associated emissions on priority, promoting partnerships and collaboration to manage FLW, raising awareness about the FLW and its associated emissions, supporting policy environment for sustainable food systems and formalized supply chains can help in designing the roles of the partners involved in the network.

To conclude, **there are high GHG emissions associated with the losses in the supply of raw apples, oranges and milk.** In order to curtail them, it is advised that **a transparent value chain along with creation of a flourishing processing sector must be developed.** The raw fruits and milk are getting lost, so better to promote agri-business development to minimize the losses and the resultant emissions. Better working processing units and advanced agri-businesses provide more benefits and thus be allowed to thrive in Indian markets too.

Appendices

GHG emissions in the value chain of apple, orange and milk across globe as reported in literature:

Appendix 1: Apple

S.No.	Location	Methodology	Supply chain stages covered	Emission factor in kg CO_2eq/ FU	Reference
1	Belgium	LCA	Harvest, sorting, storage, transportation, retailer	3810 kg CO_2eq per tonne	Goossens, Y., Berrens, P., Custers, K., Van Hemelryck, S., Kellens, K., & Geeraerd, A. (2019). How origin, packaging and seasonality determine the environmental impact of apples, magnified by food waste and losses. The International Journal of Life Cycle Assessment, 24, 667-687.
2	Belgium	LCA	Harvest	154 kg CO_2eq per tonne	Annaert, B., Goossens, Y., Geeraerd, A., Mathijs, E., & Vranken, L. (2017). Calculating environmental cost indicators of apple farm practices indicates large differences between growers. International Journal of Agricultural Sustainability, 15(5), 527-538.
3	Canada	LCA	Harvest, transportation	276 to 283 kg CO_2eq per tonne	Keyes, S., Tyedmers, P., & Beazley, K. (2015). Evaluating the environmental impacts of conventional and organic apple production in Nova Scotia, Canada, through life cycle assessment. Journal of cleaner production, 104, 40-51.
4	Canada	LCA	Harvest	160 kg CO_2eq per tonne	Bamber, N., Jones, M., Nelson, L., Hannam, K., Nichol, C., & Pelletier, N. (2020). Life cycle assessment of mulch use on Okanagan apple orchards: Part 1 - Attributional [Article]. Journal of Cleaner Production, 267, Article 121960.
5	Chile	LCA	Harvest, transportation, storage, packaging, wholesalers, retailers	540 kg CO_2eq per tonne	Iriarte, A., Yáñez, P., Villalobos, P., Huenchuleo, C., & Rebolledo-Leiva, R. (2021). Carbon footprint of southern hemisphere fruit exported to Europe: The case of Chilean apple to the UK. Journal of Cleaner Production, 293, 126118.
6	China	LCA	Harvest, transportation	6903.8 to 3554.4 kg CO_2eq ha− 1 yr− 1	Han, J., Jin, X., Huang, S., Zhu, X., Liu, J., Chen, J., ... & Feng, H. (2023). Carbon and nitrogen footprints of apple orchards in China's Loess Plateau under different fertilization regimes. Journal of Cleaner Production, 413, 137546.
7	China	LCA	Harvest	2210.18 to 2770.95 kg CO_2eq per tonne	Cheng, J., Wang, Q., Li, D., & Yu, J. (2022). Comparative analysis of environmental and economic performance of agricultural cooperatives and smallholder farmers for apple production in China. Agriculture, 12(8), 1281.
8	China	LCA	Harvest	9127 to 10 446 kg CO_2eq ha− 1 yr− 1	Liu, D., Xu, J., Li, X., & Zhang, F. (2024). Green production of apples delivers environmental and economic benefits in China. Plant Communications, 5(11).
9	China	LCA	Harvest	719.18 kg CO_2eq per tonne	Hong, J., Zhang, T., Shen, X., Zhai, Y., Bai, Y., & Hong, J. (2022). Water, energy, and carbon integrated footprint analysis from the environmental-economic perspective for apple production in China. Journal of Cleaner Production, 368, 133184.

S.No.	Location	Methodology	Supply chain stages covered	Emission factor in kg CO_2eq/ FU	Reference
10	China	LCA	Harvest, storage, transportation	913 kg CO_2eq per tonne	Zhu, Z. L., Jia, Z. H., Peng, L., Chen, Q., He, L., Jiang, Y. M., & Ge, S. F. (2018). Life cycle assessment of conventional and organic apple production systems in China. Journal of Cleaner Production, 201, 156-168.
11	Greece	LCA	Harvest, sorting, storage in warehouses, transportation	89 kg CO_2eq per tonne	Bartzas, G., Vamvuka, D., & Komnitsas, K. (2017). Comparative life cycle assessment of pistachio, almond and apple production. Information processing in agriculture, 4(3), 188-198.
12	Greece (Agena island for pistachio Agia island for almonds and apples)	LCA	Harvest, sorting, storage in warehouses, transportation	89 kg CO_2eq per tonne	Bartzas, G., Vamvuka, D., & Komnitsas, K. (2017). Comparative life cycle assessment of pistachio, almond and apple production. Information processing in agriculture, 4(3), 188-198.
13	Iran	LCA	Harvest	3.39 kg CO_2eq per kg canned	Hessampour, R., Bastani, A., Hassani, M., Failla, S., Vaverková, M. D., & Halog, A. (2023). Joint life cycle assessment and data envelopment analysis for the benchmarking of energy, exergy, environmental effects, and water footprint in the canned apple supply chain. Energy, 278, Article 127795.
14	Iran	LCA	Harvest, storage, transportation	3008.53 kg CO_2eq per kg canned	Naderi, S., Raini, M. G. N., & Taki, M. (2020). Measuring the energy and environmental indices for apple (production and storage) by life cycle assessment (case study: Semirom county, Isfahan, Iran). Environmental and sustainability indicators, 6, 100034.
15	Italy	LCA	Harvest, storage, packaging, transportation	165 kg Co_2eq per tonne	Boschiero, M., Zanotelli, D., Ciarapica, F. E., Fadanelli, L., & Tagliavini, M. (2019). Greenhouse gas emissions and energy consumption during the post-harvest life of apples as affected by storage type, packaging and transport. Journal of cleaner production, 220, 45-56.
16	Italy	LCA	Harvest, storage, transportation	612 kg CO_2eq per tonne	Longo, S., Mistretta, M., Guarino, F., & Cellura, M. (2017). Life Cycle Assessment of organic and conventional apple supply chains in the North of Italy. Journal of Cleaner Production, 140, 654-663.
17	Korea	LCA	Harvest	111 kg CO_2eq per tonne	Kim, I., Song, C. Y., & Jeon, E. C. (2020). Comparison of Product Sustainability of Conventional and Low-Carbon Apples in Korea. Sustainability, 12(22), 9364.
18	Spain	LCA	Harvest, transportation	195.3 to 206.7 kg CO_2eq per tonne	Vinyes, E., Asin, L., Alegre, S., Gasol, C. M., & Muñoz, P. (2018). Carbon footprint and profitability of two apple cultivation training systems: Central axis and Fruiting wall. Scientia Horticulturae, 229, 233-239.
19	Washington DC (U.S.)	LCA	Harvest, packaging, storage, transportation, retailer	8100 to 8970 kg CO_2eq per tonne	Magdalena, M. B., Adriana, R. H., Patricia, G. L., & Alejandro, P. R. (2024). Environmental impact of conventional vs. organic apples: A life cycle assessment of Washington state's exports to Mexico City. Cleaner and Circular Bioeconomy, 7, 100076.

Appendix 2: Orange

S.No.	Location	Methodology	Supply chain stages covered	Emission factor in kg CO_2eq/ FU	Reference
1	China	LCA	Harvest	140 kg CO_2eq per tonne	Yan, M., Cheng, K., Yue, Q., Yan, Y., Rees, R. M., & Pan, G. (2016). Farm and product carbon footprints of China's fruit production—life cycle inventory of representative orchards of five major fruits. Environmental Science and Pollution Research, 23, 4681-4691.
2	Greece	LCA	Harvest	130 kg CO_2eq per tonne	Mazis, A., Litskas, V. D., Platis, D. P., Menexes, G. C., Anagnostopoulos, C. D., Tsaboula, A. D., Mamolos, A. P., & Kalburtji, K. L. (2021). Could energy equilibrium and greenhouse gas emissions in agroecosystems play a key role in crop replacement? A case study in orange and kiwi orchards. Environmental Science and Pollution Research, 28(23), 29421-29431.
3	Italy	LCA	Harvest	257 kg CO_2eq per tonne	Giudice, A., Mbohwa, C., Clasandonte, M. T., & Ingrao, C. (2013). Environmental assessment of the citrus fruit production in Sicily using LCA. Italian Journal of Food Science, 25(2), 202-212.
4	USA	LCA	Harvest, transportation	560 kg CO_2eq per tonne	Bell, E. M., & Horvath, A. (2020). Modeling the carbon footprint of fresh produce: Effects of transportation, localness, and seasonality on US orange markets. Environmental Research Letters, 15(3), 034040.

Appendix 3: Milk

S.No.	Location	Methodology	Supply chain stages covered	Emission factor in kg CO_2eq/ FU	Reference
1	Anand district (Gujarat, India)	LCA	Milk harvest	1.7 kg CO_2eq/ kg FPCM	Garg, M. R., Phondba, B. T., Sherasia, P. L., & Makkar, H. P. (2016). Carbon footprint of milk production under smallholder dairying in Anand district of Western India: a cradle-to-farm gate life cycle assessment. Animal Production Science, 56(3), 423-436.
2	Ethiopia	LCA	Milk harvest	2.2 kg CO_2eq/ kg to 3.2 kg CO_2eq/ kg without economic allocation, & 2.0 kg CO_2eq/ kg to 2.8 kg CO_2eq/ kg with economic allocation.	Balcha, E., Menghistu, H. T., Zenebe, A., & Hadush, B. (2022). Carbon footprint of cows' milk: a case study of peri-urban and urban dairy farms within Mekelle milk-shed, Ethiopia. Carbon Management, 13(1), 55-68.
3	India	Supply chain	Milk harvest	5.9 kg CO_2eq kg−1 dry wt.	Pathak, H., Jain, N., Bhatia, A., Patel, J., & Aggarwal, P. K. (2010). Carbon footprints of Indian food items. Agriculture, ecosystems & environment, 139(1-2), 66-73.
4	India	LCA	Milk harvest	3.54 kg CO_2eq/L to 4.53 kg CO_2eq/ L milk	Pordhiy, K. I. (2023). Comparative carbon footprints of buffalo milk produced at smallholder and organised farms in Hisar district of Haryana, India. The Indian Journal of Animal Sciences, 93(04), 389-394.
5	India	Supply chain	Milk harvest	2.4 kg CO_2eq/ kg	Vetter, S. H., Sapkota, T. B., Hillier, J., Stirling, C. M., Macdiarmid, J. I., Aleksandrowicz, L., ... & Smith, P. (2017). Greenhouse gas emissions from agricultural food production to supply Indian diets: Implications for climate change mitigation. Agriculture, ecosystems & environment, 237, 234-241.
6	India	LCA	Milk harvest, transportation	5.8 kg CO_2eq/ kg FPCM	Garg et.al. 2018 Carbon Footprint of Milk in India: Past Trends and Future Prospects. Indian Dairyman.

Citations

Executive summary

[1]Taglioni, C., Rosero Moncayo, J. & Fabi, C. 2023. Food loss estimation: SDG 12.3.1a data and modelling approach. FAO Statistics Working Paper Series, No. 23-39. Rome, FAO

[2]United Nations Environment Programme (2024). Food Waste Index Report 2024. Nairobi

[3]WWF-UK (2021) Driven to waste: The Global Impact of Food Loss and Waste on Farms. Woking

[4]FAO (2013). Food wastage Footprint: impacts on natural resources, summary report. Rome: Food and Agriculture Organization

[5]Spang, E. S., Moreno, L. C., Pace, S. A., Achmon, Y., Donis-Gonzalez, I., Gosliner, W. A., Jablonski-Sheffield, M. P., Momin, M. A., Quested, T. E., Winans, K. S., & Tomich, T. P. (2019). Food Loss and Waste: measurement, drivers, and solutions. Annual Review of Environment and Resources, 44(1), 117–156. https://doi.org/10.1146/annurev-environ-101718-033228

[6]Agarwal, M., Agarwal, S., Ahmad, S., Singh, R., & Jayahari, K. M. (2021). Food loss and waste in India: The knowns and the unknowns. World Resources Institute, 10, 1-36

Main Report

[1] https://www.un.org/development/desa/pd/world-population-prospects-2024

[2] Berners-Lee, M., Kennelly, C., Watson, R., & Hewitt, C. N. (2018). Current global food production is sufficient to meet human nutritional needs in 2050 provided there is radical societal adaptation. Elem Sci Anth, 6, 52

[3] https://www.wfpusa.org/hunger/issues/

[4] FAO (2022). Bennett, A, Dubey, S., Lee, W.T.K., Damen, B. and Bucatariu, C. 2022. FAO Regional Strategy on Food Loss and Waste Reduction in Asia and the Pacific. Bangkok, FAO

[5] Loss, F. F. (2018). Waste and the right to adequate food: Making the connection. FAO: Rome, Italy, 1

[6] https://www.unep.org/resources/publication/food-waste-index-report-2024

[7] Food and Agriculture Organization of the United Nations (2022). Tracking Progress on Food and Agriculture-related SDG Indicators 2022. Rome

[8] https://www.unep.org/resources/publication/food-waste-index-report-2024

[9] https://www.unep.org/resources/publication/food-waste-index-report-2024

[10] FAO (2022). Bennett, A, Dubey, S., Lee, W.T.K., Damen, B. and Bucatariu, C. 2022. FAO Regional Strategy on Food Loss and Waste Reduction in Asia and the Pacific. Bangkok, FAO

[11] Kashyap, D. and Agarwal, T. (2020). Food loss in India: water footprint, land footprint and GHG emissions. Environment, Development and Sustainability 22(4) 2905-2918

[12] WWF-UK (2021) Driven to waste: The Global Impact of Food Loss and Waste on Farms. Woking

[13] FAO (2013). Food wastage Footprint: impacts on natural resources, summary report. Rome: Food and Agriculture Organization

[14] Zhu, J., Luo, Z., Sun, T., Li, W., Zhou, W., Wang, X., ... & Yin, K. (2023). Cradle-to-grave emissions from food loss and waste represent half of total greenhouse gas emissions from food systems. Nature Food, 4(3), 247-256

[15] WWF-UK (2021) Driven to waste: The Global Impact of Food Loss and Waste on Farms. Woking

[16] WWF-UK (2021) Driven to waste: The Global Impact of Food Loss and Waste on Farms. Woking

[17] https://www.fao.org/food-systems/news/news-detail/Leadership-Dialogue-on-Food-loss-and-waste-prevention-and-reduction-a-key-lever-for-agrifood-systems-transformation-/en

[18] Global, F. A. O. (2022). Regional and Country Trends, 2000–2020

[19] Porter, S. D., Reay, D. S., Higgins, P., & Bomberg, E. (2016). A half-century of production-phase greenhouse gas emissions from food loss and waste in the global food supply chain. Science of the Total Environment, 571, 721–729

[20] Porter, S. D., Reay, D. S., Higgins, P., & Bomberg, E. (2016). A half-century of production-phase greenhouse gas emissions from food loss and waste in the global food supply chain. Science of the Total Environment, 571, 721–729

[21] Guo, X., Broeze, J., Groot, J. J., Axmann, H., & Vollebregt, M. (2020). A worldwide hot spot analysis on food loss and waste, associated greenhouse gas emissions, and protein losses. Sustainability, 12(18), 7488

[22] Cheng, J., Wang, Q., Li, D., &; Yu, J. (2022). Comparative analysis of environmental and economic performance of agricultural cooperatives and smallholder farmers for apple production in China. Agriculture, 12(8), 1281

[23] Hiç, C., Pradhan, P., Rybski, D., &; Kropp, J. P. (2016). Food surplus and its climate burdens. Environmental Science and Technology, 50(8), 4269–4277

[24] Government of India. (2025). Economic Survey 2024–25. Ministry of Finance

[25] Ranjan, J., &; Sahni, R. (2023). Post-harvest losses of fruits and vegetables in India. Ropan, 41-43.

[26] NABCONS (2022). Study to determine post-harvest losses of agri produces in India

[27] https://www.pib.gov.in/PressReleaseIframePage.aspx?PRID=1897084

[28] National Dairy Development Board (NDDB). State-wise estimates of Milk Production ('000 tonnes) https://www.nddb.coop/sites/default/files/statistics/milk_production_by_states_2025.pdf

[29] National Horticulture Board (NHB), Ministry of Agriculture and Department of Animal Husbandry

[30] National Horticulture Board (NHB), Ministry of Agriculture and Department of Animal Husbandry

[31] Horticultural Statistics at A Glance (2021). Ministry of Agriculture and Farmers Welfare. GoI

[32] National Dairy Development Board (NDDB). State-wise estimates of Milk Production ('000 tonnes)

[33] NABCONS (2022). Study to determine post-harvest losses of agri produces in India

[34] Longo, S., Mistretta, M., Guarino, F., & Cellura, M. (2017). Life Cycle Assessment of organic and conventional apple supply chains in the North of Italy. Journal of Cleaner Production, 140, 654-663

[35] Bell, E. M., &; Horvath, A. (2020). Modelling the carbon footprint of fresh produce: Effects of transportation, localness, and seasonality on US orange markets. Environmental Research Letters, 15(3), 034040

[36] Carbon Footprint of Milk in India: Past Trends and Future Prospects (2018). Indian Dairyman

[37] Kashyap, D. and Agarwal, T. (2020). Food loss in India: water footprint, land footprint and GHG emissions. Environment, Development and Sustainability 22(4) 2905-2918

[38] NABCONS (2022). Study to determine post-harvest losses of agri produces in India

[39] Longo, S., Mistretta, M., Guarino, F., &; Cellura, M. (2017). Life Cycle Assessment of organic and conventional apple supply chains in the North of Italy. Journal of Cleaner Production, 140, 654-663

[40] Bell, E. M., & Horvath, A. (2020). Modelling the carbon footprint of fresh produce: Effects of transportation, localness, and seasonality on US orange markets. Environmental Research Letters, 15(3), 034040

[41] Carbon Footprint of Milk in India: Past Trends and Future Prospects (2018). Indian Dairyman

[42] NABCONS (2022). Study to determine post-harvest losses of agri produces in India

[43] MoFPI (2021). Development of potential value chain (Apple). Study of gaps in infrastructure & processing facilities in identified clusters

[44] MoFPI (2021). Development of potential value chain (Apple). Study of gaps in infrastructure & processing facilities in identified clusters

[45] NABCONS (2022). Study to determine post-harvest losses of agri produces in India

[46] NABCONS (2022). Study to determine post-harvest losses of agri produces in India

[47] MoFPI (2021). Development of potential value chain (Kinnow/ Mandarin). Study of gaps in infrastructure & processing facilities in identified clusters

[48] MoFPI (2021). Development of potential value chain (Kinnow/ Mandarin). Study of gaps in infrastructure & processing facilities in identified clusters

[49] MoFPI (2021). Development of potential value chain (Kinnow/ Mandarin). Study of gaps in infrastructure & processing facilities in identified clusters

[50] Negi, S., Fan, L. S., Kim, H., Hidaka, T., Rani, A., & Pan, S. Y. (2025). Unlocking the potential of global greenhouse gas mitigation by reducing food loss and waste. Journal of Agriculture and Food Research, 101925

[51] https://openknowledge.fao.org/handle/20.500.14283/ cb7380en

[52] GASL. 2024. Dairy and Socio-economic Development –What evidence does the data hold? GASL. Rome https://www.livestockdialogue.org/fileadmin/templates/res_livestock/docs/2024_Impact_Report_no_crops.pdf

[53] Lipinski, B, Hanson, C., Lomax, J., Kitinoja, L., Waite, R., & Searchinger, T. (2016). Toward a sustainable food system Reducing food loss and waste. World Resource Institute, June, 1–40. Trienekens, J. H. (2011). Agricultural value chains in developing countries a framework for analysis. International Food and Agribusiness Management Review, 14(2), 51–82

[54] Stathers, T., Holcroft, D., Kitinoja, L., Mvumi, B. M., English, A., Omotilewa, O., Kocher, M., Ault, J., & Torero, M. (2020). A scoping review of interventions for crop postharvest loss reduction in subSaharan Africa and South Asia. Nature Sustainability, 3(10), 821–835

[55] GASL. 2024. Dairy and Socio-economic Development –What evidence does the data hold? GASL. Rome https://www.livestockdialogue.org/fileadmin/templates/res_livestock/docs/2024_Impact_Report_no_crops.pdf

[56] GASL. 2024. Dairy and Socio-economic Development –What evidence does the data hold? GASL. Rome https://www.livestockdialogue.org/fileadmin/templates/res_livestock/docs/2024_Impact_Report_no_crops.pdf

[57] Hartwich, F., Ruhe, A., &; Tezera, D. Agroindustry's role in achieving zero hunger: What strategic actions can developing countries take?

[58] Agarwal, M., Agarwal, S., Ahmad, S., Singh, R., & Jayahari, K. M. (2021). Food loss and waste in India: The knowns and the unknowns. World Resources Institute, 10, 1-36

Contact

NIFTEM Campus
Plot No. 97, Sector 56
HSIIDC Industrial Estate, Kundli
District Sonepat - 131028 (Haryana), India
Telephone: +91 130 2281000, +91 130 2219759-64

Tetra Pak India
Plot No. B-53, MIDC Chakan, Phase-II
Village Vasuli, Taluka Khed
District Pune - 410501 (Maharashtra), India
Telephone: +91 2135 678101
Fax: +91 2135 661801