

An Overview for Reducing Food Loss and Food Waste in Supply Chains

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Abstract

Creating systems designs by considering a balance between economic, environmental and social effects is significant in today's sustainability concern. Sustainability has become an emerging topic, growing concerns and attention for companies. Especially companies operating on a global scale aim to develop strategies for the sustainable supply chain management. When the supply chain is a food chain, that concern increases exponentially and sustainable management of the chain becomes a critical challenge requiring the development and implementation of innovative practices by all stages within value chains. According to the Food and Agriculture Organization (FAO), a significant food amount is wasted or lost in the journey from farm to fork. This waste affects the global economy, food availability, as well as the environment negatively. In this work, we, therefore, focus on addressing these aspects by searching how food waste or food loss could be reduced throughout a supply chain network. We provide solution ways for the food waste/loss reduction obtained from current works in literature.

1. Introduction

Food loss and waste (FLW) are complex issues, often due to multiple and interrelated reasons operating at different levels. In the food sector, there might be several serious issues to consider for its sustainable growth among others. This is because food product might be affected by so many factors such as climate changes, specific temperature requirements of products, limited availability of natural resources for food production, rapid consumer changes, variability in shelf-life attributes of products, food waste, etc. Those issues increase the importance of efficient management of the food supply chain network. If those critical factors cannot be managed correctly throughout the network, then the supply chain (SC) network may result in

increased cost, decreased responsiveness and decreased sustainability which is recent multi-objective trends in recent supply network management to optimize.

In that multi-objective perspective, food waste and loss management is involved as a critical management issue in the network, not only for cost minimization but also sustainability and responsiveness maximization objectives. FAO predicts that food waste or loss is in charge of one-third of all food produced in the world (FAO, 2021). Hence, all stakeholders should take a role in food waste reduction in the world.

FAO (FAO, 2021) determines food waste as “the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food service providers and consumers”. According to FAO (2021), the food waste is due to following reasons:

- Food products having undesired shapes, sizes and colours, are usually discarded in sorting processes.
- Food products that are close to, at or beyond the expiration date are mostly discarded in the SC.
- A large food quantity is discarded (e.g. even wholesome edible food) in eating environments.

Differently, definition of food loss is given by FAO (2021) as decrease of food quantity or quality in food supply chains, not including retailers, food service providers and consumers. According to that the food that is discarded, incinerated or disposed during the food supply chain (FSC) excluding the retail level, and that food which does not re-enter in any re-production such as feed or seed is counted to be food loss. Figure 1 shows the difference between those two, FLW, cases based on at what stages they occur.

By the FLW definitions, it can be concluded that decreased FLW would contribute to the efficient usage of land and the efficient management of water resources. That would also create a positive impact on climate change and livelihoods. Hence, research studies on the minimization of FLW throughout SC networks would be an emerging topic for a sustainable world.

As the reduction of FLW create a positive contribution to the environment, this action can also improve food security and nutrition, reduce greenhouse gas (GHG) emissions, lower usage of water and resources as well as improve productivity and economy. Thus, effective policies for

FLW reduction should be explored by focusing on how much and where foods are wasted or lost throughout FSCs.

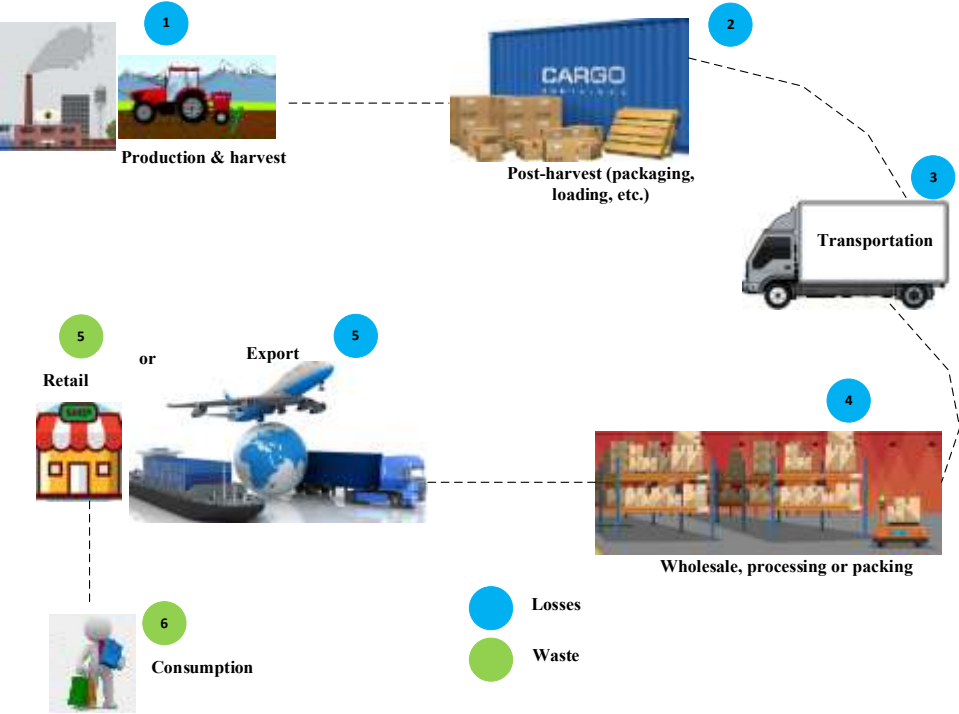


Figure 1: Stages where food loss and waste occur (re-drawn from FAO Learning Guide, 2019, <http://www.fao.org/3/ca5312en/CA5312EN.pdf>)

A work of FAOs result on the reduction of food waste and loss is presented by “Food Loss and Waste Database” (FAO database, 2021) for countries. Figure 2 shows FLW percentages by the value of domestic production during the year of 2000 and 2017 versus stages in the world. That graph is obtained from FAO’s web site which is collected on both food waste and food loss presented throughout the literature and surveys. That database includes data and information from several reports and works measuring FLW based on food products, the value chains, and geographical locations. Besides Figure 2 shows, FAO also provides data results based on countries, years as well as so many different options. Here, we select the year interval as 2000 and 2017 where 2017 is the closest year in the database having the food loss and waste data.

From Figure 2, we observe that the most losses take place in the export stage and the highest waste takes place at the consumer stage, etc. With today’s Industry 4.0 and IoT technological developments, having end-to-end connections for digital smart supply chains is possible, that could also be utilized for FSCs to reduce food waste and losses throughout the network. By digitalization and smart SCs concepts, businesses can balance their stocks while keeping their

cost and responsive efficiency targets. For instance, by the implementations of smart SC technologies, it could also be possible to predict bottlenecks in advance, prevent an excess amount of production, optimize product and inventory control, develop and design marketable products, track real-time data at any stages for adaptive control, etc. Thus, the connection of physical networks and implementations of smart technologies make food supply chains more sustainable, cost and responsive effective.

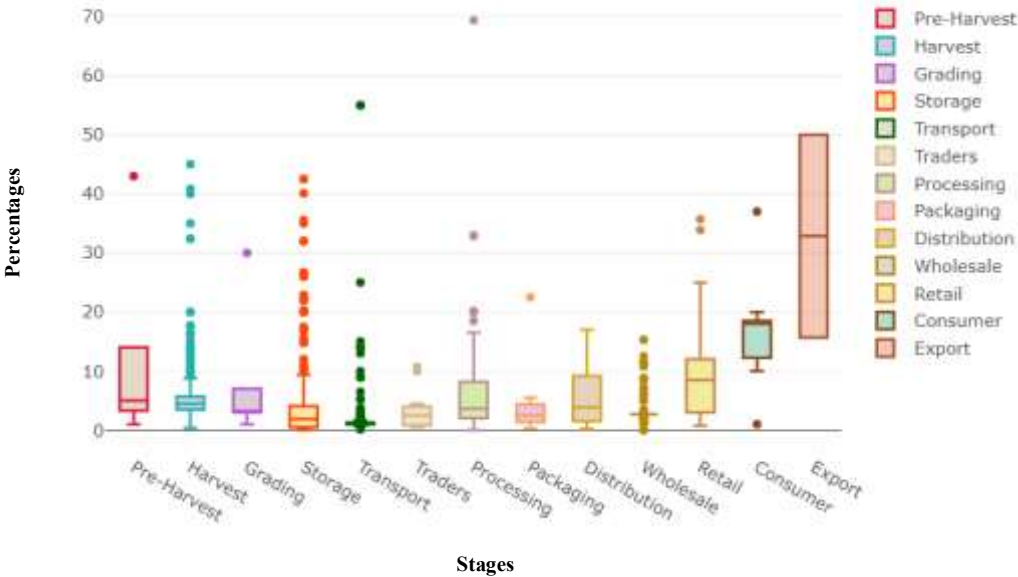


Figure 2: Boxplot showing of food loss and waste percentages happened in the years between 2000 and 2017 (source: Food and Agriculture Organization of the United Nations, <http://www.fao.org/platform-food-loss-waste/flw-data/en/>)

In this work, by focusing on Figure 2 stages and the help of today’s digital and smart SC technologies, we investigate how FLW could be reduced throughout a FSC.

The paper continues with the solution approaches for FLW reduction in FSC in Section 2. We mention the related works from literature while providing the solutions in each stage within that section. Last, we summarize our work by a conclusion part.

2. Reducing Food Waste and Loss

FLW occur at almost every stage of SC. However, consumer-facing businesses such as grocery stores, restaurants, etc., and in homes (see Figure 2) are the major food waste contributors. From this section, we refer to food waste as “any food that is grown and produced for human

consumption but ultimately is not eaten”. Hence, we consider food waste as any loss beginning from the upstream of supply chain, at farms, food manufacturing businesses, distribution, and marketing phases.

Food waste is a solvable problem. According to the ReFed’s Roadmap to 2030 and Insights Engine analysis (ReFed, 2021), there are seven key action areas to focus on in food waste reduction. These are: 1- Harvest optimization, 2- Enhancing distribution of product, 3- Refining management of product, 4- Maximization of utilization of product, 5- Reshaping environment of consumers, 6- Strengthening rescue of food, 7- Recycling remaining. ReFED’s those seven actions are developed mainly by considering these three solution steps: prevention, recovery, and recycling.

Prevention helps waste not to occur in the first place whereas recovery searches ways for aids of surplus food to reduce hunger. Recycling treats scraps as value-added products instead they go to landfill. The first five actions: 1- harvest optimization, 2- enhancing distribution of product, 3- refining management of product, 4- maximization of utilization of product, 5- reshaping environment of consumers, are developed as prevention solution approaches, while the sixth and seventh actions, strengthen food rescue and, recycle anything remaining, are considered under the recovery and recycling solutions, respectively. We detail each solution area provided in that roadmap, along with the suggested implementations searched during this work below.

2.1 Harvest Optimization

Optimizing harvest belongs to the very initial step of a supply chain. Optimizing the harvest means, optimizing the harvest of grown crops with a minimum difference from its overproduction. Namely, here the aim is to grow crops as required. However, if overproduction takes place, actions for selling and donating of those lefts would be one of the good options for improving that step. To minimize the overproduction in the harvesting step, recent information and technological developments such as data-sharing as well as real-time data and information tracking technologies could be utilized contributing to that target. However, to be able to implement those solution approaches correctly, it maybe also required to implement them across all SC actors.

According to Trimble (2021a), there are two main reasons for food waste in the harvesting step. These are: wrong harvest timing and harvest approaches. Several methods are suggested to be applied in conjunction with “precision farming” to diminish losses on harvest (Trimble 2021b). For instance, those are: 1-Data collection, 2- Analysis of data, 3- Decision making, 4- Managing operations.

According to FAO Toolkit (2013), harvest losses are mainly due to the harvest time, and harvesting approaches. Some practical suggestions are presented in that report. For instance, the usage of catching bags for high trees might prevent the falling of fruits on the ground and bruising. For some vegetables and fruits such as lettuce, cabbage, melons, bananas, etc. usage of some cutting tools might be beneficial. In addition, Rolle (2006) suggests harvesting while the crop and the climate are cool as well as the plant has the highest moisture content. This would help to prevent the quick spoilage of products for example due to insufficient infrastructure for transportation, storage, cooling and markets.

According to Nikkel et al. (2019), in Canada, food waste for instance for tomato on farm or greenhouse takes place due to aesthetic criteria, forecasts, prices, variety, temporary and seasonal workers related reasons. They suggest a couple of solution approaches in minimization of that waste as improved coordination between food rescue and donor, crop insurance, and the perception of liability.

According to ReFed (2021) waste prevention in harvest, the below opportunities are suggested:

- Alternative markets development including online channels to facilitate sales; finding markets for crop lefts, etc.
- Proposing new agreements with customers on whole crop purchasing and novel communication data tools improving communication.
- Diversifying farm labor sources for the possibility of labor shortages.
- In order to align harvest with customer demand adopting advanced technological agricultural tools also to track the regarding pattern changes in time.
- Apply and increase capabilities on the process to utilize from full harvest.

Of course, the world’s food waste problem doesn’t come from only farmers. Post-harvest and consumers are also huge sources of food waste (see Figures 1-2). However, as the population

of world is estimated to be more than 2 billion by 2050, stages in FSC should be optimised to utilize all the food produced. Thus, this will require each link in the food supply network to work in harmony in the most effective way, where we start with the harvesting stage at the beginning of that issue. The following post-harvest stage is the distribution stage where we discuss on it, in the following section.

2.2 Enhancing Distribution of Product

Product distribution is the process of transporting food products from one place to another within the supply chain. It includes the transportation of products to where it is processed and/or ultimately sold and consumed. It becomes complicated especially when the food product is a time-sensitive product, it is having strict quality standards, and requiring specific temperature requirements. Food waste in distribution activities are relatively low within all activities (see Figure 2), however still improvements can be realized.

Here, by enhancing product distribution, it is aimed to implement smart applications to maximize the freshness and selling time of products by the utilization of technological solutions such as intelligent routing and sensors, real-time tracking, big data analytics, etc. (ReFed, 2021). Those technologies would provide advantages in cold chain management by contributing to the remaining shelf life of products positively and shortening the transit times throughout the chain. Namely, by the utilization of those recent technological developments, freshness and quality of food products can be increased benefiting both suppliers and buyers.

According to Nikkel et al. (2019), in the distribution process, food waste occurs due to incorrect temperature storage of products, handling and transportation, delayed shipments, late delivery of products from their best before or expiry dates, etc. Thus, this might lead to products being rejected or spoiled. Except for those, human-related errors and equipment malfunctions may also cause food waste during distribution. For instance, meat and dairy products are time and temperature-sensitive, special attention and implementations could be applied for those products preventing spoil.

While improving the transportation process, its negative effect on the environment should also be considered. Namely, this step should be carefully designed so that the trade-off between transportation and energy/environmental impacts should be balanced. For instance, while frequent and small deliveries might contribute to the freshness of food products positively, those

might affect the carbon footprint negatively. Under a trade-off case, Wakeland et al. (2012) suggest consolidation of operations in the supply chain and use of sustainable alternatives to improve transport efficiency such as railway and water transit.

ReFed (2021) provides the below key solutions for enhancing product distribution:

- To maximize the shelf life of products for the end-users, the application of dynamic decision models considering transportation of foods based on distances and freshness would be beneficial.
- To track the real-time information from traffic, optimize the pickup and delivery times as well as the whole food transportation process, utilization of recent technological and information developments are suggested to be applied.
- To increase the accessibility with a decreased cost and resource effect, the development of shared economies across the sector especially for cold storage and transportation is recommended to implement.

Except for the distribution of food products stage, the product management step, where processing, packing, etc. kind of operations take place, should also be designed carefully in waste minimization. We discuss that step in Section 2.3.

2.3 Refining Management of Product

Inefficient or non-optimized product management may lead to food waste throughout SC. 20% of unsold food product at the retail level is estimated to be because of handling errors (ReFed, 2021). Here, refining product management refers to aligning purchases with sales (ReFed, 2021). One of the quick solutions to that, when surplus takes place, evaluating those products by secondary outlets plan should be ready.

Nikkel et al. (2019) report why and where food waste occurs during processing and manufacturing as:

- **Grading:** It is the sorting of food products based on several attributes such as their shapes, appearance, and size, etc. If the product does not meet the required specifications, and if there is no secondary outlet exists to sell then, all those unmet specifications products become waste.
- **Inaccurate forecasts:** A large lost sale cost or a fear of being backorder may result in over production and excess amount of inventories in supply chains. If demand is less

than what is estimated, it would result in excess stock. If demand is higher than what forecasted, then it can be penalized for unmet orders.

- **Process inefficiencies:** Inefficient supply chain management, incorrect packing processes, and order changes may cause food waste. For instance, products may fall onto the floor during processing due to incorrect machine operations; sudden order changes may cause products to be discarded, etc.

The aim of refining product management is to develop solutions such that the system results with less over-purchasing. According to FAO Toolkit (2013), improving communication throughout the supply chain would contribute to reducing food waste. Since different food supply chain actors are dependent on each other and one's action and practice may influence the other's decisions, uninterrupted communication of those actors is significant. With today's Industry 4.0 technological developments, end-to-end connection in SCs is possible which also helps tracking real-time information from the SC. By that, SC efficiency could be greatly improved.

ReFed (2021) suggests the below solution applications:

- Optimal on-site handling systems and processes development.
- Smart and dynamic inventory management (e.g. dynamic pricing by AI methods).
- Methods estimating future demand changes so that future product orders would not cause excess supply and waste.
- Diversifying product outlets in case of excess products occurrence.
- Diversifying alternative marketing channels for last-minute products sales.

Even if the production process is optimized, it is inevitable to have byproducts and surplus products through the supply chain. Hence, maximization of product utilization is another significant suggestion towards waste minimization in the supply chain. We discuss that, in Section 2.4.

2.4 Maximization of Utilization of Product

Maximizing product utilization means designing facilities, operations, and menus such that each product is utilized at its highest level. In this concept, during food processes, byproducts and surplus products obtained are intended to be turned into food products. By innovation and investment, this step can be thought of as an upcycling process for getting rid of "waste".

The Upcycled Food Association (UFA) aiming to reduce food waste defining upcycled foods as ones using ingredients that would not be utilized by human, also having a positive impact on the environment. For instance, Philabundance, Treasure8, and Toast Ale are some of the upcycling companies repurposing for instance excess milk or "ugly" vegetables as nutritious cheeses and chips. Solutions in this action area focus on (ReFed, 2021):

- using everything and parts regarding the products,
- minimizing waste on a production line,
- extending product life,

Some of those above issues can be implemented by basic staff training. However, other solutions might be the development of new processing equipment.

Maximizing product utilization also searches for novel ways for packaging. Packaging works to reduce food waste should take into account the extension of shelflife of food products as well as the creation of environmentally friendly packaging. Namely, novel packaging should focus on both its environmental impact including recyclability and biodegradability as well as food wastage reducibility.

With the help of smart packaging applications, it is possible to trace the current status of the food within the package. The sensor technologies can be placed within or outside of the package to monitor quality changes and safety-related information about the food product (Sohail et al., 2018). Hence, by using the correct materials and packaging technologies, high product quality and freshness can be realized until the products are commercialized and consumed (Brown, 1992; Stewart et al., 2002).

According to EU Commision (2011), well-designed food packaging can promote sensible consumers behaviours towards food consumption. Smaller package sizes and split packages are recommended as solution options. It can lead to improved consumer's product keeping attitude. There are other solutions that could also contribute on increase of shelf life of products such as the use of vacuum and shrink wrap or resealable packs.

A suggested for a solution this action is (ReFed, 2021):

- Applying smart packaging technologies so that the product shelf life of products increases and spoilage of products decreases.

One of the prevention approaches for food waste occurrence focuses on reshaping the consumer environment where the largest waste occurs. We provide the “reshape consumer environment” prevention approach in Section 2.5.

2.5 Reshaping Environment of Consumers

The largest total food wastage amount occurs at the consumer level (FAO Toolkit, 2013). The potential reasons are explained to be: urbanization, lack of awareness from food production (e.g., costs for time, worker and environment), retail implementations, encouraging excess buying (e.g. free offers) etc. also assuring impression on consumers that food waste is not expensive and has few consequences.

According to the Netherlands Nutrition Centre (2014), the reasons why food is wasted in households are categorized by preparation, storage, buying and others. In the preparation, it is declared that people do not know the right amount to cook. They do follow their instincts or they cook the whole pack (e.g. when cooking rice, pasta, etc.). Hence a huge amount is thrown away. In storage, it is thought that since people forget what they have in stock and being away from home, it results in products passing the best-before date or spoiling. In buying, people usually buy more than they require. Attracting consumers on environmental considerations related with food wastage awareness can be one of the solutions for this issue. EU Commission (2011) provides possible tips for consumers to reduce food waste for households as:

1. ***Planning the shop***: According to that, planning of meals for a week is significant. Consumers can prepare a shopping list for just the extras they require. While shopping, it is helpful to take the list with them and stick to it, in reducing food waste.
2. ***Checking the product dates***: When consumers do not plan to eat food products within a short ‘use by’ dates, then it might be helpful to have longer ‘use by’ date ones or to buy them on the time they need. Hence, awareness of meaning of date labels is significant. For instance, ‘use by’ means that the food can be consumed until the indicated day; ‘best before’ means that the food can be consumed the date up until if it retains its expected quality. For example, products can still be safe even after the indicated ‘best before’ day.
3. ***Considering the budget***: It should be kept in mind that food waste indicates money waste.

4. ***Keep the fridge healthy***: Checking the temperature and the seal of the utilized refrigerator are significant. For instance, most food products require to be kept between 1 and 5 degrees for long freshness.
5. ***Rotation***: When a new food product is purchased, bringing the older dated ones in front of the new ones would help earlier consumption of them. Hence, placing the new food products at the back side is significant in reducing the risk of waste.
6. ***Using leftovers***: Leftovers can be utilized to make new meals for the following day. For instance, fruits turning bad can be used for making smoothies and fruit pies or soups.
7. Serving small size of food dishes would help in minimizing food waste. Awareness can be increased on that people can come back and get more food again, once they finish their plate.
8. Storing food based on the instructions provided on packages are significant.
9. ***Freezing***: Freezing the appropriate foods (e.g., bread) in freezer, when a small amount is eaten might be helpful in minimizing waste.
10. ***Turning food into garden***: When some food waste is unavoidable, setting up a compost bucket for those (e.g. fruits and vegetables) would be beneficial. After a few months, those waste would turn to be rich and valuable compost for plants.

Solving the food waste problem in households is not an easy task. In recent years, great effort has been put into raising awareness and knowledge for consumers. Further behaviour change interventions on consumers are required to reduce food waste in the future. Internet-based solutions and smart shopping list apps with AI abilities, etc. might be proper approaches for future applications to diminish food waste. Besides, technological innovations like colour changing stickers based on temperature or chips on packages tracking the expiry date, etc. could also be other possible solutions.

In the following sub-section, we provide a recovery solution approach for the food waste minimization problem that is the “strengthen food rescue” (ReFed, 2021).

2.6 Strengthening Rescue of Food

Food rescue is the practice of gathering rescuable food and redirecting it for human consumption. Over the years this has emerged as a way by the food industry to tackle food waste. By strengthening food rescue high-quality and nutritious food throughout the supply chain can be saved. This could be done by increasing the capacity of food relief agencies in terms of storage, transportation, and staffing, overcoming distribution bottlenecks, and improving communication flow from food business donations. Those can also be realized by business education or coordination and matching technologies that help food donation easier (ReFed, 2021). In realizing that, real- or near-time data sharing can also play a key role especially for more food donation and identifying gaps through the chain.

The growth of food redistribution over the last decade is significant. There are many organizations across the globe that are engaged in redistribution of food (Food Banking, 2019). However, it is challenging to recover and redistribute food, due to legal and operational inquiries. According to FAO (2019), to recover and redistribute food products, development of suitable policies and legislation providing food safety including those concepts are significant:

- ***Food requires to be safe.*** Distributed food should be healthy for any consumers.
- ***Food requires to provide minimum quality needs.*** Administrations may consider some flexibilities for this issue.

Policies have significant roles in liability protections. It is important to make clear the food safety guidance, and improve tax incentives. Any of them can support the suggested solutions significantly.

Some suggestions for this action are provided by ReFed (2021):

- Utilize real and near-time data-sharing technologies conveying information on product types, amounts, status, location, etc. that would expire.
- Develop close relationships with organizations related with food recovery and gleaners to ensure efficient donated food recovery.
- Provide a suitable environment for direct donation.

Bozhinova (2018) highlight sixteen applications dealing with donation by intelligent approaches in reducing hunger and eliminating waste. Those applications provide quick communication and solution for food donations of households, restaurants, retailers, etc.

In the following last sub-section, we provide a recycling solution approach for food waste that is the “recycle anything remaining” (ReFed, 2021).

2.7 Recycle Anything Remaining

According to ReFed (2021) roughly, 70% of surplus food becomes “waste”. Those include after harvest lefts, foods incinerated, dumped, deposited in the sewer, sent to landfill, etc. Recycling provides one of the important applications in reducing the food waste.

Recycling stands for, usage of any remaining scraps or food from the food products without losing their nutrients, energy, or other valuable parts. Practical solutions to this action are feeding livestock, innovative applications such as insect farming, biogas, etc.

Composting is one of the oldest ways of recycling food waste. It converts food waste into a usable and beneficial substance (Isustain, 2019). According to the Environmental Protection Agency, roughly 90 percent of the garbage produced by households, cafeterias, restaurants, and supermarkets involves recyclable scrap food. When this waste is sent to the landfill, it contributes to the environment negatively. For instance, except that it occupies space, it also releases methane gas causing greenhouse emissions. To recycle this food, it would be a good application to provide regular pickup vehicles collecting those waste and taking them to the composting facilities.

Conclusion

This study aims to provide an overview of food waste and food loss along with ways to reduce them through a food supply chain. FLW loss is a global issue challenging food security as around one-third of global food production is lost or wasted along the entire food chain. Therefore, to address the food waste issue a better understanding is needed. In this study, we have therefore reviewed food losses and waste reasons in several stages of the SC and summarize the solution approaches suggested by some of the current works.

Our findings show that by utilization of recent IT developments, it is possible to digitize supply chains which creates end-to-end visibility tracking real-time data through the chain to prevent over production. Other tools can also create dynamic decision-making tools to prevent products to expire or recover them before they expire.

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