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Master thesis

Quantification of food waste disposal in developed and developing countries: A Meta-Analysis

Kvantifisering av matsvinn i industrialiserte land og i utviklingsland: En metanalyse

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This research study entitled “Quantification of food waste disposal in developed and developing countries: A Meta-Analysis” is prepared for the partial fulfilment of Master of Applied Ecology of Inland Norway University of Applied Sciences. This research study involves the contribution of various personnel of different level who are directly and indirectly involved in its accomplishment.

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Content

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English summary (abstract)

Food waste is an urgent problem, where waste is generated through all stages of the value chain, and this happens in developed as well as developing countries. Increasing concern about food security and environmental impacts attributed to food waste due increased land use and the emission of greenhouse gases (GHS) during production and value chain.

A systematic literature review was performed to detect where in the value chain the problems are the highest and to observe if there is a difference between developed and developing countries. The research followed Meta-analysis approach and synthesised reference with data on food waste. Both qualitative and quantitative data were collected through references found by using Google Scholar and ISI Web of Science as search engines.

Analysis and data interpretation were made for five developed countries and five developing countries, and this was done through its value chain from post-harvest to consumer level. Identified that major food loss in developing countries take part post-harvest and before it reaches to consumer level, while food waste in developed countries takes place more at the consumer level. Identification of the detrimental effects of food waste on environment, economy, and food security are discussed.

There is an urgent need for dialogue between actors in the value chain from producers to consumer, to implement strategies to reduce food waste. With an estimated population of 9 billion by 2050, and with limited natural resources, increased production is not the solution. Reducing food waste is the part of the solution as exploitation of natural resources (land, water, and energy) to feed the growing population will results in serious environmental and economic consequences.

Key words: Food waste, Food loss, post-harvest loss, developed countries, Developing countries, Value chain.

Norwegian summary

Matsvinn er et aktuelt problem, der avfall genereres gjennom alle ledd i verdikjeden, og dette skjer i så vel utviklede som utviklingsland. Økende bekymring for matsikkerhet og miljøpåvirkninger tilskrevet matsvinn på grunn av økt arealbruk og utslipp av klimagasser under produksjon og i verdikjeden.

En systematisk litteraturgjennomgang ble utført for å avdekke hvor i verdikjeden problemene er størst og for å observere om det er forskjell mellom industri- og utviklingsland. Forskningen fulgte meta-analyse tilnærming med en syntese av referanser med data om matsvinn. Både kvalitative og kvantitative data ble samlet fra artikler som ble funnet gjennom via Google Scholar og ISI Web of Science.

Analyse og datatolkning ble gjenomført from fem industrilland og for fem utviklingsland, og dette le gjort gjennom hele verdikjeden fra inghøst til forbrukernivå. Identifisering av mattap i utviklingsland fra etterhøst til forbrukernivå og matsvinn i utviklede land på forbrukernivå. Identifisering av skadelige effekter av matsvinn i miljø, økonomi og matsikkerhet.

Det er et stort behov for dialog mellom aktører i verdikjeden, fra produsenter til forbrukere, for å implementere strategier for å redusere matsvinnet. Med en befolkning som er estimert til å være 9 milliarder innen 2050, og med reuserte naturressurser, er økt produksjon ikke eneste løsning, men reduksjon av matsvinnet må også inkluderes.Utnyttelsen av naturressurser (land, vann og energi) for å brødfø den voksende befolkningen vil resultere i alvorlige miljø messige og økonomiske konsekvenser.

2. Introduction

Food Waste (FW) is referred as spoilage, and loss of food from harvest to possession at the final consumer which prevents food to reach the digesting system of the consumer (Figure1: Table1). Food waste also includes what is prevented receiving to consumers which could be minimized with infrastructure development whereas also includes behavioural issues (Parfitt et al., 2010).

Food waste and food loss are often synonyms but some authors make a distinction, where food loss occurs due to lack of facilities of infrastructure, transportation, processing and market facilities which shows mostly in the pre-consumer stages of supply chain whereas food waste occurs during the market and consumer stages due the issue of quality standard, expiry dates, poor temperature regulation during display, food habits, lack of planned cooking and grocery(Gustavsson et al., 2011).

A sustainable use of natural resources is critical as the estimated population by 2050 is about 9 billion (Cohen, 2001) and worldwide food supply would not be able to fulfil the demand, this would result in starvation and the affect would be mostly faced by less developed countries mostly from the continents of Asia and Africa (Hodges et al., 2011). To fulfil the demand of food supply, decrease of food waste is as crucial as the increase in production of food, as losses occurs in qualitative and quantitative way between harvesting and consumption (farm to table) which reduces the availability of food products(Kader, 2004). Annually about 1.3 billion metric tons of edible food which is about one- third of total food losses in supply chain (Ominski et al., 2021).

The analysis of food loss could be tackled by categorizing losses from agricultural production, post-harvest handling and storage, processing and packaging, distribution and consumption in both developed and developing countries(Gustavsson et al., 2011). The causes of food waste in both developed countries could be due to mechanical malfunction such as poor temperature management, cool and heat sensitive, expiring dates of food, leftover and kitchen wastes which could be tackled whereas in developing countries causes of food waste starts from lack of basic infrastructure, storage, market, poor packaging(Gustavsson et al., 2011). In the developed countries, prevention of food waste should focus in individual behaviours from restaurants to household levels whereas in developing countries focus should be in its infrastructure, storage, retail and distribution system (Girotto et al., 2015).

It is estimated that about 25% from total food purchased by households in European union (EU) are wasted which has caused the European commission (EC) to start implementing rules and polices to prevent and reduce the food wastage (Canali et al., 2017). EU estimated the projection of food waste to be 126 million tonnes by the year 2020 (Salomone et al., 2017) whereas total edible food waste by united states of America is about 70 million metric tons (Dou et al., 2016). Food waste has an enormous impact and emits an annual carbon foot-prints of 3.3 giga-ton of carbon dioxide equivalents (Heller et al., 2019).

During the post-harvest system qualitative and quantitative food loss occurs such as harvest to consumption refers as post-harvest losses (Hodges et al., 2011). Qualitative and quantitative food loss occurs mostly in fruits and vegetables whereas losses are less at production and harvesting stage in the Europe , North America and Industrialized Asian countries are low (Hailu & Derbew, 2015). About 15 to 50% of vegetables and fruits loss occurs during post-harvest stages (Soomro et al.).

The gap between facilities of transportation, storage, processing and packaging in developed and developing countries is significant which leads to minimum food waste in early phases in developed countries (Liu et al., 2016). Transportation plays important role in adding value chain of food products by moving products to storage, processing facilities and market places (Kumar & Kalita, 2017). Lack of proper infrastructure during transportation including cold store and handling equipment causes spoilage and damage of food (Parfitt et al., 2010). In developing countries, amount of food are lost in storage are high as crops grown are seasonal and stored for seeds and as food reserves in traditional stores resulting in damage by pests and diseases (Kumar & Kalita, 2017). Storage facilities of grains and fruits and vegetables requirement are different as fruits and vegetables are perishable crops with short shelf-life (Parfitt et al., 2010) emphasizing temperature regulation and packaging for longer storage of fruits and vegetables is critical as it is not stored for longer time whereas for grains proper storage facilities along with proper packaging, temperature regulations, pests and rodent control are crucial (Costa, 2014).

Packaging is essentials process to maintain the quality of food products during transportation and storage (Han, 2005). Incorrect packaging system during processing, or simple approaches without packaging causes food waste (Gooch et al., 2010). Plastic packaging reduces food waste during storage and transportation, which lead to less greenhouse gases emission from food waste (Gooch et al., 2010). Packaging protects food from 3 external influences such as

chemical, biological and physical (Marsh & Bugusu, 2007). However, its impact in global plastic waste production has increased drastically as the plastics used in packaging are increasing oil consumption and about 30% of the plastics used are not disposed approximately (Dilkes-Hoffman et al., 2018). The problem especially occurs in the developing countries where the plastics used in packaging are disposed in open-area and landfills as there are no alternatives associated with single time use plastics (Hoornweg & Bhada-Tata, 2012).

Food processing causes intentional and unintentional food losses and non-utilized by-products (Raak et al., 2017) and also losses in the form of residue, faulty batches, sample used in analysis and by-products (Raak et al., 2017). Food waste due to rejection by customers due to its appearance and expectation which may be caused by mechanical damage and food producing including farming, processing and carrier not following legal measures or government food protocols in production (Aschemann-Witzel et al., 2015).

Large contribution of GHG emission is through agriculture sector directly through soil and livestock farming and indirectly through fossil fuels, agrochemicals, machinery used which emits 2.3Gega tons carbon dioxide i.e. 17 and 34% global anthropogenic GHG emission (Smith & Gregory, 2013). In current situation ,emphasis on reducing food waste and producing food should be equal in order to better use of land , human efforts, investment (Kumar & Kalita, 2017). Various environmental constraint threatening the world such as climate change, land degradation and water scarcity is challenging the food security in future on the other hand issue of post-harvest losses is still being undermined with lack of research and funding related to post-harvest loss (Porat et al., 2018). Deterioration of land and water resource along with climate change could be reduced with decrease in post-harvest loss as emphasis on development of infrastructure in developing countries and decrease in post-harvest loss rather than just focusing on production to meet the food demand (Porat et al., 2018). Life cycle assessment (LCA) method contributes to analysis of food waste management through different eco-friendly solution which includes turning food waste in compost acting as fertilizer and different production chain (Mondello et al., 2017).

Figure 1. illustration of the value chain related to food loss and food waste

Table 1. Phases of value chain and causes of food waste and food loss at each phase

Phases of value chain	Causes of food loss and food waste
Post-harvest losses	• Early and late harvesting • Mechanical and labor malfunction during harvesting • Losses during processing, cleaning, grinding, winnowing, and drying
Storage	• Mechanical failure of raw materials • Damage by rodents and pest • Lack of proper temperature and humidity regulations • Improper handling of crops with short shelf life • Lack of modern storage facilities
Transportation	• Lack of proper roadways and transportation facilities like refrigerated trucks • Improper handling during loading and unloading
Processing and packaging	• Losses due to faulty batch, form of residue, sample used. • Malfunction of cold chain • Equipment malfunction
Supply chain and market	• Mishandling • Due to expiry date • Short shelf life • Lack of proper storage and exposure condition
Consumers	• Large portion of food • Large quantity purchase for household • Due to expiry date • Lack of storage and management of food with short shelf life

(Lemanowicz & Jasiulewicz, 2021)

Objective

The objective of the study was two-fold:

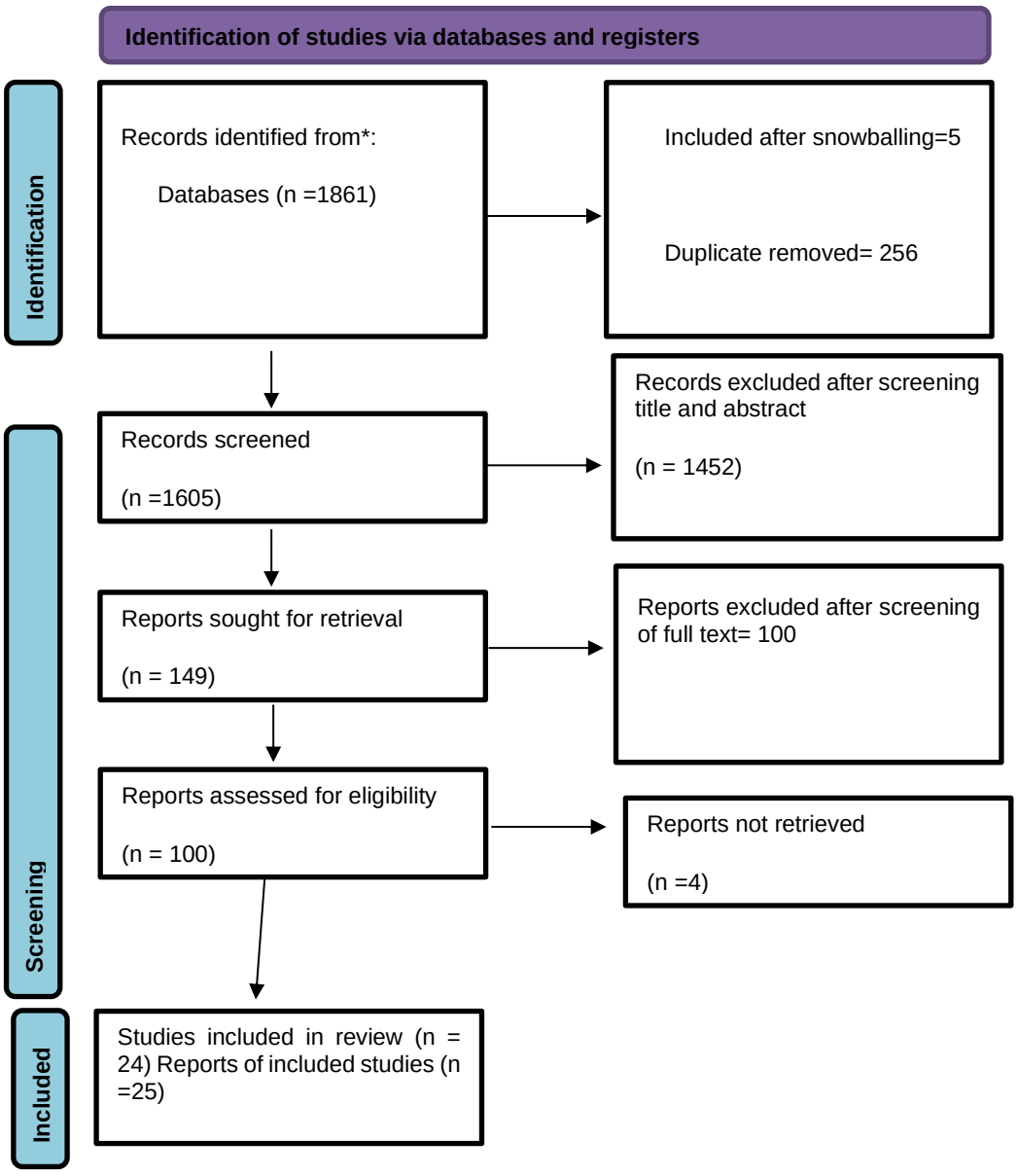
The research questions were:1) Where in the value chain are the losses taking place? And 2) Are there differences in developed and developing countries?

3. Materials and Methods

A systematic literature review was performed to detect studies comparing the food waste in developed and developing countries. Meta-analysis and research synthesis were used in analysis of food waste in developed and developing countries. To compare different studies with similar effect, standardized effect sizes had been used.

Data of qualitative and quantitative food waste from developed and developing countries were found using Google search engine such as Google Scholar and International Databases such as ISI Web of Science was used. Our focus was to obtain to trace the interest of scientific community as it has been difficult to obtain data on food waste in developing countries. Snow-ball sampling method was also applied to obtain interesting and useful information and data. Primary search terms combinations such as presented in Figure 2.

Figure 2. Flow diagram showing the database search process with number of records.



In Google scholar, and ISI Web of Science the key words for search strategies was “food waste management”, “food waste”,” food loss”, “post-harvest loss”, “quantification”, “food waste in household”, “developed countries”, “developing countries”, “value chain” were used.

The following script was used in my searches: (((((((AB=(quantification)) AND AB= (food waste)) OR AB= (food loss)) OR AB= (post-harvest losses)) OR AB= (food waste management)) OR AB= (food waste in household)) AND AB= (developed countries)) OR AB= (developing countries)) AND AB= (value chain)

The papers that were included the further analysis were thoroughly inspected and judged based on the following criteria

1. The study was related to food waste in developed or developing countries
2. The study included accessible data on losses food from farm to table i.e., post-harvest losses, transport, processing, packaging and households and restaurants.
3. The study paper was published in English in a scientific peer reviewed journal and was accessible: i.e., post-harvest losses, transport, processing, packaging and households and restaurants.

Information regarding the food waste in developed countries such as USA and European countries were available. Whereas such information as amount of food waste measured in standard unit kilogram, tons and in percentage is unavailable.

Information based on different features were tabulated into categories by post-harvest loss, storage, transportation, processing and packaging, retail, and consumer. The data were analysed using Microsoft Excel. Some of the data were in percentage form whereas some of the data had different reference unit. During analysis all the data were placed under same unit that i.e., tons and kg.

4. Results

This section deals with the data analysis and interpretation of the selected references. In total, references from 10 countries, amongst which five were developed countries and five were developing countries. Food waste differs in the value chain and from developed and developing countries. In the context of developed countries emphasis to elements value chain such as processing and packaging, consumers and supply chain and market was given as high amount of Food Waste (FW) occurred in these stages. As in developing countries food loss occurs in the initial stages of value chain i.e., post-harvest, storage, packaging and processing, market chain and households. Thus, lack of infrastructure including cold storage, refrigeration, modern harvesting technologies and trained manpower resulted in food loss in initial phases which was very high.

In developing countries, data was collected from post-harvesting stages to consumer level. In context of developing countries availability of data in the stages of value chain was less. Due to lack of proper research and division of population amongst rural and urban area access of legit data from both ends had difficulties of access. Research related to food waste were conducted in urban areas which could be either individual cities or cluster of urban cities. Hence, data from the rural areas of developing countries were tough to obtain.

The major contributing factors in developed countries was food being discarded at consumer level and processing and packaging. Food was discarded for passing its expiry dates, leftovers, and not being purchased due physical appearance of food products in the market. Whereas food waste in developing countries begins from the field and continues through the storage, as the quality of the storage is often poor. Due to lack of infrastructure such as cold chain, transportation and harvesting technology were the major contributing factors.

4.1 Annual food waste in developed countries

Table 2 shows the amount of food waste in developed countries in stages of value chain. It shows the total amount of food waste (FW) in tons. Amongst the 5 countries USA was highest producer of food waste (FW) with 440,922,452 tons whereas Norway being the lowest with 385,000 tons. Likewise, consumers or households and retail was largest producer of FW with USA and Canada being largest producers (Table 2).

Table 2. Amount of FW in developed countries in stages of value chain

Developed countries	Total amount of FW (tons)	Food waste (kg per person	Processing and packaging (kg per person)	Consumer / households (Kg per person)	Supply chain and market (kg per person)	Reference
Norway (A) Population (P)=5.2 mil	385,000	73 kg	18 kg	43kg (B)	9.8 kg	A= (Stensgård & Hanssen, 2016) B= (Szulecka et al., 2019)
Germany P=82.3 mil	18,700,000	82 kg	38 kg	93.9 kg	15.9 kg	(Sedlmeier et al., 2019)
Sweden P=9.6 mil	1,010,000	105 kg	17.8 kg	40.6 kg	70 kg	(Gjerris & Gaiani, 2013)
USA P=316.1 mil	440,922,452	90.7 kg	104.6 kg	94.9 kg	66.6 kg	(Nunley, 2013)
Canada P=34 mil	39,132,052	115 kg	207 kg	586.9 kg (51%)	126 kg	(Gooch et al., 2010)

Annual food waste of 5 different countries from Europe and North America i.e., Norway, Germany, Sweden, Canada, and United states of America were analysed. The amount of food waste also depends upon then population of a country as data were also collected based in per capita FW. Here, out of 5 countries America produces large annual food waste whereas Norway being lowest with 385,000 tons food waste whereas the United States being the producers of food waste with 44 million tons (Figure 3).

Most food waste in developed countries are beyond farm-gates, larger amount is by consumer behaviour and supply chain and market. Emphasizes on processing and packaging, retails and households are given as it was the major contributor of food waste in developed countries. Table 2 indicated major contributing factors for United states of America was processing and packaging as it produced 104kg per person of waste. In supply chain and market, food grading to specify product has led to food waste. Cosmetic appearance and intolerance of sub-standard foods (small and large size) increases rejection of food products which is later discarded as it goes unsold due to physical appearances.

In consumer or households FW data from restaurant, canteens, hospitals, and other service sectors were not included due to lack of adequate data. Food wastage generated in consumer level due to over purchasing of grocery items, throwing leftover, food passing expiry dates, socio-economic trends, eating habits and cooking skills was reason behind such quantity of food waste. In Norway, 67% of waste are generated from household levels. Other developed nations in the Table 2 shows similar trends in the food waste in household level due to its population. Unsurprisingly, the countries large population generates large household waste with Canada and USA generating 586kg per person i.e., 51% of total food waste and 94kg per person. Prevention of food waste is possible by shifting the focus towards individual behaviours from restaurants to household levels as large quantity of food wasted in those area of value chain (Figure 4).

With the time taste of humans have also evolved from consuming fresh food to various processed foods for its variation in taste and have longer shelf life. Processing helps to increase economic value of agricultural product. Food packaging play critical role in prolong product shelf life of food by conserving moisture. However, during the processing and packaging millions of tons of food waste in generated through faulty batches, mechanical malfunction of cold chain, equipment malfunction. Canada and United states losses 207kg per person and 104kg million tons respectively during the processing and packaging. Norway losses throughout the processing and packaging is 21% of its total food waste which is 18 kg per person. To meet the demand in market size and shape of food items are minimized but the major problem of packaging must be the plastics used which as mostly single use plastic which is not eligible to recycle and reuse. These are basically thrown in landfills and has hazardous environmental effects.

Food waste in supply chain and market occurs due to malfunction of equipment, aesthetic appearance of food, and food passing expiry dates. Here, food waste at market and supply chain Canada with 126 kg and Norway with 9.8kg the largest and lowest producer of waste.

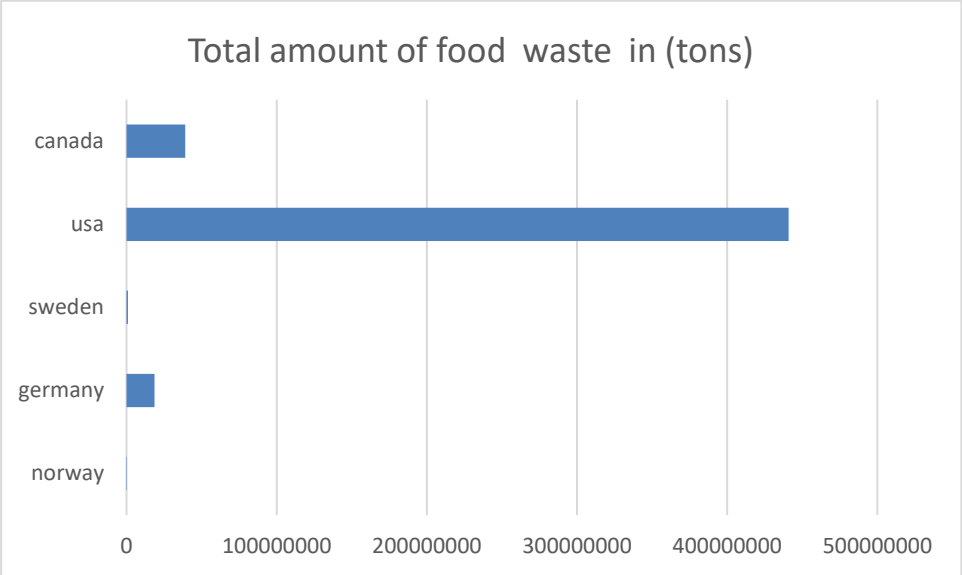


Figure 3 illustrates annual food waste in developed countries.

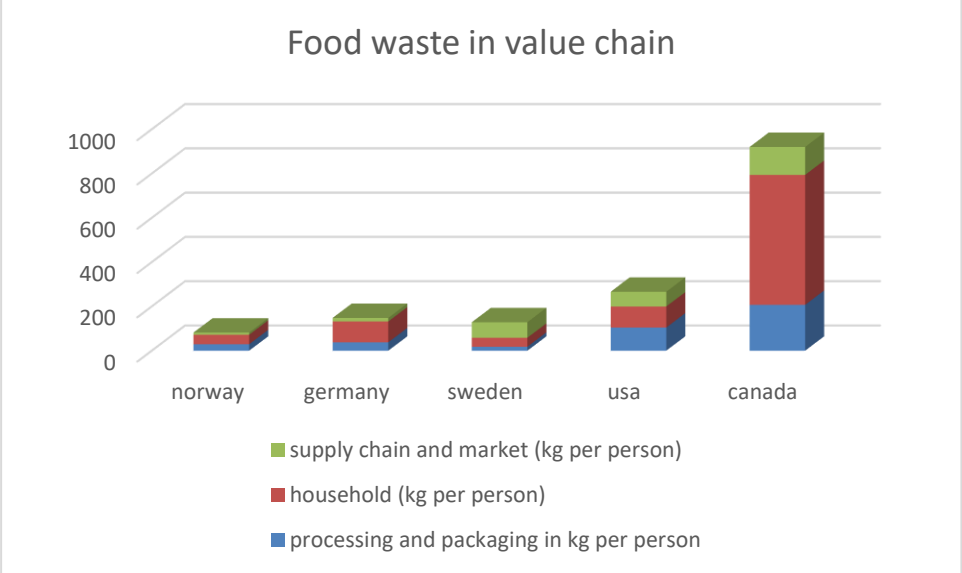


Figure 4 represents the FW in stages of value chain in developed countries

Environmental impacts due to food waste in developed countries based on carbon emission, food waste per capita per year, land used, and oil used and economical losses (Table 3). The food waste has significant toll on environment which in future lead to deforestation, water scarcity, energy and fuel scarcity and contribute to climate change.

Table 3 Environmental impacts due to food waste in developed countries based on carbon emission, food waste per capita per year, land use and oil used and economical losses

Developed countries	Carbon emission per year from total FW (Tons)	Waste (kg per person per capita	Land use and oil used	Economic loss (Per person per year)	References
Norway	1.3 million	73kg		5800 NOK	(Stensgård & Hanssen, 2016)
Germany (A)	48.47million (B)	82kg (C)		234 euro (D)	A= (Leverenz et al., 2021) B= (Eberle & Fels, 2016) C= (Vowell, 2019) D= (Bräutigam et al., 2014)
USA	113 million (A)	90.7kg (B)	300 million barrels (C)	390 dollars (D)	A= (Venkat, 2011) B= (Nunley, 2013) C= (Hall et al., 2009) D= (Vowell, 2019)
Sweden	6.8million (A)	30 kg (B)		146 euros (B)	A= (Brancoli et al., 2020) B= (Gjerris & Gaiani, 2013)
Canada	45 million (A)	85kg (A)	348 m^2 per person per year (A)	794Canadian dollar (B)	A= (Von Massow et al., 2019) B= (Gooch et al., 2010)

4.1.1 Environmental impacts due to food waste

The table 3 illustrated the different environmental impacts due to food waste on developed countries. The environment impacted from the landfills of food waste which producing harmful methane gas, carbon emission form burning of fossil fuel during production in intensive farming and transportation of produces goods, overuse of land and water resource for production to fulfil the enormous demand of food. Production of food consumed millions of hectors of land, fuel in form of millions of barrels of oil and water which is supplied through rainwater and irrigation from many water resources. After all the resources used for the production and supply of food from farm to table food items being discarded from all the food chains results in waste of those resources and the food produced itself. The effects of these wastage have environmental as well as economic consequences as billions of dollars are invested throughout the production to the value chain of the food products.

4.1.2 Carbon emission per year

The carbon emission from inputs in animal production including feeds needed to feed the animals per unit is higher. The carbon emission from transportation, processing and storage of the food items should also be taken into consideration. Generally, carbon emission from meat, cheese and milk products are significantly higher than fruits and vegetables. America emitted the largest amount of carbon in the atmosphere through their food industry i.e., 113 million metric tons per year. Individually, Sweden produces 0.66 kg per person of carbon per year which is half of what Canada produces which is 1.2 kg per person per year.

4.1.3 Waste generated per person per capita

However, waste generated per capita in developed countries are significantly higher where amongst selected 5 developed countries the lowest waste generated was 30 kg per capita in Sweden and the largest being in united states of America with 90.7 kg per capita. Since household level are the most significant producer of food waste in the western countries the waste generated per person per capita will always be significantly high. Norway, Germany, and Canada per person per capita is double as Sweden i.e., 73kg, 82 kg and 83 kg respectively. Taking Sweden as an example action similar from Sweden should be initiated in other countries to reduce food waste per capita.

4.1.4 Land used or oil used

Out of 5 countries data were found only from 2 North American countries United states and Canada. America calculates resource on basis of barrels of oil used throughout the value chain. 300 million barrels of oil throughout the value chain. Food waste in large quantity means waste of those valuable resources as well. Whereas Canada calculates its resource based on total area of land used which is 348 m^2 per household per year.

4.1.5 Economical loss

With the total amount of food waste during the value chain the economic loss in all the countries would be astronomically high. Data were obtained in entirety of economical loss of country and economical loss per person per capita. Economical loss in Norway and Canada was 22 billion Norwegian krone and 27 billion Canadian dollar. Germany loses 234 euro per person per capita and United states with 390 per person per capita. Sweden amongst all the countries were the lowest producer of food waste with 146 euros per person per capita.

4.2 Food waste in developing countries

In context of developing food loss from production to consumer level through value chain occurred due to infrastructure, technology, and knowledge. It showed the total amount of food waste in tons. It also represents stages of value chain i.e., post-harvest, storage, processing and packaging, supply chain and market, and consumer.

The table below (Table 4) shows the Food waste and losses annually and in stages of value chain. Data of five developing countries India, China, Thailand, Kenya, and Bangladesh were collected where China was largest producer of FW and Thailand being lowest. Research in urban areas were available but data regarding rural areas were unavailable which made finding data for developing countries difficult. Likewise, with the available data in the table illustrate post-harvest and storage has large Food losses in developing countries.

Table 4. Annual food waste in value chain in developing countries

Developing countries	Amount of FW (million)	Food waste per person (kg)	Storage (kg per person)	Post-harvest (kg per person)	Household / consumer (kg per person)	Processing and packaging (kg per person)	Supply chain and market (kg per person)	References
India (A) P=1.296 billion	125ton	96 kg	29kg	62.5kg	10.4kg	7.8 kg	19kg	A= (Gangwar et al., 2014)
China (B) P^n=1.3 billion	195ton	150kg	33kg	32.5kg	38kg	5.7kg	21kg	B= (Liu, 2014)
Thailand P^n= 63 mil	15ton	248kg		39.9kg				C= (Wattanasilp et al.) (2001)
Kenya (D) P^n =53.77mil	19ton	350kg		123kg	16kg			D= (Huho et al., 2020)
Bangladesh (E) P^n=166.5million	37ton	220kg		92kg	22.8kg	14.21kg	12.8kg	E= (Ananno et al., 2021)

With countries like India and China with half of the world population feeding and minimizing the food waste and loss in value chain is difficult which was illustrated in table 4 as those two countries were the largest producers of food waste with 125 million and 195 million tons. A single country China or India producing food waste equivalent to entire European Union (EU). The table 4 illustrated the food waste per person per capita almost above 100 kg. In the developed countries, household and consumers contributed largely to food waste per capita whereas food waste in developing countries spread throughout the value chain form production to the stages of value chain. Specific data with large cities and provinces are available in consumer level but due to lack of collective data of entire country solid number in consumer level are tough to be found.

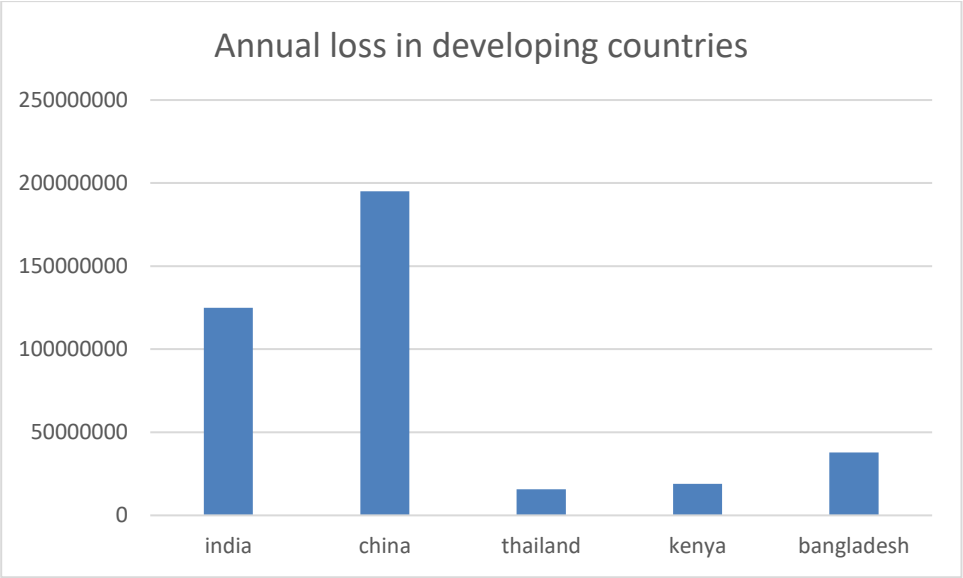


Figure 5 illustrates annual food waste in developing countries.

In the developing countries, the amount of food loss in different value chain is higher than in developed countries where food waste in consumption level is high. Emphasis was given to the various value chain losses such as post-harvest, storage, retail and wholesale, processing and packaging and household level. With countries like China and India having population of over a billion people the quantities of food losses in those countries in value chain was astronomically large i.e., with 195 million tons and 125 million tons respectively (Figure 5). These number are enough to feed entire continents. The data in table 4 illustrated food loss during post-harvest period was high with India losing 62.5kg per person of food and China with 32.5kg per person in post-harvest losses is significantly large with the total population in both countries.

With these countries lacking infrastructure during different value chain causes losses in transportation, post-harvest, processing and packaging, retail, and wholesale. During storage China and India loses 33 and 29 kg person food respectively. Unfortunately, due to lack of proper data of other 3 countries storage loses in developing countries was justified countries with available data. Household food waste compared to developed countries are minimum where China producing 38kg per person and India with lowest with 10.5kg per person. Kenya and Bangladesh produce 16kg and 22kg respectively. In the developed countries, people are less depended on processed and packed food where largest producer of food wastage was Bangladesh with 14.21 kg per person and India and China with 7.8kg and 5.7kg per person.

With the increase in global population and food waste various projects by advocacy groups, individuals and countries are being introduced to reduce global food waste. The value chain showed that post-harvest loss in developing countries contributes factor in compared to other value chain are higher.

Table 5. Environmental impacts due to food waste in developing countries based on carbon emission, food waste per capita per year, land use and oil used and economical losses

Developing countries	**Carbon emission per year (tons)**	**Waste generated per person per capita**	**Land used and oil or energy used per year**	**Economical loss**	**References**
India	64.1 million (A)	50 kg (B)	300 million barrels	15.19 billion USD (A)	A= (AGARWAL et al.) B= (Matharu et al., 2022) C= (Parlińska & Pagare, 2018)
China	60.8 million (A)	43.8kg (B)	60502 Mm^3 Land used (A)		A= (Sun et al., 2018) B= (Ananno et al., 2021)
Thailand		51.1kg			(Thi et al., 2015)
Kenya	4.4 million (A)	61 kg (B)		96 USD per person (A)	A= (Huho et al., 2020) B= (Thi et al., 2015)
Bangladesh	9.53 million (A)	91.25kg (B)	17215 Mm^3 Land used (A)		A= (Ananno et al., 2021) B= (Sujauddin et al., 2008)

4.2.1 Carbon emission per year

The carbon emitted throughout production and distribution of food products throughout the value chain contributes to large amount of carbon emission. India and China while having large population density than of United states of America emits less carbon than America as the larger number of populations is still dependent in subsistence or traditional farming which used low number of machinery and equipment. Carbon emission due to the food waste considerably high in India and China with 64.1 and 60 million tons per year (Table 5). Amongst the developing countries Kenya was the lowest emitter of carbon with 4.4 million ton per year. Due to the lack of availability of data regarding the environmental impacts in Thailand data related total carbon emission per year was unavailable.

4.2.2 Waste generated per person per capita

Food loss in developing countries mostly contributed by the lack of infrastructure and facilities, modern equipment's, training, and knowledge in value chain. However, food waste by individual per capita was also high in quantity. Bangladesh with 91.25 kg per person generates highest food waste per capita whereas China being lowest with 43.8 kg per person per capita. India, Kenya and Thailand generated 50kg, 61kg and 51.1kg respectively.

4.2.3 Land used and oil used

Energy used in context of India was measured in the amount of oil or fuel used which was about 300 million barrels from production to value chain. China and Bangladesh used land used during as the measuring factor. China used about 60502 Mm^3 and Bangladesh used 17215.2 Mm^3. Kenya and Thailand data related to energy used was unavailable and not presented in table 5.

4.2.4 Economical loss

Food waste not only effects the environment but also proves to be huge financial burden to the country. Each plate or each kg of food going to waste causes environmental damage it also contributes loss in financially with the energy used to produces, transport and conserve the food until it reaches the plates. India alone losses 15.1 billion USD through food waste in per capita which are total GDP for many countries in the world. Kenya also loses 96 USD per person per year which is large amount considering the income of people. China, Bangladesh, and Thailand had lack of data regarding the financial loss faced by its country.

Therefore, environmentally emphasis should be given to decrease in food waste and loss in different value chain as the demands of food will grows each day with increasing population. And solving the food crisis in future would not be possible by just increasing the production of food, reducing the food loss in value chains, and changing our food culture by limiting wastes from all the sources such as restaurants, canteens and households will help fulfil the demand of food.

5. Discussion

The study analysed the food waste or food loss in various stages of value chain throughout 5 developed and developing countries. The meta-analyses emphasize on food waste in developed countries as food in developed countries are discarded mostly from the consumer level which are based on the freshness, food habits and expiry dates. The literature was differentiated as food waste in developed countries and food loss in developing countries based on the impacts on the value chain. In the developed countries Post-harvest losses are minimized in food industry with government incentives and food by-products are used to produce other marketable products minimizing the financial loss due to PHL (Hodges et al., 2011).

Whereas, in developing countries food loss are the major contributing factor of food waste as large amount of food loss occurs during the value chain due to lack of infrastructure and other facilities such as roadways, post-harvest losses, proper storage, due to pest and rodent and proper refrigeration. China alone has 250 million small farmers where the food loss occurs during production, post-harvest handling, storage facilities and lack of transport and technologies(Liu, 2014). Post-harvest management of production from those 250 million farmers is a huge task as the products produced from those farmers are to be collected, properly stored and distributed amongst market and consumer. Distribution of all the produced goods from those number of farmers comes with its own challenges. All the governmental entity should be responsible for the food loss and waste in their respective countries. Countries like India and China with the huge economy incorporated in the status of developing countries is due to the uneven financial status amongst the rich and the poor. People involving in subsistence farming produces to feed its family and sell surplus food.

5.1 Gaps to be filled in developing countries

Research and information on critical loss points in the food value chains for better understanding and finding solutions to reduce the losses. Finding causes and solution regarding the subsistence farmers. Financial evaluations and benefit analysis of the intervention to losses management. Removing the gap between technology and information to manage food loss and waste

In the developed countries like Sweden for the likes of reduction of food waste Swedish food waste reduction governance was created SaMMa (Swedish collaboration group of reduced food waste) in 2012 for the purpose of food waste prevention, information exchange and assisting in reductio of food waste (Szulecka et al., 2019). In UK the waste and resources action program (WRAP) launched a campaign “love food hate waste” which help establish support for sustainable waste management and promoting recycling throughout the country (Leverenz et al., 2021). Government should be accountable towards the food waste and losses as it affects the environmental sector as well as loss in financial sector with billions of dollars. In context of developed countries such as UK 74% food waste is at household level and amongst that 78% waste is classified as avoidable waste (Jellil et al., 2018) which are the food discarded based on its expiry dates, taste of consumer, eating habits and its quality. These ways of food waste could be handled or minimized through educating consumers regarding the unplanned grocery shopping, over purchasing, proper storage of cooked food, quantifying their food intakes.

Products hold different carbon intensities based on industrialized intensive farming and subsistence farming. For example, vegetables and fruits produced in industrialized developed countries is more carbon intensive due to use of intensive means of production such as in green houses than vegetables produced in developing countries.

Food waste further along the chain, the more carbon intensive the wastage. For example, a potato spoiled at the harvesting stage will have low carbon footprint than potato chips wasted at consumer level as the harvesting, processing, packaging, transportation, and storage accumulates additional greenhouse gases. In developed countries, per capita food waste footprint on climate in higher than developing countries, due to wastage patterns on the consumer level being high. The major issue in 21st century have been climate change which exacerbates with significant increase of carbon footprint. The link between climate change and food loss and waste are recognized and its link of dependency between them are also recognized. We are increasingly seeing how extreme weather events are disruptive to both agriculture and supply chain resiliency. Globally, farmers losses their crops due to untimely rainfall, drought, heat wave, hail, and other climatic issues. And, the intensive industrial agriculture, supply chain and food loss and waste contribute to millions of tons of carbon footprint which further contributes to climate change. The food waste filling the landfills

produces copious amount of methane- a greenhouse gas more potent than carbon dioxide. The single time use plastic and packaging used to increase the self-life of the agricultural commodities later are thrown away at landfills. In Intensive farming, single use plastic is used in making green-house and mulching of soil which after its used are discarded. Globally, plastic pollution is the serious issue threatening our land and marine ecosystem.

For sustainable approach food production is not only an option with the estimated population in future. Food waste not only decreases the availability of food, also carries environmental and financial burden. An approach towards food waste management could bring value to discarded food which afterwards provide financial and environmental aid. Regarding financial aspect both developed and developing countries lose billions of dollars each year and the carbon emission during production and its value also have detrimental effect on the environment.

Food loss and waste reduction approach at all stages of value chain for many reasons are dependent on the local condition within each country. At global level, the pattern of food loss and waste are clearly visible, developed countries wasted food in processing and consumer level whereas food loss in developing countries occurs during production and post-harvesting. Reduction of food waste in developed and developing countries needs different approach. In context of high-income countries, wastage at distributing and consumer level is high due to aesthetic preferences, arbitrary expiry dates, bulk grocery shopping and food consumption culture. Foods from restaurants and hotels are largely discarded, food that are easily consumable due to the hotels and restaurant policies.

Many non-profitable organizations collaborate with households, companies, politics, and education to tackle food waste. Government policies are critical for implementing and educating public towards reduction of wastage in the community level. Educating pubic at community level and children at schools' crucial approach towards reduction of food waste. For example, government in France implemented rule of distributing of food close to expiry and damaged goods to shelter than discarding it in dumpster. Different application such as "Too good to go", "Food2Change", "Karma", "Matsmart", contributes to reduction of food waste by selling their extra products at discounted price and people having extra food at home rather than throwing away giving at cheaper price. This application brings together millions of households, companies, restaurants, and hotels together in the fight against food waste.

However, tackling food waste and loss at developing countries is different gravy as the wastage is high at production and post-harvesting. In developing countries, lack of infrastructure, transportation, knowledge of proper storage and food handling, and environmental conditions favours in food loss. Post-harvest handling reductions are feasible through improvement in knowledge through training, adopting improved technologies, better handling practices, market availability. Subsistence farmers should be properly trained, subsidized, provide quality seed and technologies. For reduction of food loss in production and post-harvest level, development of infrastructure, modern equipment's, training and educating, storage facilities, refrigeration, and market availability throughout the country is essential.

5.2 Limitations

The main limitation of the study is the lack of availability of the secondary data in few of the developing countries due to limited research conducted regarding the food wastage. China and India with vast diversity amongst geography, population, and overall development, divided by province and states which consists of cities as well as rural areas will millions of populations. Data regarding food waste from cities and larges states are accessible but data regarding food loss from rural areas are limited. Required data for the value chain and its environmental constraint are unavailable so, research papers of different year of publication were included. In the chart o developing countries, does not properly represent the value chain due to data unavailability for countries like Thailand, Kenya, and Bangladesh.

6. Conclusions

Food waste is issue at national and international levels. Little research has been conducted on economic and environmental impacts of food waste. The current study was the systematic review with meta-analysis of some of the published work with a quantification of food waste disposal in developed and developing countries.

Food waste is a complex issue with multiple factors impacting the food wastage in value chain. It is possible to identify the stages in the value chain where much of the food waste and food loss occurs, allowing to have holistic approach towards minimizing the food waste. This will be important for food security, but also for environment protection, and the economy of the world The environmental impact during the production, transportation, storage, and distribution level in form of fuel consumption, water consumption, gases emission during refrigeration and gases emitted line methane and carbon dioxide causing emission of greenhouse gases GHS further decrementing our fragile environment.

Therefore, for sustainable future fulfilling the demand of an increasing population, which is predicted to be 9 billion by 2050, a reduction of food waste and loss is as vital as production because reduction of food waste saves the valuable resources that had been invested in them, benefits our environment by minimizing the production of harmful gases, minimum land, water, and energy use. So, zero waste from production to consumer level in future would fulfil the demand of growing population and protect our environment.

References

AGARWAL, M., AGARWAL, S., AHMAD, S., SINGH, R., & JAYAHARI, K. (2021). FOOD LOSS AND WASTE IN INDIA: THE KNOWNS AND THE UNKNOWNS. https://www.wri.org/research/food-loss-and-waste-india-knowns-and-unknowns

Ananno, A. A., Masud, M. H., Chowdhury, S. A., Dabnichki, P., Ahmed, N., & Arefin, A. M. E. (2021). Sustainable food waste management model for Bangladesh. *Sustainable Production and Consumption, 27*, 35-51.

Aschemann-Witzel, J., De Hooge, I., Amani, P., Bech-Larsen, T., & Oostindjer, M. (2015). Consumer-related food waste: Causes and potential for action. *Sustainability, 7*(6), 6457-6477.

Brancoli, P., Bolton, K., & Eriksson, M. (2020). Environmental impacts of waste management and valorisation pathways for surplus bread in Sweden. *Waste management, 117*, 136-145.

Bräutigam, K.-R., Jörissen, J., & Priefer, C. (2014). The extent of food waste generation across EU-27: Different calculation methods and the reliability of their results. *Waste Management & Research, 32*(8), 683-694.

Canali, M., Amani, P., Aramyan, L., Gheoldus, M., Moates, G., Östergren, K., Silvennoinen, K., Waldron, K., & Vittuari, M. J. S. (2017). Food waste drivers in Europe, from identification to possible interventions. *9*(1), 37.

Cohen, J. E. (2001). World population in 2050: assessing the projections. Conference Series-Federal Reserve Bank of Boston,

Costa, S. J. (2014). Reducing Food Losses in Sub-Saharan Africa. *An 'Action Research'Evaluation Trial from Uganda and Burkina Faso*.

Dilkes-Hoffman, L. S., Lane, J. L., Grant, T., Pratt, S., Lant, P. A., & Laycock, B. (2018). Environmental impact of biodegradable food packaging when considering food waste. *Journal of cleaner production, 180*, 325-334.

Dou, Z., Ferguson, J. D., Galligan, D. T., Kelly, A. M., Finn, S. M., & Giegengack, R. (2016). Assessing US food wastage and opportunities for reduction. *Global Food Security, 8*, 19-26.

Eberle, U., & Fels, J. (2016). Environmental impacts of German food consumption and food losses. *The International Journal of Life Cycle Assessment, 21*(5), 759-772.

Gangwar, R. K., Tyagi, S., Kumar, V., Singh, K., & Singh, G. (2014). Food production and post harvest losses of food grains in India. *Food Science and Quality Management, 31*, 48-52.

Girotto, F., Alibardi, L., & Cossu, R. (2015). Food waste generation and industrial uses: a review. *Waste management, 45*, 32-41.

Gjerris, M., & Gaiani, S. (2013). Household food waste in Nordic countries: Estimations and ethical implications. *Etikk i praksis-Nordic Journal of Applied Ethics*(1), 6-23.

Gooch, M., Felfel, A., & Marenick, N. (2010). Food waste in Canada. *Value Chain Management Centre, George Morris Centre, November*.

Gustavsson, J., Cederberg, C., Sonesson, U., Van Otterdijk, R., & Meybeck, A. (2011). Global food losses and food waste.

Hailu, G., & Derbew, B. (2015). Extent, causes and reduction strategies of postharvest losses of fresh fruits and vegetables–A review. *Journal of Biology, Agriculture and Healthcare, 5*(5), 49-64.

Hall, K. D., Guo, J., Dore, M., & Chow, C. C. (2009). The progressive increase of food waste in America and its environmental impact. *PloS one, 4*(11), e7940.

Han, J. H. (2005). New technologies in food packaging: Overiew. In *Innovations in food packaging* (pp. 3-11). Elsevier.

Heller, M. C., Selke, S. E., & Keoleian, G. A. (2019). Mapping the influence of food waste in food packaging environmental performance assessments. *Journal of Industrial Ecology, 23*(2), 480-495.

Hodges, R. J., Buzby, J. C., & Bennett, B. J. T. J. o. A. S. (2011). Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. *149*(S1), 37-45.

Hoornweg, D., & Bhada-Tata, P. (2012). What a waste: a global review of solid waste management.

Huho, J. M., Kosonei, R. C., & Musyimi, P. (2020). Sociodemographic Determinants of Households' Food Waste in Garissa Sub County, Kenya. *Budapest International Research and Critics Institute-Journal (BIRCI-Journal) Vol, 3*(2), 932-946.

Jellil, A., Woolley, E., & Rahimifard, S. (2018). Towards integrating production and consumption to reduce consumer food waste in developed countries. *International Journal of Sustainable Engineering, 11*(5), 294-306.

Kader, A. A. (2004). Increasing food availability by reducing postharvest losses of fresh produce. *ISHS Acta Horticulturea 682, International postharvest symposium*, 2169-2176. https://doi.org/10.17660/ActaHortic.2005.682.296

Kumar, D., & Kalita, P. (2017). Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. *Foods, 6*(1), 8.

Lemanowicz, M., & Jasiulewicz, A. (2021). Attitudes and Behaviour of Polish Consumers Regarding Food Waste in the Food Chain. *European Research Studies Journal, 24*(2), 636-648.

Leverenz, D., Schneider, F., Schmidt, T., Hafner, G., Nevárez, Z., & Kranert, M. (2021). Food Waste Generation in Germany in the Scope of European Legal Requirements for Monitoring and Reporting. *Sustainability, 13*(12), 6616.

Liu, C., Hotta, Y., Santo, A., Hengesbaugh, M., Watabe, A., Totoki, Y., Allen, D., & Bengtsson, M. (2016). Food waste in Japan: trends, current practices and key challenges. *Journal of cleaner production, 133*, 557-564.

Liu, G. (2014). Food Losses and Food Waste in China. https://doi.org/doi:https://doi.org/10.1787/5jz5sq5173lq-en

Marsh, K., & Bugusu, B. (2007). Food packaging—roles, materials, and environmental issues. *Journal of food science, 72*(3), R39-R55.

Matharu, M., Gupta, N., & Swarnakar, V. (2022). Efforts are made but food wastage is still going on: a study of motivation factors for food waste reduction among household consumers. *Asia-Pacific Journal of Business Administration*. https://www.emerald.com/insight/1757-4323.htm

Mondello, G., Salomone, R., Ioppolo, G., Saija, G., Sparacia, S., & Lucchetti, M. C. (2017). Comparative LCA of alternative scenarios for waste treatment: The case of food waste production by the mass-retail sector. *Sustainability, 9*(5), 827.

Nunley, M. (2013). From farm to fork to landfill: Food waste and consumption in America. https://scholarship.claremont.edu/pitzer_theses/37

Ominski, K., McAllister, T., Stanford, K., Mengistu, G., Kebebe, E., Omonijo, F., Cordeiro, M., Legesse, G., & Wittenberg, K. (2021). Utilization of by-products and food waste in livestock production systems: a Canadian perspective. *Animal Frontiers, 11*(2), 55-63.

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical transactions of the royal society B: biological sciences, 365*(1554), 3065-3081.

Parlińska, M., & Pagare, A. (2018). Food losses and food waste versus circular economy. *Problems of World Agriculture/Problemy Rolnictwa Światowego, 18*(1827-2018-3525), 228-237.

Porat, R., Lichter, A., Terry, L. A., Harker, R., & Buzby, J. (2018). Postharvest losses of fruit and vegetables during retail and in consumers' homes: Quantifications, causes, and means of prevention. *Postharvest Biology and Technology, 139*, 135-149.

Raak, N., Symmank, C., Zahn, S., Aschemann-Witzel, J., & Rohm, H. (2017). Processing-and product-related causes for food waste and implications for the food supply chain. *Waste management, 61*, 461-472.

Salomone, R., Saija, G., Mondello, G., Giannetto, A., Fasulo, S., & Savastano, D. (2017). Environmental impact of food waste bioconversion by insects: application of life cycle assessment to process using Hermetia illucens. *Journal of cleaner production, 140*, 890-905.

Sedlmeier, R., Rombach, M., & Bitsch, V. (2019). Making food rescue your business: Case studies in Germany. *Sustainability, 11*(18), 5101.

Smith, P., & Gregory, P. J. (2013). Climate change and sustainable food production. *Proceedings of the Nutrition Society, 72*(1), 21-28.

Soomro, A. H., Shaikh, N., Miano, T. F., Marri, A., Khaskheli, S. G., & Kumar, D. (2009, 2010). FOOD WASTE MANAGEMENT STRATEGIES IN FOOD SUPPLY CHAIN. *International Journal of Ecosystems and Ecology Science (IJEES), 11*(4). https://doi.org/ https://doi.org/10.31407/ijees11.413

Stensgård, A. E., & Hanssen, O. J. (2016). *Food Waste in Norway* (1762). (Report No: OR.17.16, Issue.

Sujauddin, M., Huda, S., & Hoque, A. R. (2008). Household solid waste characteristics and management in Chittagong, Bangladesh. *Waste management, 28*(9), 1688-1695.

Sun, S., Lu, Y., Gao, H., Jiang, T., Du, X., Shen, T., Wu, P., & Wang, Y. (2018). Impacts of food wastage on water resources and environment in China. *Journal of cleaner production, 185*, 732-739.

Szulecka, J., Strøm-Andersen, N., Scordato, L., & Skrivervik, E. (2019). *Multi-level governance of food waste: Comparing Norway, Denmark and Sweden* (1st ed.) https://www.taylorfrancis.com/chapters/oa-edit/10.4324/9780429460289-13/multi-level-governance-food-waste-julia-szulecka-nhat-str%C3%B8m-andersen-lisa-scordato-eili-skrivervik

Thi, N. B. D., Kumar, G., & Lin, C.-Y. (2015). An overview of food waste management in developing countries: Current status and future perspective. *Journal of environmental management, 157*, 220-229.

Venkat, K. (2011). The climate change and economic impacts of food waste in the United States. *International Journal on Food System Dynamics, 2*(4), 431-446.

Von Massow, M., Parizeau, K., Gallant, M., Wickson, M., Haines, J., Ma, D. W., Wallace, A., Carroll, N., & Duncan, A. M. (2019). Valuing the multiple impacts of household food waste. *Frontiers in nutrition, 6*, 143.

Vowell, C. M. (2019). Food Waste in German Households: A Policy Analysis. *Honors theses*. https://egrove.olemiss.edu/hon_thesis/1114/?utm_source=egrove.olemiss.edu%2Fhon_thesis%2F1114&utm_medium=PDF&utm_campaign=PDFCoverPages

Wattanasilp, C., Reubroycharoen, P., Kenharaj, R., & Chonchanachai, S. Evaluation of Efficiency and Utilization Biogas from Food Waste in Thailand.