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Leveraging Block Chain, Artificial Intelligence, and Machine Learning to Mitigate Food Loss and Waste: Impact on the Circular Economy in India

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ABSTRACT

Given the extent of poverty levels, unemployment and dependence on Agriculture, India must reduce its Food Losses. This can effectively be addressed using blockchain technology and advanced AI. All post-harvest losses would be minimised and positively impact the food supply chain and, thus, the circular flow of the economy.

Key Words: Food Loss and Food Waste, blockchain, AI, Sustainable Development Goals, Post-Harvest losses, Poor Infrastructure, Food security, natural resources, environment, logistics and Infrastructure.

Research Question: The paper will analyse the importance of Food Loss and Food waste (FLW) on the extent of Income generated from the agricultural sector. How important is the plugging of FLW impact the circular economy of a developing economy like India? Would it help address poverty, low income and unemployment issues? How far will the adoption of new technology like AI, ML and BlockChain help in achieving these goals? These and other questions will be addressed in the course of the paper.

1. Introduction

Food losses and food waste (FLW) have become an imperative issue in recent times. So much so that the United Nations has stated FLW in its Sustainable Development Goals Target (12.3). There is a paucity of data concerning this field. It is important to understand the difference between Food Loss and Food Waste. It is generally considered that Food Loss occurs in developing nations, while food waste occurs in developed nations, but in fact, they exist in both sets of economies, except that Food losses are at a very high percentage in developing economies, while food waste is at a high level for developed economies.

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FLW occur along the whole food supply chain. One of the reasons that it has become important is that it poses a serious global concern towards food security, natural resources, environment, and human health and is considered a key obstacle to sustainable development.

According to the Food and Agriculture Organisation (FAO) of the United Nations, about one-third of food production was lost or wasted worldwide that was *meant for human consumption.* This translates into:

4.4 gigatonnes of CO_2 equivalent (FAO, 2015)

250 km^3 of blue water footprint (FAO, 2013)

28% of the total agricultural land globally during agricultural production

Economic cost of about USD 750 billion (equivalent to the Gross Domestic Product of Turkey (FAO, 2013).

Tracing the trend amongst developed nations, it has been analysed that in the United States, for example, FLW increased by about 50% between 1979 and 2003(Hall et al., 2009).

Research that has been carried out in developing nations has focused on food waste at the retailing and consumption stages. Other studies have concentrated on post-harvest losses that mainly exist in developing countries like India.

In understanding the major problem at hand, it is important to analyse the existing data on FLW, which is necessary to track the progress towards achieving the SDG goals that have been spelt out by the United Nations. To achieve these goals, relevant policy measures must be undertaken by all governments of the world. This would contribute to raising awareness, informing mitigation strategies, as well as giving priority to preventing and reducing FLW. Comparisons between countries can help in finding the right mix of policies that could help reduce FLW, further helping in analysing the social, economic and environmental impacts of FLW.

2. Definition

There is a larger percentage of Food Loss that occurs in developing nations, while a greater amount of Food Waste occurs in developed nations, thus impacting the different policy measures that would have to be adopted in the two sets of countries.

According to FAO (2019), “Food loss and waste is defined as the decrease in quantity or quality of food along the food supply chain”.

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Figure 1: Virtual description of FLW

Source: onethird.io

These are essentially divided into two;

- Quantitative (Food that exits the food supply chain)
- Qualitative (Decrease in food attributes that reduces food value in terms of intended value)

Food losses occur along the food supply chain from harvest/ or slaughter up until it's retail, but not including retail. "Food loss represents the amount of food postharvest that is available for human consumption but is not consumed for any reason. It includes cooking loss and natural shrinkage (for example, moisture loss); loss from mould, pests, or inadequate climate control; and food waste."

2.1 Food Loss

Food loss is the decrease in edible food mass throughout the part of the supply chain that reduces food for human consumption. This includes the production, postharvest and processing stages. This food loss is likely to occur due to;

- Loss from mould, pests, or inadequate climate control

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- Cooking loss and natural shrinkage(e.g. moisture loss)

Food loss occurs mainly in the post-harvest and processing stage (Gustavsson J et al., Global Food Losses and Food Waste, 2011). This is caused;

- by poor practices,
- technical and technological limitations,
- labour
- financial restrictions
- Lack of proper infrastructure for transportation and storage.

It is extremely important to reduce food losses in terms of nutritional security, serious environmental impact, economic, poverty and natural resource impact as it decreases dissipated investment in the agricultural sector, leading to severe inefficiencies in the input sector such as land, labour, water, fertilisers and energy.

FAO has defined FL as “decrease in weight (dry matter) or quality (nutritional value) of food that was originally produced for human consumption”. Most of these losses have likely occurred along the food supply chain due to poor logistics and infrastructure, scarcity of technology, knowledge, skills, and management capacity of supply chain participants and lack of market access.

Figure 2: Visual Representation of Food Loss

Source: dreamstime.com

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2.2. Food Waste

Food waste is a specific part of food loss. The US Department of Agriculture's (USDA) Economic Research Service (ERS) defines it as "food discarded by retailers due to colour or appearance and plate waste by consumers." This includes half-eaten meals left on the plate at a restaurant, food scraps from preparing a meal at home and also the sour milk that is poured into a drain. Food waste can also be defined as 'food that is suitable for human consumption but has been wasted'. This does not only relate to the non-utilisation of edibles but also includes inappropriate waste of energy, water, and land resources (Tsang et al.2019).

It can be experienced at various stages given below:

2.1.1. Food wasted at the retail level

Most of the loss in retail operations is in perishables that, include baked goods, produce, meat, seafood and prepared meals. The USDA has estimated that in 2010, supermarkets lost $15 billion annually in unsold fruit and vegetables alone. The reasons are;

- overstocked product displays,
- Expectation of cosmetic perfection of fruits
- Vegetables and other foods
- Oversized packages
- Schemes like 'availability of prepared food until closing'
- Expired "sell by" dates
- Damaged goods
- Outdated seasonal items
- Purchasing of unpopular foods
- Understaffing

2.1.2. Food Waste in Restaurants and Institutions

Drivers of food waste at restaurants include oversized portions, inflexibility of chain store management and extensive menu choices.

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2.2. Food Waste in Households

In the US, an average person in 2010 wasted 21% of the food they buy. A large portion is in fresh fruits and vegetables, followed by dairy products. Major contributors to household food waste include;

- Food spoilage (due to improper storage, lack of visibility in refrigerators, partially used ingredients and misjudged food needs.
- Over-Preparing
- Date label confusion (Research has indicated that standardising food labelling and clarifying its meaning to the public would help in reducing household food waste.
- Overbuying: Sales of unusual products and promotions encourage impulse and bulk buying, leading to spoilage before they can be used.
- Poor Planning: making inaccurate estimates of the amount of ingredients that are required for cooking.

Figure 3: Image of Food waste

Source: USDA

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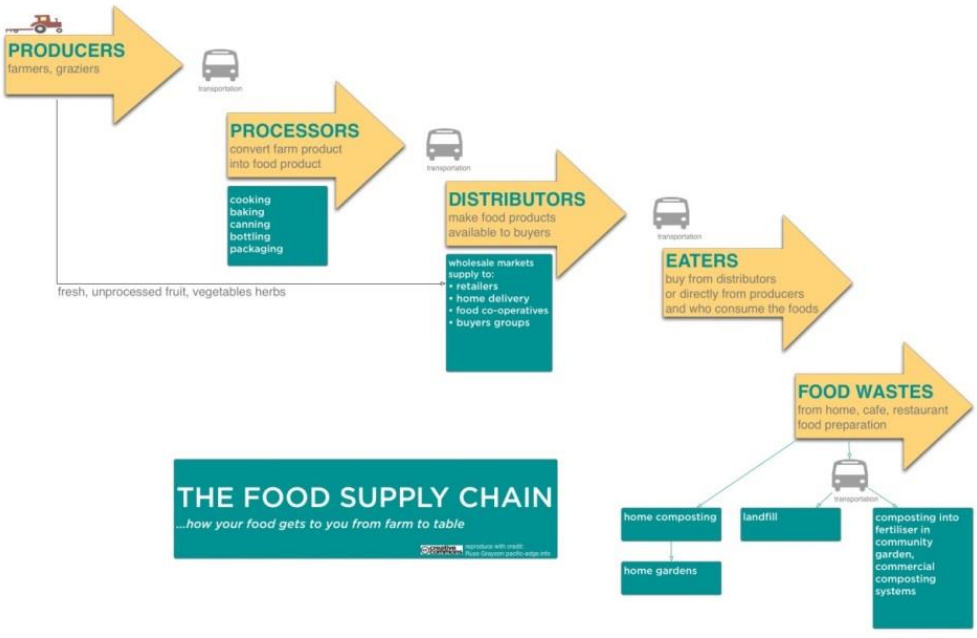
2.3. Food Supply Chain

This comprises food production, storage, delivery and retailing of food to reach customers by the due date. It is the process that all food products go through, from production to consumption. The key stages in this chain are:

- Production-
- Handling and storage
- Processing and Packaging
- Distribution
- Retailing
- Consumption

This chain is extremely important in ensuring food safety and traceability of products. This can be done both by the manufacturer and the consumer. It traces the steps right from its origin and how it was produced, helping to ensure minimum FLW.

Figure 6: Food Supply Chain



Source: pacific-edge info

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2.4. Latest Technologies in reduction of FLW

The latest set of technological developments in this sphere includes 'smart packaging', which changes colour as food goes rotten, and Blockchain and radio frequency identification tags that track information to identify potential sources of contamination along the food supply chain. Most of the technology that has been applied in this sector has been adopted primarily to reduce production costs and alleviate food security issues. FLW was rarely the main reason in recent years when FLW has become a part of UN sustainable goals. The need to increase food production by 50% by 2050 requires that these advanced techniques have to be adopted to reduce FLW. Increasing food production by digital technology would be futile if FLW is not parallelly addressed.

3. Extent of FLW in Developing Economies

In developing countries like India, managing food waste is a serious environmental and socio-economic issue.

Some of the reasons are attributed to increased urbanisation, modernisation and population growth. India, with a population of over 1.3 billion, produces organic waste of 0.5 kg of organic waste per individual per day (Paulraj et al. 2019). According to the United Nations Environment Program's (UNEP) Food Waste Index Report 2021(Chaudhary et al. 2021), the existence of food waste to the tune of 1.3 billion of the total agricultural land could occupy 28% of the total available land.

The sources of food waste fall into four main categories namely;

- Production of food and its harvesting
- Food processing
- Storage
- Domestic food waste
- Retail counters.

Crops are subjected to insect manifestation and harsh climatic conditions from the time they are planted, resulting in pre-harvest losses. Cultivators who use heavy machinery for crop harvesting generate food waste as, more often than not, they are unable to distinguish between ripe and immature crops. Heat, along with high humidity, creates perfect conditions for the breeding of pests, which is a common cause of food waste during storage (FAO 2012).

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Food waste can be divided into;

- Carbohydrates
- Proteins
- Lipids
- Inorganic substances

Food waste is made up of vegetables and rice, which are heavy in carbohydrates, whereas trash is made up of meat and eggs that are high in proteins and lipids

3.1 Comparison of the problems and loss at each phase of the Value Chain

Table 1: Representation of the impact of Harvesting on Indian Farmers

Harvest	Harvest	Unscientific harvesting leads to poor quality of produce. (Under ripe or overripe produce with low quality and low shelf life)	
	Post- harvest loss	Loss in transportation and storage	1. Post-harvest loss due to poor supply chain-distress selling. 2. Low quality of output 3.Loss in produce (in the case of fruits and vegetables) 4. Low-value product
	Access to market	Sell their produce to the local middlemen	
	Access to agriculture infrastructure	Limited facilities for storing and primary processing of their produce.	
	Access to credit	No access to credit to meet their post-harvest requirement. Often resulting in distress in selling.	
	Processing	No linkage with the processors for assured market.	

The above table indicates the extent of food losses that an Indian farmer may have to face due to the poverty levels that exist in the farming sector. It states the problems faced by the farmer at each level of harvest and post-harvest level. This is important as the Indian agricultural share in GDP has declined to less than 15% due to the high growth in the Industrial and services sector, but three-fourths of India's families still depend on rural incomes (2012). The majority of India's

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poor (about 70%) are found in rural areas. The economic survey (2022-23) stated that 65% of the population lives in rural areas, and 47% of the population is still dependent on agriculture for livelihood. To feed its burgeoning population, India's food security depends on the production of cereal crops, as well as increasing the production of fruits, vegetables and milk and reducing FLW to meet the demands of the population.

4. Reforms in the food sector: Emphasis on reduction of Food Loss.

Unequal patterns of food access and availability are contributing to non-communicable diseases in middle and high-income countries and, on the other hand, insufficient calorie intake in the world's poorest countries. While there is a consensus the world over to transform food systems, there is no unanimity on the policy pathways for achieving it. One of the reasons could be the inherent conditions in the countries are extremely different.

The viability of reforms requires consideration of the complexity of local, national and global conditions, as well as the political institutions in which food policy decisions take place.

In recent years, besides the farmers and other stakeholders in the agricultural sector, there are a range of non-traditional stakeholders that include insurance companies, banks, technology firms, as well as transnational civil society advocates.

In India, the aim of agricultural research is to address agricultural growth, poverty and food security. Amongst them are the objectives of adoption and impact of improved technologies with respect to:

- Identifying key factors associated with the adoption of vertical farming, hydroponics and precision farming in selected locations in India.
- Explore policy issues in promoting these technologies.
- Need for more investment in research and development for disruptive technology innovations, such as in irrigation systems and the cold chain, which has the possibility of accelerating sustainable food systems transformation.
- Use of Technology to mitigate FLW

Inadequate storage and transportation infrastructure contribute to post-harvest losses. According to a government-backed study, India lost 5-13%of its fruits and vegetables and 3-7% of other commodities like oil seeds and spices between harvesting and consumption in 2022. The cost of this would be approximately Rs 1, 52,000/ crores. The lack of cold storage facilities, proper packaging, and transportation systems leads to spoilage and deterioration of food quality.

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Inefficiencies in the supply chain, including poor inventory management, inadequate distribution networks and lack of coordination among stakeholders, lead to food loss and waste at various stages of the food system.

Table 2: Post-harvest loss (PHL) of various Agricultural commodities. (2015-2022)

Agricultural Commodities	% of food loss 2012	2015(%)-ICAR-CIPHET Study	NABCONS Study 2022(%)
Cereals	3.9-6.0%	4.65-5.99	3.89-5.92
Pulses	4.3-6.1%	6.39-8.41	5.65-6.74
Oilseeds	2.8-10.1%	3.08-9.96	2.87-7.51
Fruits	5.8-18.1%	6.70-15.88	6.02-15.05
Vegetables	6.9-13.0%	4.58-12.44	4.87-11.61

Source: own source

It is important to note that in comparison to global levels, India faces higher PHL in cereals, pulses, and oilseeds, indicating lower levels of farm mechanisation and poor infrastructure for storage and transportation. In the case of Fruit and Vegetables, what has been captured in the above table has been quantity loss and not quality loss. Addressing quality loss is equally crucial as damage and spillage of grain leads to price reduction as well as a decline in nutritional value.

Figure 6: Food loss in India

Source: ICRIER

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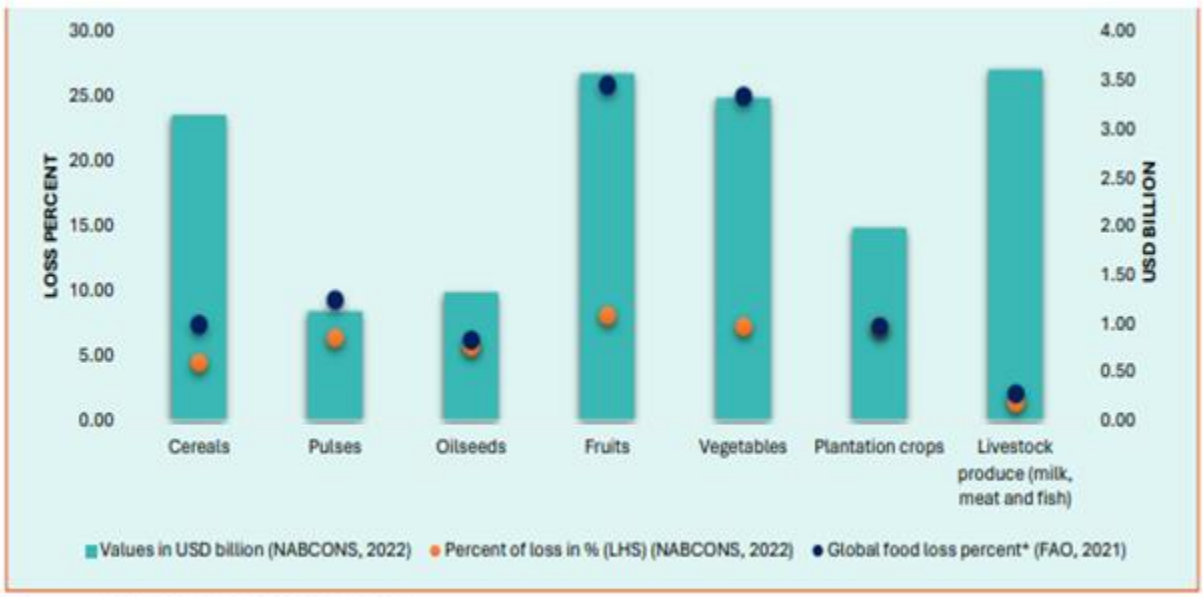
India suffers a food loss of about Rs. 1.53 lakh crores (USD 18.5 billion) every year as per the latest large-scale study conducted by NABCONs from 2020 to 2022 (NABCONS,2022). While at the farmer level, mechanisation and the use of proper storage techniques are crucial to reduce losses, it is imperative for the government to reduce losses in grain management at the centre and state levels as well during the process of procurement, storage, and distribution.(Ashok Gulati, Raya Das, Alex Winter-Nelson, ICRIER.)

Graph 1: Percentage of losses and economic cost



Source: NABCONS 2022, FAO, 2021

5. Measures for plugging Food Loss in India

According to the WRI (World Research Institute) analysis, the economy could experience 60% more food calories in 2050 than in 2006; 56% more than in 2010 are expected to be lost (if the current rate of food loss and waste were to remain as at the same level of 2006), the gap would grow to more than 900 kcal per person per day. In short, current global food availability is insufficient to feed the world in 2050. It is important to put in place a 'Balancing Act' (balancing the need for food with sustainability) by bridging the gap between food production and distribution and *decreasing both food loss and waste*. Both have to be addressed together. In India, the issue is that food is a major factor for developing nations both in terms of food security as well as income for the farmers (2/3rd of the population is dependent on the agricultural sector).

It is essential to increase the growth of this sector, which marginally declined to 3% in 2021-22, when it grew at 3.3% in 2020-21, by reducing food losses and increasing domestic production.

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Demand, both domestic and external, will increase the earnings for the population dependent on this sector.

Losses in India were Rs 926.51 billion in 2014(World Resource Institute, Working Paper). Any amount of food loss and waste is a wasted opportunity to increase food availability, improve income, ease pressure on land and water resources and reduce GHGs. India, over the years, has achieved great progress in export from the agricultural sector to the extent that it is ranked the following in the world;

- Rice; Punjab - 4th; UP – 2nd
- Wheat: 10th largest exporter of wheat in the World; UP is leading with MP, Punjab, Haryana, Rajasthan, Bihar
- Sugar – India is the second largest exporter after Brazil; UP, Bihar, Haryana, and Punjab in the North
- Cereals – Southern States: Andhra Pradesh, Karnataka and Tamil Nadu
- Meat (Buffalo) – India ranks 5th in the world; UP, Maharashtra, West Bengal, AP, Telangana, … Punjab and Bihar.
- India is the third largest citrus producer in the world, after China and Brazil.

India needs to take advantage of their export potential to improve the lives of the marginalised population. For this, FLW needs to be addressed.

6. Conclusion, Issues and the way forward.

The main issue in addressing FLW is that there are not adequate systems of measurement of food losses. The existing data on losses are not comparable due to differences in measurement metrics. Empirical research on food waste is very scarce. One of the factors that can control losses is to revamp the logistic infrastructure, as a large amount of exports as well as domestic supply from the agricultural sector consists of perishable items.

The loss parameter along the supply chain depends on infrastructure and technology. One of the areas that should be looked at closely is blockchain technology to minimise these losses.

Using Blockchain technology revolutionises interactions between businesses. It has the ability to completely revamp currently existing processes to unlock new sources of efficiency and value. A strong food supply chain is essential for addressing customer demand for high-quality foods. To boost consumer trust and buy willingness, the food chain must become more sustainable. Tracking and authenticating data across the whole food supply chain is crucial for identifying and treating contamination sources. A supply chain must have both primary and secondary

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information on the finished packaged food and its ingredients to be considered successful. Blockchain technology is the best way to meet these challenges.

The features that can be made accessible from this technique are to decrease the losses of perishable goods in the following manner;

- Traceability of the product, i.e. indicating the type of raw materials used, e.g. certain products that are exported to the Middle East categorically require a statement of the extent of pesticide that is used, and it must be within the 'halal limits' as notified by the Government.
- Blockchain technology enables tracking of every step of the agro supply chain from raw material supply to the last poi the last point of the product.
- It can be used to track components and products throughout their life cycle.
- Also used for inventory management and quality control
- Transparency
- Reduces mistrust and opaqueness of information among parties
- All parties have access to a seamless exchange of value
- Data Accuracy
- Decentralisation
- Intelligent farming
- Insurance for Agriculture

Blockchain is a means to an end and not an end in itself. Important for India, especially the agro-export sector, to grow as well as minimise the extent of loss during transportation. The Ease of doing business through a trusted medium would improve India's stature in 'enforcing contracts. Effectively tackling India's ranking in the 'corruption perception index', the economic potential of this technology is fairly feasible as well as it has a high impact factor. Losses of the product can be reported in real-time via IoT (internet of things), sensors, and real-time acknowledgements. No single entity controls the nodes or dictates the rules eventually; the blockchain completes solutions with complementary technologies such as AI, IoT, and decentralised self-sovereign identity (SSI) solutions, leading to controlled temperature while transporting the product, alerts concerning moisture or any spoilage that may occur so that the

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problems can be immediately addressed. IoT sensors monitor temperature, humidity and other environmental factors during the transportation and storage of sensitive perishable goods. They ensure the integrity of the cold chain, preserving the product's quality and safety.

The problem areas that may arise are the spread of the internet and globalisation, as it could be a potential target for cyber-attacks. It is possible that different IoT devices may not be compatible; the cost could increase, especially for small businesses. For all of the above, the most important infrastructure that has to be prevalent is an uninterrupted power supply.

Despite the above-stated disadvantages, the advantage of using advanced technology like Blockchain far overrides the problems. It is imperative that developing countries like India invest and encourage the adoption of such technology if they have to address major issues like poverty and unemployment.

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