

An Overview for Food Loss and Waste Reduction in Food 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 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) one-third of all food produced in the world is lost or wasted from farm to fork. This waste has great negative impact on global economy, food availability, as well as environment. In this work, we focus on food loss and waste subject by searching how they could be reduced in 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 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 food supply chain network. If those critical factors cannot be managed correctly throughout the network, then the supply chain network may result with 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. It is estimated that one-third of all food produced globally is lost or goes to waste (FAO, 2021). Hence, all stakeholders should take serious roles in reducing the food loss and waste in the world.

The Food and Agriculture Organization (FAO) (FAO, 2021) determines the 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), food is mostly wasted due to those reasons:

- Food products having undesired shapes, sizes and colours, are usually discarded during sorting operations.
- Food products which are close to, at or beyond the expiration date are mostly discarded in supply chain.
- A large amount of food quantities adopted (e.g. even wholesome edible food) are usually unused or leftover and discarded from eating environments.

Differently, food loss is defined by FAO (2021) as: “the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retailers, food service providers and consumers”. It is explained as: “empirically, it refers to any food that is discarded, incinerated or otherwise disposed of along the food supply chain from harvest/slaughter/catch up to, but excluding the retail level, and does not re-enter in any other productive utilization, such as feed or seed”. Figure 1 shows the difference between those two, food loss and waste, cases based on at what stages they occur.

By the food waste and loss definitions, it can be concluded that decreased food loss and waste would contribute to efficient usage of land and efficient management of water resource. That would also create a positive impact on climate change and livelihoods. Hence, researches on minimization of food loss and waste throughout supply chain networks would be an emerging topic for a sustainable and a not hunger world.

Since the reduction of food loss and waste would also create a positive contribution to the environment, this action can also be seen as a means toward achieving other beneficial objectives. For instance, by the food loss and waste minimization, it is also possible to improve food security and nutrition, reduce greenhouse gas emissions, lower usage of water and

resources as well as improve productivity and economy. Thus, effective policies for food loss and waste reduction should be explored by focusing on how much and where foods are lost or wasted throughout food supply networks.

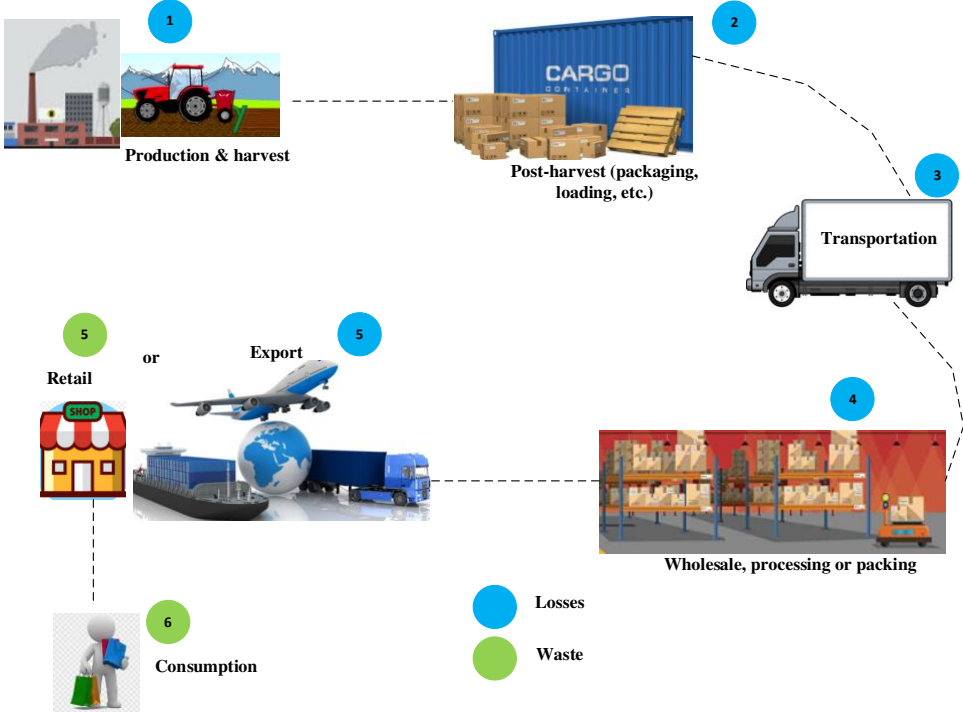


Figure 1: Stages where food loss and waste occur (re-drawn from FAO Learning Guide, 2019, <http://www.fao.org/3/ca5312en/CA5312EN.pdf>)

A work of FAOs result on reduction of food loss and waste is presented by “Food Loss and Waste Database” (FAO database, 2021) for countries. Figure 2 shows food loss and waste 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 loss and food waste presented throughout the literature and surveys. That database includes data and information from several reports and studies measuring food loss and waste based on food products, stages of the value chain, 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, it is possible to have end-to-end connection for digital smart supply chains that

could also be utilized for food supply networks to reduce food losses and waste throughout a the network. By digitilization and smart supply chains concepts, businesses can balance their stocks while keeping their cost and responsive efficiency targets. For instance, by the implementations of smart supply chain technologies, it could also be possible to predict bottlenecks in advance, prevent 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, connection of physical networks and implementations of smart technologies could help food supply chains to be more sustainable, cost and responsive effective.

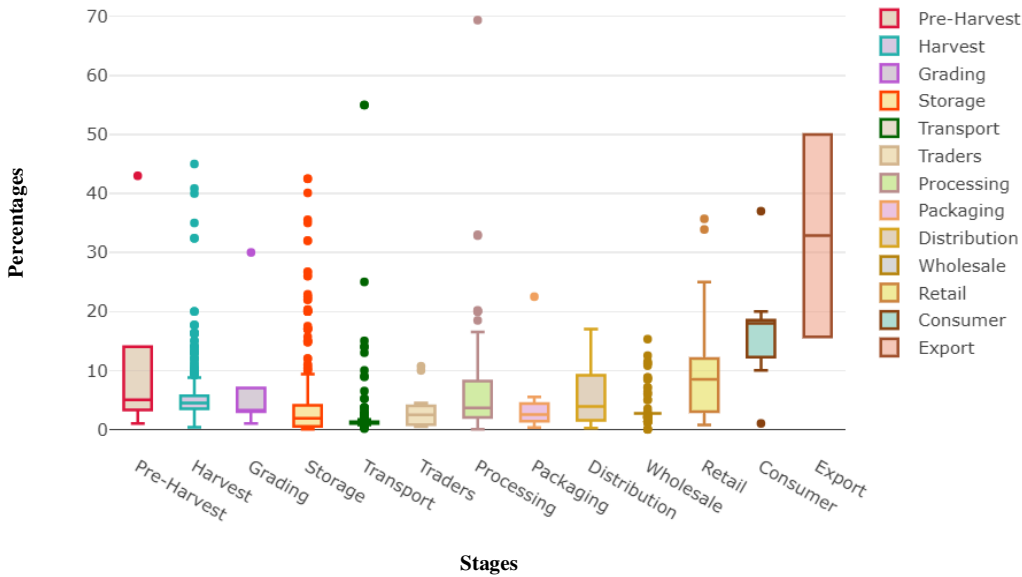


Figure 2: Boxplot showing of food loss and waste percentages happened in the years between 2000 and 2017 (source: Food and Agriculture Organization of the United Nations, <http://www.fao.org/platform-food-loss-waste/flw-data/en/>)

In this work, by focusing on the Figure 2 stages and help of today’s digital and smart supply chain technologies, we investigate how food loss and waste could be reduced throughout a food supply chain.

The paper continues with the solution approaches for food waste and loss reduction in food supply chain in Section 2. We mention the related works from literature while providing the solutions in each stage. Last, we summarize our work by a conclusion part.

2. Solution Ways for Food Waste and Food Loss Reduction

Food loss and waste occur at each stage of the supply chain. However, the majority of food waste takes place at consumer-facing businesses such as grocery stores, restaurants, etc., and in homes (see Figure 2). From this section, we refer food waste as “any food that is grown and produced for human consumption but ultimately is not eaten”. Hence, we consider the food lost beginning in upstream of supply chain, at farms and food manufacturing businesses.

Food waste can be a solvable problem. According to the ReFed’s Roadmap to 2030 and Insights Engine analysis (ReFed, 2021) which is drawn from several experts and practitioners from the food industry, professional trades, solution providers, academia, and more, there are seven key action areas to focus on in food waste reduction. These are: “ 1- Optimize the Harvest, 2- Enhance Product Distribution, 3- Refine Product Management, 4- Maximize Product Utilization, 5- Reshape Consumer Environments, 6- Strengthen Food Rescue, 7- Recycle Anything Remaining”. ReFED’s those seven actions are developed mainly by considering these three solution steps: prevention, recovery, and the recycling.

Prevention helps waste not to occur in the first place. Recovery, searches ways for donations of surplus food to reduce hunger. Recycling treats scraps as value-added products instead they go landfill. The first five actions, “optimize the harvest, enhance product distribution, refine product management, maximize product utilization, reshape consumer environments” are developed as prevention solution approach, 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 in below subsections.

2.1 Optimize the Harvest

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 good options improving that step. To minimize the overproduction in harvest step, recent information and technological developments such as data-sharing as well as real-time data and information tracking technologies could be utilized contributing that target. However, to be able to implement those solution approaches correctly, it might be also required to implement them across all supply chain actors.

According to Trimble (2021a) there are two main reasons for food waste in the harvest step: “poorly selected harvest time and inadequate harvest methods”. Several methods are suggested to be used 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 based on analyzed data, and 4- Managing field operations based on the decisions”.

According to FAO Toolkit (2013), harvest losses are due to the timing of the harvest, as well as harvesting methods, equipment and conditions. Some practical suggestions are presented in that report. For instance, usage of catching bags for high trees might prevent falling of fruits on the ground and bruising. For some of 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 preventing 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 in farm or greenhouse takes place due to aesthetic criteria, forecasts, prices, variety, temporary and seasonal workers related reasons. They suggest 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 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 world’s

population is expected to reach over 2 billion people by 2050, all stages of the food supply chain should be optimised to utilize all the food produced. Thus, this will require each link in the food supply network working with a harmony in the most effective way, where we start with the harvesting stage at the beginning of that issue. The following stage post harvest is the distribution stage where we discuss in the following section.

2.2 Enhance Product Distribution

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 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 for both suppliers and buyers.

According to Nikkel et al. (2019), in 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 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 transportation process, its negative effect on 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 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 supply chain, use of rail way and water transit to increase transport efficiency.

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

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

Except 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 Refine Product Management

Inefficient or non-optimized product management may lead to food waste throughout supply chain. 20% of unsold food product at the retail level is estimated to be because of handling errors (ReFed, 2021). Here, refining product management refers aligning purchases with sales (ReFed, 2021). One of 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 occur 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 with over production and excess amount of inventories in supply chains. If demand is less

than what estimated, it would be resulted with 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 of food waste. Since different actors involved in a food supply chain are dependent each other and one's action and practice may influence the other's decisions, uninterrupted communication of those actors are significant. With today's Industry 4.0 technological developments, it is possible to create end-to-end supply chain connections helping to track real time information from the supply chain. By that, supply chain 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 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 supply chain. We discuss on that, in Section 2.4.

2.4 Maximize Product Utilization

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 to food products. By innovation and investment, this step can be thought of an upcycling process for getting rid of “waste”. The Upcycled Food Association (UFA) aiming to reduce food waste defines upcycled foods as ones that "use ingredients that otherwise would not have gone to human consumption, are procured and produced using verifiable supply chains, and have a positive impact on the environment." For instance, Philabundance, Treasure8, and Toast Ale are some of 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 equipments.

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

By 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, safety related information about the food product (Sohail et al., 2018). Hence, by the correct materials and packaging technologies, it is possible to realize high product quality and freshness until the products are commercialized and consumed (Brown, 1992; Stewart et al., 2002).

According to EU Commission (2011), a well-designed food packaging can help consumers buy the required and right amount of food. Smaller package sizes and split packages are recommended as solution options. Since it is believed that consumer's product keeping attitude would be improved, re-closable packs, new vacuum and shrink wrap packaging are also other solution suggestions that could also contribute on increase of shelf life of products.

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

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

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

2.5 Reshape Consumer Environments

The largest total food wastage amount occurs at consumer level (FAO Toolkit, 2013). The potential reasons are explained to be: urbanization, consumer detachment from the reality of producing food (e.g., time, labor and environmental costs), retail implementations, encouraging excess buying (e.g. free offers) etc. also assuring impression on consumers that wasting food is not expensive and has minor consequences.

According to 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 amounts 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.

Integrating environmental considerations into 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:

1- “***Plan your shopping***: Plan your meals for a week. Prepare a shopping list for just the extras you need. Take your list with you and stick to it when you're in the store.”

2- “***Check the dates***: If you are not planning to eat a certain item with a short ‘use by’ date, look for one with a longer ‘use by’ date or just plan to buy it on the day you require. Be aware on the meaning of date labels: ‘use by’ means that the food is only safe for consumption until the indicated day (e.g. for meat and fish); ‘best before’ indicates the date up until when the

product retains its expected quality. Food products are still safe to consume even after the indicated 'best before' day."

3- "**Consider your budget:** Wasting food means wasting money."

4- "**Keep a healthy fridge:** Check the seals and the temperature of your fridge. Food needs to be stored between 1 and 5 degrees, Celsius for maximum freshness and longevity."

5- "**Rotate:** When you buy new food from the store, bring all the older items in your cupboards and fridge to the front. Put the new food at the back to reduce the risk of finding something mouldy in your food storage compartments."

6- "**Use up your leftovers:** Instead of scraping leftovers into the bin, they can be used for lunches the following day, go into the next day's dinner or be frozen for another occasion. Fruit that is just going soft can be used to make smoothies or fruit pies. Vegetables that are starting to wilt can be made into soups."

7- "Serve small amounts of food with the understanding that everybody can come back for more once they've cleared their plate."

8- "Store food in accordance with the instructions on the packaging."

9- "**Freeze:** If you only eat a small amount of bread, then freeze it when you get home and take out a few slices a couple of hours before you need them. Likewise, batch cooked foods so that you have meals ready for those evenings when you are too tired to cook."

10- "**Turn it into garden food:** Some food waste is unavoidable, so why not set up a compost bin for fruit and vegetable peelings? In a few months you will end up with rich, valuable compost for your plants. If you have cooked food waste, then a kitchen composter will do the trick. Just feed it with your scraps, sprinkle over a layer of special microbes and leave to ferment. The resulting product can be used for houseplants and in the garden."

Solving the food waste problem at 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 color

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 food waste minimization problem that is the “strengthen food rescue” (ReFed, 2021).

2.6 Strengthen Food Rescue

Food rescue is the practice of gathering rescuable food and redirecting it for human consumption. It is one of the main ways for the food industry to tackle with food waste. Strengthening food rescue means further strengthening the rescue ways for high-quality, nutritious food throughout the supply chain. That could be possible by increasing the capacity of food relief agencies in terms of storage, transportation, and staffing, overcoming distribution bottlenecks, and improving communication flows 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 currently more than 25 organizations redistributing food (Food Banking, 2019). To be able to recover and redistribute food, there may be barriers due to legal and operational issues for donors and recipients. According to FAO (2019), in order to develop appropriate policies and legislation assuring food safety in food recovery and redistribution operations, these concepts are significant:

- ***Food requires to be safe.*** Distributed food should be healthy for any consumers.
- ***Food needs to meet minimum quality requirements.*** Countries 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 direct relationships with food recovery organizations and gleaners to have beneficial options once donatable product appears.
- Provide suitable environment for direct donation.

Bozhinova (2018) highlight sixteen applications dealing with donation by smart efforts to reduce hunger and eliminate waste. Those apps 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 are either left in the fields after harvest, incinerated, dumped, deposited in the sewer, sent to landfill, or applied to the land for use of other purposes. In fact, recycling offers one of the largest opportunities for decreasing the amount of food going to waste in a food system.

Recycling means, usage of any remaining scraps or foods 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. Solutions that make use of existing food for other creatures are preferable to the next category of recycling, which requires processes including composting, anaerobic digestion, and co-digestion at water treatment plants to break down the materials for their more basic nutrients. Alternatively, innovative markets for waste-derived bioplastics, agricultural inputs, and other industrial uses model the development of circular economies that can capitalize on existing wasted materials for new products, fuels, packaging materials, and more.

Composting is one of the oldest ways in 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 those food, it would be a good application to provide regular pickup vehicles collecting those waste and taking them to the composting facilities.

ReFed (2021) suggests the below opportunity for minimization of waste as recycling in this step:

- “Assuring packhouse culls sent to highest use to minimize waste: exploring alternative markets and upcycled products first, then livestock feed, and finally anaerobic digestion or composting.”

Conclusion

This study aims to provide an overview for food loss and food waste along with ways for reduction of them through a food supply chain. Globally around one-third of total food production is lost or wasted along the entire food chain, which is a significant issue for food security to improve. Therefore, better understanding of food waste is needed for waste reduction. Here we review food losses and waste reasons in several stages of supply chain and summarize the solution approaches suggested by some of current works.

It is come up with that by utilization of recent IT developments, it is possible to digitalize supply chains helping to create end-to-end visibility to track real time data through the chain to prevent overproduction. Other tools can also create dynamic decision making tools to prevent products expire or recover them before they expire.

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