Sustainable Food Waste Management: A Review

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Abstract

Food wastage and loss is the major problem faced globally and affects developing and developed countries equally. Lost and wasted food represents a missed opportunity to feed the growing world population. Food is wasted at all the levels of food supply chain. Food products are heterogenic in nature and types of food waste and its composition also varied so it is difficult to apply a waste hierarchy to food products. Therefore, the waste hierarchy must be assessed for each type of food waste, rather than for "food waste" as a whole. This chapter will discuss in detail various preventive measures, impact of food waste and along with this various technology that can be used for the treatment of food waste. Best way to prevent food waste is using sustainable food waste management approaches to reduce and prevent food waste.

Keywords

Food loss and waste · Food supply chain · Prevention and treatment of food waste

1.1 Introduction

"Waste" is the term which denotes discarding a material after use at the end of their intended lifespan. Management of waste started from segregation, collection, transportation and is a collective activity utilising its reprocessing, recycling and disposal of waste. Waste management should be environmentally sound, socially satisfactory and must use techno-economically viable methods then only it would be considered

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sustainable waste management. Two terms i.e. food losses and food waste, can be defined as "food losses" is one that take place at production, postharvest and processing stages in the food supply chain and "food waste" is one that occurs at the end of the food supply chain i.e. at retail and final consumption stage by consumer (Parfitt et al. 2010).

"Food" waste or loss is measured only for products that are directed to human consumption, excluding feed and parts of products which are not edible. Food losses or waste are the masses of food lost or wasted in the part of food chains and therefore food that gets out of human food chain which was originally meant to human consumption is considered as food loss or waste.

According to definition given by Food and Agriculture Organisation (2013), food loss is considered as the decrease in dry matter (mass) or nutritional value (quality) of food that was originally intended for human consumption. This is caused due to various inefficiencies throughout the food supply chain like poor infrastructure, technological insufficiencies, lack of knowledge and skills of participants at different levels of FSC. Whereas food waste refers to food appropriate for human consumption being discarded, whether or not after it is kept beyond its expiry date or left to spoil.

1.2 Types of Food Losses/Waste

Food-related waste (including edible and non-edible parts) represents an important proportion of total waste. Food losses can be grouped into two categories as Avoidable losses and Unavoidable losses.

Unavoidable food losses are those that cannot be in generally eaten by human beings like bones of fishes and the skin of pineapple. On the other hand, avoidable FLW occurs for the types of foods that are edible but neither used nor eaten. Food policies and researches should focus on avoidable FLW.

All the five system boundaries of food supply chain (FSC) as depicted in Fig. 1.1 include both vegetable and animal commodities which can be wasted or lost at each stage. Starting from production where losses occur due to mechanical damage during threshing, picking of fruits and vegetables during harvesting each stage of FSC depicted food loss and waste. At postharvest and storage stage losses occur due to

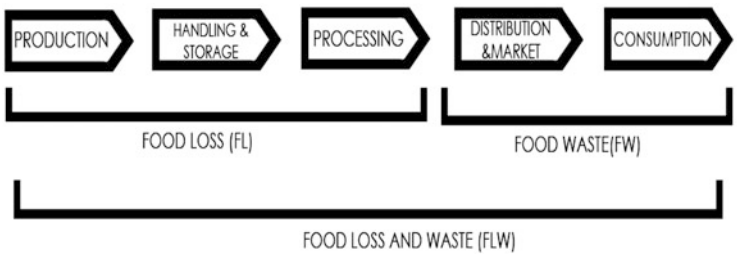

Fig. 1.1 Food supply chain (FSC) stages related to food loss and waste

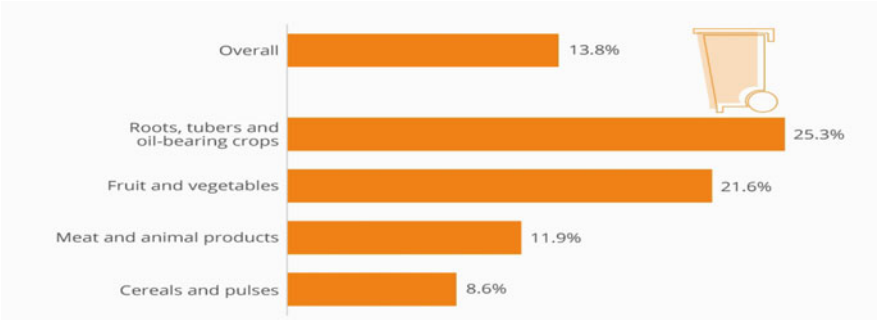

Fig. 1.2 Percentage of food loss globally. Source: FAO (2016)

Table 1.1 Food loss and waste among developed and developing countries

	Food loss	Food waste	Food loss and waste
Developing countries	30%	14%	44%
Developed countries	21%	35%	56%

spillage and mishandling of products. Along with this during storage and transportation between farm and distribution also cause some losses. During processing at industrial or domestic level and finally losses can take place in the market and consumption of food at hotel or household.

As per estimations globally about 1.3 billion tons of edible food produced for human consumption get wasted per year which is roughly around one-third of the edible parts produced throughout the FSC. In medium- and high-income countries food is wasted by thrown away even if it is still suitable for human consumption, whereas among low-income countries food is mainly lost during the early and middle stages of the food supply chain than at the consumer level (FAO 2011). Figure 1.2 showed the global food loss of various type of food group and commodities.

The UN, FAO and World Resources Institute (WRI) on global FLW highlight the significant differences in per capita FLW between economies (Gustavsson et al. 2011). As depicted in Table 1.1 56% of the FLW occurs in developed countries, while the other 44% occurs in developing countries. Figure 1.3 depicted the generated FLW that varies in each stage of FSC among developed and developing countries. There is relatively greater amount of food loss among developing countries, while developed countries have a higher portion of food waste.

There are various food waste/loss drivers in the food system such as industrialisation, urbanisation, globalisation, economic growth, socioeconomic factors, Dietary transations and diversification, product and packaging characteristics, retail market strategies, consumer skills, behaviour, habit motivation, poor education, lack of technology. Detail description of various causes of FLW at different level of food supply chains (FSC) has been presented in Table 1.2.

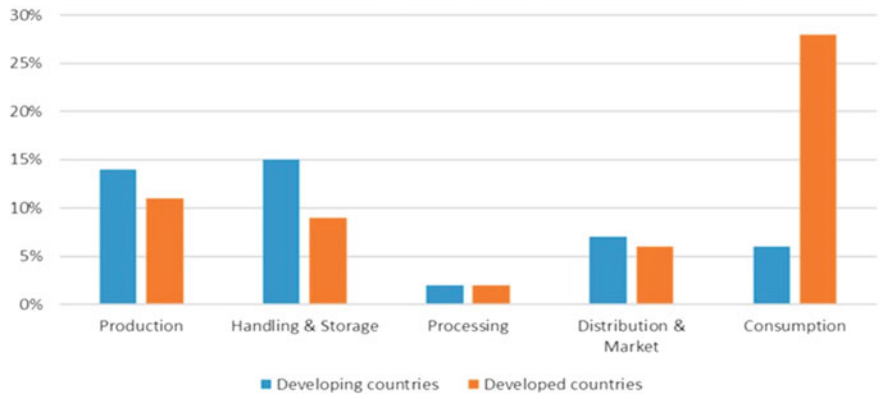

Fig. 1.3 Percent food loss and waste in food supply chain (Source: Lipinski et al. (2014))

1.3 Principles of Food Waste Management

1.3.1 4Rs: Refuse, Reduce, Reuse & Recycle

- *Refuse*: Refuse is the best method to manage waste of any type. Reduce suggests cutting the amount and the kind of products which we buy. The best way to reduce is to consume less and generate less waste. Avoid buying any food without its use.
- *Reduce*: Reduce the amount of garbage generated. Waste reduction is a good method of prevention of waste. Elimination of the source producing waste demands for large scale treatment and disposal facilities. Some protocols should be followed to reduce source that generates waste, for example, use scrapers and other equipment like high pressure spray to clean floors, donation of unwanted items, backyard composting, etc. Reducing the amount is the most significant of all the options to manage waste. Other method of reducing waste is to donate extra food to people who need them and also to use it for animal feeding. Along with this rendering fat for industrial use can also be used to reduce waste at source.
- *Reuse*: The term reuse refers to putting products and materials back into use before they become waste. It involves no physical change in the product and therefore keeps the products in use for longer. Reusing products reduce raw material consumption and energy use and associated costs. It also reduces the requirements for waste collection, treatment, and disposal.
- *Recycle*: Recycling means manufacturing of a new product by using items derived as raw material from the waste. Recycling occurs in three phases: first the waste is sorted and recyclables collected, secondly raw material is created out of sorted recyclable material and finally in the third phase a new product is produced using derived raw materials. Both recovery and recycling reprocess

Table 1.2 Possible causes of food loss and waste during different stages of food supply chain

Stage of FSC	Causes of FLW	Reference
Production stage	Infrastructural limitation	Gustavsson et al. (2011) and HLPE (2014)
	Over production	Kaipia et al. (2013) and Garrone et al. (2014)
	Harvesting timing and method (manual/mechanical)	Kumar and Kalita (2017), Grover and Singh (2013) and Kannan et al. (2013)
	Pesticides and fertilisers	Thompson (2008)
	Economic problems	FAO (2014)
	Quality standards and norms	Garrone et al. (2014) and Stuart (2009)
Postharvest handling and storage stage	– Degradation and spillage of product composition	Yusuf and He (2011), Bett and Nguyo (2007), Willersinn et al. (2015) and FAO (2014)
	– Loss during transportation from farm to distribution	
	– Storage infrastructure	
Processing and packaging stage	– Unavoidable losses	HLPE (2014), Beretta et al. (2013), Schieber et al. (2001) and Darlington and Rahimifard (2006)
	– Technical malfunctions	
	– Methods and changes in processing lines	
	– Contamination in processing lines	
	– Legislation restrictions	Gustavsson et al. (2011) and Papargyropoulou et al. (2014)
	– Packaging system	Stuart (2009)
	– Overproduction	Khedkar and Singh (2018) and Murthy et al. (2009)
Distribution and marketing stage	– Inappropriate transport conditions (temperature-controlled aircrafts and ships)	Martinez et al. (2014), Fox and Fimeche (2013), Kaipia et al. (2013), HLPE (2014), Papargyropoulou et al. (2014), Khedkar and Singh (2015) and Garrone et al. (2014)
	– Contamination of transportation	
	– Transportation and market facilities	
	– Road and distribution vehicles	
	– Packaging management	
	– Commercial conditions	
	– Consumer reference	
Consumption stage	– Composition unit and size of household	Parizeau et al. (2015), Pingali and Khwaja (2004), Neff et al. (2015) and Schanes et al. (2018)
	– Income group	
	– Demographics and culture	
	– Individual attitude	
	– Cooking practices and methods	

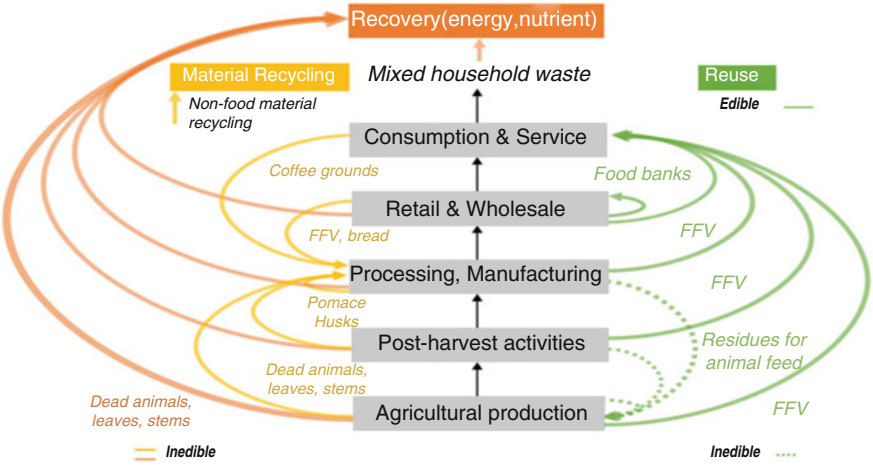

Fig. 1.4 Food waste and food loss management at different level of FSC (adapted from Teigiserova et al. 2020)

food waste materials into usable material. Recovery differs from recycling in which energy production also included. Recycling creates new opportunities of employment in areas of collection, treatment and reprocessing of recyclable materials particularly where new uses and applications for materials can be developed. The need is to increase the demand and markets for recycled products.

Food products are heterogenic in nature and types of food waste and its composition also varied so it is difficult to apply a waste hierarchy to food products. Therefore, the waste hierarchy must be assessed for each type of food waste, rather than for "food waste" as a whole.

Figure 1.4 describes the food waste produced at each level of food supply chain both edible or inedible. The diagram subsequently followed by arrows and making further indicator selections. The figure denoted various types of waste management alternatives which differ as per indicators for that food type. Food waste sub-grouped on the basis of treatment applied for both type of waste, i.e. plant-based waste and animal-based waste. Both types of waste should be assessed independently hence segregated and collected separately. On that basis more targeted management practices can be carried out on the different food waste streams. When separate collection is not possible, a thorough waste sorting is still recommended.

Various food waste management alternatives have been discussed in Fig. 1.5. Some of these alternatives have been grouped and applied, for example, various bio-compounds from food products can be extracted through various physical and chemical process and also there are various possibilities of utilising various food waste for industrial applications (Khedkar and Singh 2018). It is therefore not possible to apply all options explicitly for all the food waste categories. Each type of food waste needs to be assessed independently and studied so that suitable

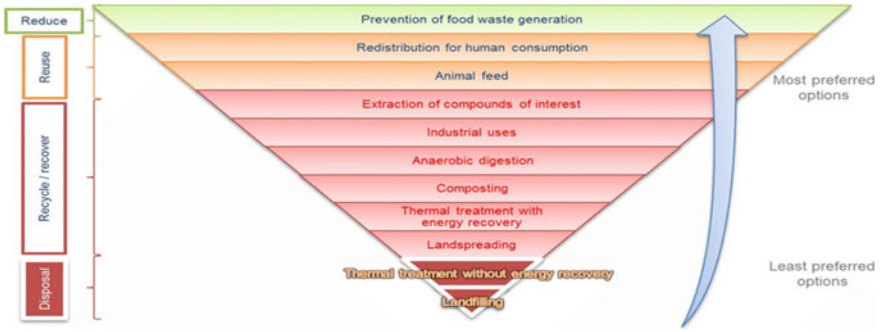

Fig. 1.5 Waste hierarchy for surplus food and food waste (adapted from Garcia-Garcia et al. 2015)

opportunities can be used to treat that waste and various compounds of interest of industry can be extracted out of it.

1.4 Prevention of Food Waste

Prevention of food waste generation is at the top of the food waste hierarchy and the least preferred options are landfilling and thermal treatment without energy recovery. Prevention of food waste can be applied to all types of edible food wastes likewise land spreading can be used with the majority of food waste types, but according to the food waste hierarchy (Fig. 1.5) this alternative is less beneficial than composting. Since food is such an incredibly valuable resource so this resource should not be wasted. Food waste utilisation for the generation of valuable commodities can be utilised as a way to overcome loss and waste of food at various levels of food system and must be considered before putting in a landfill or incinerator (Khedkar and Singh 2018). Various methods used for prevention of food waste are described in detail as below:

1.4.1 Redistribution for Human Consumption

Best way to prevent food loss is redistribution for human consumption. Food charities and food banks are good examples of this method. Food that is used for this purpose must be edible, eatable and improves resource utilisation.

1.4.2 Animal Feeding

The best alternative and sustainable solution of utilising food waste is animal feeding. The foods which are not fit for human consumption but can be given for animal (farmed animals like cow, goat, sheep, etc.) feeding after assessing it

properly. The products which are used for animal feeding must either be eatable or uneatable for humans but eatable for animals and non-catering waste. Mixed waste containing animal products from manufacturers is suitable for animal feeding when the animal product is not the main ingredient. Meat (or plant-based products containing meat) cannot be sent for animal feeding. Eggs and egg products (or plant-based products containing them) must come from the agricultural or manufacturing stage when used for animal feeding after utilising specific treatments.

1.4.3 Quantification and Characterisation of Food Waste

Quantification helps in identification of the source and type of food waste. It also helps in implementing suitable targeted preventive measures. On the basis of characterisation of food waste standardised protocols can be formulated to prevent and utilise food waste. These protocols can be further used at different stages of food supply chain to develop food waste and loss inventories and management system to overcome losses.

1.4.4 Awareness and Communication Policies

A tailored communication instruments are required to deal with the changes occured in consumption pattern and social behaviour over a period of time. With the change in food choice, availability and type of food (RTE, RTC), the type of waste produced also changed and hence the prevention and management techniques need to be updated. Packaging waste increases, while food waste falls as people cook less at home (Tara Slade 2016). Awareness of stakeholders to overcome such waste needs to be communicated. Various types of information education communication material (IEC) can be used for awareness campaigns like printed materials, public meetings pamphlets, etc. Along with this other methods like seminars, surveys can be used for collecting information, constant monitoring and reporting.

1.4.5 Reporting and Monitoring

The management of food wastes is easier and more sustainable approach to prevent and it can be used if the amounts and quality of food waste produced are regularly monitored and accounted for. Good manufacturing practices and dissemination of best practices and its reporting prevent food waste. Businesses or industry that generate large quantities of food waste may be required to report the origin, volume and disposal methods of such waste. This helps in monitoring the amount and cost of their waste and thus encouraging its reduction.

1.4.6 Regulatory Initiatives

According to the Indian Constitution, the state government and the urban local bodies (ULBs) are responsible for solid waste management. MSWM is governed by the Municipal Solid Waste Management and Handling Rules, 2016. The rules designate ULBs responsible for the management of only solid waste and directed ULBS responsible for the management of municipal solid waste within their territorial area and also for the generation of infrastructure for implementation.

1.4.7 Research and Innovations

Innovating new ways of reducing food waste and also utilisation of food waste for production of more valuable commodities like extraction of pectin from fruit waste is hot topic for researchers. Along with this researches should be initiated to minimise food loss and waste at every stage of food handling which is the demand of this era.

1.5 Food Waste Treatment Technologies

1.5.1 Anaerobic Digestion (AD)

AD is the process in which organic matter gets decomposed using bacteria in an oxygen-free environment. Optimal conditions are required to conduct this process like alkaline pH, controlled temperature and minerals like nitrogen, phosphorous and potassium. Various benefits have been demonstrated by this method like reducing the health impacts which may occur otherwise due to poor waste management and it helps in recovery of energy. Anaerobic digestion recovers 60% more energy than direct combustion (Valorgas 2014). It also helps in producing a fertiliser that is rich in nutrients and hence replenishes soils.

1.5.2 Composting

Composting is relatively simple, predictable and naturally occurring process in which decomposition of organic matter using oxygen is done by the action of microorganisms and small invertebrates in controlled conditions. During composting heat is created by the biodegrading mass itself and its temperature may rise to 70 °C which further accelerate the biodegradation process and natural fermentation of the biomass. There are many composting techniques which can be utilised at small scale like backyard compositing and for larger volumes of waste aerated like in-vessel composting.

Various advantages of this technique include production of high organic matter compost that can be used to increase yield of plant and restore soil. It helps in

stabilising and sanitising food waste. Various disadvantages of this techniques include that it does not recover energy and requires careful management of contaminants and odour.

1.5.3 Liquefaction

Liquefaction is the process where food waste gets converted into liquid effluent by using multiple methods like mechanical, biological or hydrothermal liquefaction and resultant effluent may be discharged into the drainage as in household or in municipal wastewater system. This method is simple to use but utilised where there is a wastewater treatment system and also requires energy input.

1.5.4 Rendering

Rendering is a process that converts waste animal tissue and by-products into usable material like high-quality fat and protein products. It is of two types: wet and dry rendering. Separation of fat from raw materials by boiling in water is done in wet rendering, whereas dehydrating the raw material to release the fat is done in dry method (Parry et al. 2015). Along with fat commodity rendering also produces highly valued protein meal. Rendering food waste provides a very good substitute for conventional animal feed which provides high protein supplement. This process requires close regulation and stringent legislation as it deals with food waste containing animal by-products. One big disadvantage of this process is that it requires energy input.

1.5.5 Thermal Treatment Can Be Used for Energy Recovery

These treatments can be applied to every type of food waste. Thermal treatments with energy recovery, which includes various techniques like gasification, pyrolysis and incineration, are the only alternative available to treat packaged food (non-separable from packaging) in non-biodegradable packaging, except the cases when the product is also edible, eatable and processed, and therefore can be redistributed for human consumption. It can also be used for mixed food waste also

- *Gasification*

Gasification is a process which uses a high temperature (>700 °C) with a controlled use of oxygen or steam to decompose organic materials like food wastes or combinations of organics and inorganics into a combustible gas called syngas. It is therefore a technology that involves thermochemical conversion, like incineration or pyrolysis. One big disadvantage of this method is lack of nutrient recovery. But according to the World Energy Council 2016, both gasification and pyrolysis are

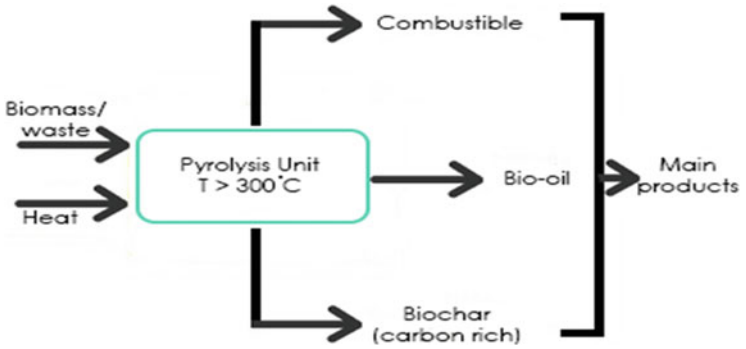

Fig. 1.6 Pyrolysis of food waste

more efficient and score better in environmental impacts than incineration with energy recovery.

- *Incineration*

Controlled exothermic combustion of mixed solid waste at extremely high temperatures is known as incineration. This method is applicable on municipal food waste and also generated from commercial and industrial sources ideally non-recyclable one. In this process food and other waste are not separated at the source hence save collection costs. This method is an effective approach that maximises recycling rates and recovers energy from non-recyclable residual waste. Depending on the treatment options for the bottom ash formed by the inorganic constituents of the waste, ferrous and nonferrous metals can be recovered and the remaining ash can be further enhanced to be for road construction and buildings.

- *Pyrolysis*

Pyrolysis is a thermo-chemical decomposition of organic material which gets converted into gases and biochar which are the main products of pyrolysis unit. Heating is done in the absence of oxygen. Compared to combustion in other methods, pyrolysis causes less emissions of air pollutants and biochar produced can be used to increase agriculture productivity (Fig. 1.6).

1.5.6 Mechanical Biological Treatment (MBT)

Mechanical biological treatment (MBT) is the combination of both biological and physical processes. This is a waste processing system in which sorting of food waste is further treated with various biological treatments like anaerobic digestion or compositing to produce biogas (Fig. 1.7).

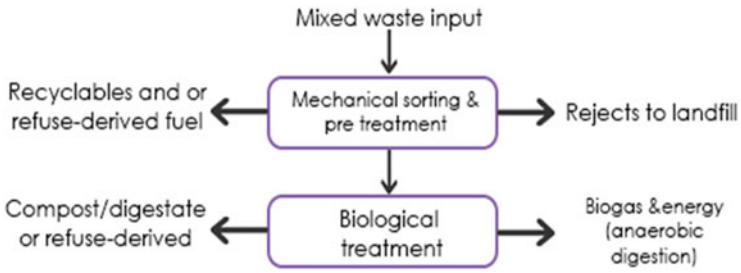

Fig. 1.7 Process of MBT

This technique can be used for mixed household, commercial as well as industrial waste. It helps in recycling of food waste which if not treated will be inefficiently combusted or landfilled. Other advantages of this method reduce the cost associated with the separation and segregation of food waste and allows energy recovery via the anaerobically digested organic fraction.

1.6 Impact of Food Waste

Along with squandering of resources needed for the production of food (including energy, carbon, water and nutrients), poorly managed food waste adversely affects our climate due to the emission of greenhouse gasses due to decomposition, water contamination, leaching of nutrients and place of breeding vector for diseases and other health hazard. Various impacts of food waste are discussed below:

1.6.1 GHG Emissions and Climate Change

Greenhouse gases are emitted at all stages of the food life cycle which contribute to global warming and climate change (Eco Watch 2017). Greenhouse gases CO_2, CH_4, N_2O are produced by the burning of fuels for energy production, emissions from manure and slurries, pasteurisation, refrigeration and transport of food. Landfill sites or dumpsites where waste food decomposes emitted these gases to the atmosphere. Composting or anaerobic digestion was considered as better option as compared to landfills and open dumps as they prevent methane emission to the environment. From long back fossil fuel has been used to produce biogas-based energy that can be used as an option to solid domestic fuel. This not only helps in improving indoor air quality but also helps to mitigate climate (Food and Agriculture Organisation of the United Nations 2015). Along with this if inorganic fertilizers can be substituted with bio fertilisers using different treatments like compost or digestate on food waste, will also help in managing carbon dioxide emissions. It is estimated that 580 kg CO_2 eq. can be saved per each tonne of food waste diverted from landfill

to an anaerobic digester when the resulting biogas is used to replace natural gas (Ellen MacArthur Foundation 2013).

1.6.2 Water Footprint

Water is essential for life. In places where rainfall is not adequate or seasonal, water is extracted by the plant irrigation from groundwater aquifers and surface water bodies. For the growth of plant water is major essentiality hence the uncontrolled disposal of food waste has an impact on surface water as well as groundwater bodies. Along with this overuse and subsequent run-off of fertilisers and pesticides have an adverse impact on the water quality of both types of waterbodies: ground and surface. Dumpsites and landfills can also pollute the groundwater and surface water as leachate from them can reach that level of water. In various food processing industry untreated wastewater is released to water bodies which pollutes the surface water. Hence preventing food waste can reduce the pollution of water.

1.6.3 Nutrient Loss of Agriculture Land

Changes in agriculture practices from decades have resulted in nutrients depletion of the soil. Agriculture land usage is not increasing as the population increasing day by day and hence the demand of more food to feed that population is creating more loss of nutrient and organic matter. This leads to more usage of synthetic fertilisers to increase yield of the land. Food, agriculture waste and even human excreta production increase in cities due to urbanisation did not returned back to farm which in past recycled and naturally move to farmland (UN 2014). Recycling urban waste through the use of methods like digestate and compost can be used to overcome this gap created by urbanisation and unsustainable agriculture practices. Various benefits of replenish agriculture land are that it maintains reserves of phosphorus, potassium, nitrogen and organic carbon back to soil and will reduce the use of inorganic fertilisers. Nutrient recycling also prevents run-off nutrients to surface water bodies and hence prevents water pollution and aquatic life and the livelihood of people who depend on it.

1.6.4 Hygiene and Sanitation

Globally, about 50% of food waste is sent to landfills, while 13 to 33% of waste is still being openly dumped in lower- and middle-income countries (The World Bank 2012). These landfills and dumpsites can lead to various health hazards in the populations living and working near these places. Organic waste in dumpsites becomes the centre of various communicable diseases and place of breeding for mosquitoes and flies which further increase the health risk transfer of food borne diseases (ISWA 2015). Treatment of food waste using suitable technology helps in

preventing spread of rodents and various disease spreads. One good example favouring the prevention spread of disease and foul odour from food waste is anaerobic digestion. It also helps in promoting sanitation and hygiene.

1.6.5 Ecological Impacts

Various types of ecological changes take place to increase food production so as growing global population can be fed. These changes include cutting of forests to be used for other purposes like agriculture or houses building. There is a loss of various species of biodiversity which in turn lead to various transition in eating habits and development of various life style related diseases. Various indicators were used at global scale to find the impacts of this damage from food production like quality of soil, loss of biodiversity, etc. Various evidences have suggested that segregation of food waste is one of the approach to make it measurable and this allows effective targeted policy making and preventive measures. To avoid dumping of food waste in landfills and open dumping proper collection and management system is a necessity. Various methods like anaerobic digestion and composting are better techniques that can be utilised to convert food waste to more productive fertilisers for farmland and in turn can prevent environmental pollution like water and air.

1.6.6 Economic Impacts

Nearly one-third of the food that is produced each year goes uneaten, costing the global economy over $940 billion. Uneaten food is responsible for emitting about 8% of planet-warming greenhouse gases into the atmosphere. Economic cost of waste management includes the maintenance of landfills, transport cost, treatment plant operation cost and also separation and segregation cost. The total annual economic, environmental and social costs of food waste to the global economy are in the order of USD 2.6 trillion food waste which is not separately collected and disposed of in landfill. Along with this wasting food also rises financial crisis. Rising food prices and food shortage further increase cost of diseases and healthcare.

1.7 Conclusion

Food waste throughout food supply chain is complex and it imparted significant impact on various dynamics and factors. It imparts a great impact on economics, agriculture and food security of the country. Along with this the waste utilisation and management will determine the environmental conservation and human health. For resolving the problem of food waste there is a need to develop sustainable strategies which require cooperation between all stakeholders. The key to successful food waste management is to develop and utilise appropriate eco-friendly, sustainable technologies that can prevent and reduce the wastage. If wastage is generated, then

use of appropriate technology that can reduce its impact on environment and generate energy out of it should be preferred. Consumer awareness and education is also very important and a great challenge. The challenge must be accepted by each stakeholder throughout food supply chain and use of sustainable eco-friendly reduction approach is the key to manage this vast problem faced globally by many countries.

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