# THE EFFECTS OF FOOD LOSS AND WASTE (FLW) ON GREEN HOUSE GAS (GHG) EMISSIONS

Food loss and waste (FLW) and greenhouse gas (GHG) emissions are produced at every phase in the global food supply chain, starting with agriculture and ending with consumers. In general, the food supply chain consists of four main phases: primary production, distribution and processing, retail, and consumption [1]. Primary production (agriculture), is the initial production of the raw materials used to make food products. Distribution and processing encompass the packaging, treating, and transportation of food after it is harvested. The retail phase involves the distribution of food from grocery stores, restaurants, and other food retailers. Consumption is the final phase of the food supply chain in which people ultimately eat the food. Although the farm-to-kitchen food supply chain can be generalized into these four steps, there are many other sub-processes within this food cycle.

FLW Throughout the Food Supply Chain

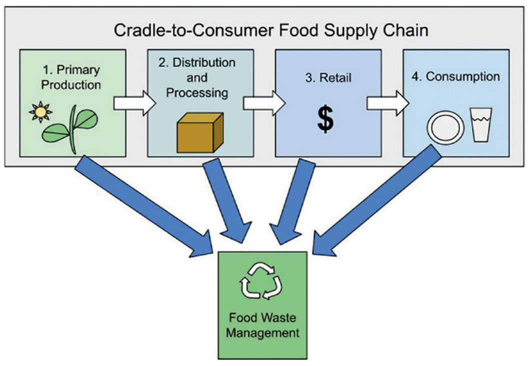


*Figure 1: The four main stages of the U.S. food supply chain [1]*

The U.S. food cycle is dynamic and complex with many points where FLW is generated. Within the first agricultural step of the food supply chain, agricultural inputs, and imports of raw food and materials are used to produce agricultural products. These products include crops, poultry, livestock, and fisheries. Imported and exported food enter and leave the food supply chain at various points, including as ingredients, raw commodities, and finished products. The food items that are imported and produced are distributed throughout retail outlets, such as grocery stores and restaurants. Each added layer to the food supply chain is another possibility for increased FLW.

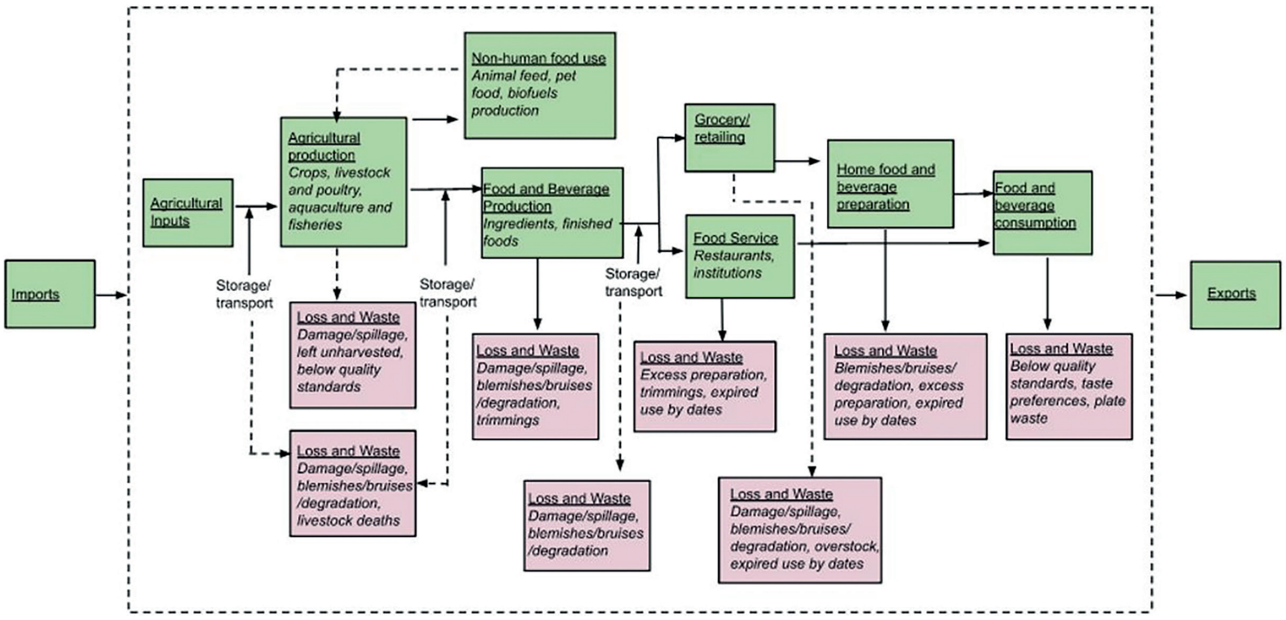


*Figure 2: In-depth schematic of the steps and stages within the food supply chain and FLW associated with each stage [9]*

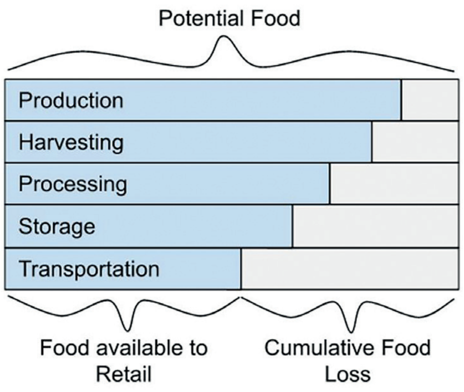


*Figure 3: Illustration of the loss of food from upstream FLW to downstream FLW [3]*

Within the U.S. food supply chain, as well as the global food supply chain, the upstream operations of primary production accounts for the most FLW out of the four phases of the supply chain. Production and post-harvest handling accounts for around 54% of FLW. The remaining 46% of loss occurs during processing, distribution, and consumption [10]. In upstream processes, many crops are unharvested. This FLW happens due to pests, disease, weather, and failure to meet quality standards [11]. FLW also occurs during agricultural production because of damage, degradation, or trimmings from food preparation [12]. FLW in retail stores and restaurants happens when food expires or is too close to its expiration date, when food becomes bruised or blemished, or food is not purchased. FLW occurs between all steps in the food supply chain during transportation,

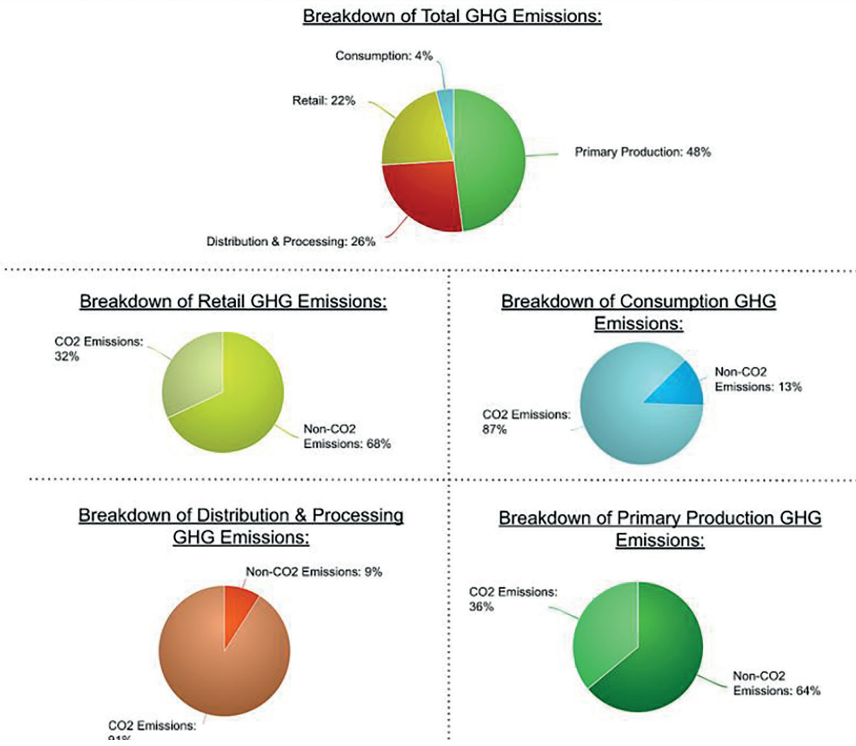


*Figure 4: GHG emissions produced during each stage in the food supply chain [1]*

handling, and storage because of operational shortcomings such as inadequate refrigeration during transport [13]. FLW in consumer homes and restaurants arises from excessive purchases, consumer preference, overabundant preparation, and food degradation [14, 15].

Municipal solid waste (MSW) accounts for institutional, commercial, and residential waste and includes waste from the grocery/retail, home preparation, and food service phases in the food supply chain [17]. In 2015, 39.7 million tons of food ended up as MSW, which is 15.1% of the total MSW generated by the U.S. that year. Out of the 39.7 million tons of food MSW, 2.1 million tons were composted, 7.4 million tons were used for combustion to produce energy, and 30.3 million tons ended up in landfills [16].

## GHG Emissions from FLW

The production and disposal of FLW leads to substantial amounts of GHG emissions. GHGs trap a considerable amount of the Earth's outgoing energy from escaping to space causing the retention of heat within the Earth's atmosphere. While GHGs are naturally found in the atmosphere, human activities have drastically increased the amount of GHGs in the atmosphere to unsustainable amounts. The increase in atmospheric GHG concentration from human activity is the primary cause of the 1-degree Celsius increase in the global air surface temperature that has happened over the past 115 years [26]. While this may seem like a negligible increase in temperature, this climate change has immense impact on global natural systems. Global warming has raised land, water, and air temperatures, caused variations in precipitation amounts and timing, decreased snowpack, led to a rise in sea level, and resulted in increased wildfires and hurricanes. GHG emissions are produced at all stages of the U.S. farm-to-kitchen food supply chain. The amount of GHGs created and the types of GHGs emitted vary by each stage and each process within the supply chain.

Primary production is the phase in which the most GHG emissions are produced within the food supply chain. Agricultural production contributes a far greater amount of GHG emissions than transportation. When GHG emissions from primary production and international transportation were studied, it was estimated that international transportation accounted for only around 3% of total emissions. Previous studies have concluded that primary production is responsible for the greatest amount of GHG emissions compared to the other three stages of the food supply chain. Primary production is responsible for around 48% of total GHG emissions in the food supply chain (Fig. 4). These emissions originate from a multitude of processes that make up primary production. For example, nitrous oxide is released into the atmosphere from manure management and nitrogen fertilization. Carbon dioxide is emitted from soil treatment practices, such as the reduction in soil carbon absorption which results in the release of additional carbon dioxide into the air. Large amounts of methane are emitted due to the enteric fermentation that occurs during the digestion process of ruminant animals, such as cattle, goats, and sheep. Methane is an extremely potent GHG, with a Global Warming Potential around 25 times greater than carbon dioxide [27]. Energy used by farm equipment also contributes to GHG emissions from food production.

Fertilizer production also results in GHG emissions. Many fertilizers contain chemicals that require high amounts of energy to manufacture, such as ammonia [2]. The energy needed to make fertilizers is usually obtained from burning fossil fuels, such as coal and natural (methane) gas, which results in the emission of carbon dioxide. The manufacturing of ammonia contributes between 1 to 2% of the worldwide carbon dioxide emissions [4]. In addition, crops only take in around half of the nitrogen being provided by fertilizers on average [5]. The remaining nitrogen remains unused and contributes to run-off in waterways or is being broken down by microbes in the soil. These processes release nitrous oxide, which is a GHG that is 300 times stronger per pound at retaining heat than carbon dioxide [7]. Although nitrous oxide makes up only a small portion of worldwide GHG emissions [6], it is still adding to the GHG emissions produced during the food supply chain.

A major consequence of FLW is the waste of resources that were used to produce the wasted food, such as water, fertilizers, and energy. The production and transportation of these resources leads to GHG emissions. The production, handling, and transportation of food throughout the food supply chain generates GHG emissions. Any food that ends up as FLW results in unneeded GHG emissions. U.S. FLW each year results in 170 million MTCO2e GHG emissions, excluding landfill emissions, which is equivalent to 42 coal-fired power plants. Roughly one third of all food produced in the United States is never consumed, resulting in the waste of food as well as the waste of resources used to produce this uneaten food [8]. FLW takes a significant toll on the environment through GHG emissions. During all stages of the food supply chain from primary production to consumption in the U.S., it is estimated that around 161 to 335 billion pounds of food is lost or wasted per year. This amount of food is approximately 35% of the U.S. food supply. This FLW is equivalent to 492 to 1032 pounds of food per person per year. Around half of this FLW occurs during the consumption phase of the food supply chain.

Animal products, especially cow-derived products, have been shown to make up a majority of the GHG emissions originating from FLW. Foods that are considered animal products are beef, lamb, veal, pork, poultry, eggs, fish, seafood, milk, and other dairy products. Animal products result in more than half of the energy and land used for food production, as well as over half of the GHGs emitted from FLW. These products also used the largest amount of fertilizer and water for irrigation. The category of food associated with beef, veal, and lamb were found to produce the greatest amount of GHG emissions within the retail and consumption stages of the food supply chain, followed by pork and dairy products (other than fluid milk). All animal products combined resulted in 73% of GHG emissions from retail and consumption FLW. However, animal products only accounted for 33% of FLW by weight and 23% of FLW by calories. It was also found that beef constituted 44% of farm-to-kitchen GHG emissions from FLW. All ruminant FLW (beef and dairy FLW) accounted for 60% of FLW GHG emissions. Although fruits and vegetables make up a much larger portion of FLW by weight than meat, poultry, and eggs, the animal-related products still make up a higher percentage of GHG emissions. This illustrates the potent impact that animal-related FLW have on GHG emissions.

## FLW-related GHG Emissions in the US

Large amounts of FLW are an inherent outcome of the U.S. food system due to the excessive overproduction of food and mismanagement of FLW reuse. According to the USDA, the amount of food consumed by people in the U.S. is much less than the amount of food produced for consumption. Various studies have examined the GHG emissions associated with FLW during each stage in the food supply chain. The figure below illustrates the findings of previous studies on the correlation between GHG emissions and stages in the food supply chain (see figure 6).

The U.S. currently creates more FLW and more FLW per person than any other country [20]; because of this, the U.S. food system is a significant contributor to anthropogenic GHG emissions compared to other countries in the world.. The U.S. also produces more animal food product waste and more food downstream than the global average [20]. Consequently, the environmental impact of each unit of U.S. FLW is greater than that of other countries. In 2017, the U.S. had annual per capita GHG emissions of 686 kg CO2e/person/year during all four stages of the food supply chain [20]. The global average in 2017 for the annual per capita GHG emissions during all four food supply chain stages was 331 kg CO2e/person/year [20]. In 2020, the consumption stage of the U.S. supply chain accounted for 167 kg CO2e/person/year of annual per capita methane and nitrous oxide [20]. The global average in 2020 for annual per capita methane and nitrous oxide in the consumption phase of the food supply chain was 45 kg CO2e/person/year [20].

In 2020, the U.S. was found to be the third largest emitter of FLW-related GHGs in the world with an annual emission of 222 million metric tons CO2e per year [1]. China and India were the only countries that trumped the U.S. on FLW-related GHG emissions. The U.S. is the only developed country on the list of the top 10 FLW-related GHG emitting countries. These top 10 FLW-related GHG emitting countries, in order of descending emissions, are China, India, U.S., Indonesia, Brazil, Nigeria, Russia, Pakistan, Mexico and Malaysia [1]. These countries are responsible for around 60% of global FLW and FLW-related GHG emissions [1].

## How Can FLW-related GHG emissions be minimized?

One effective strategy to decrease GHG emissions produced from FLW is to reduce the amount of FLW produced during the consumption phase of the food cycle. Although there are many steps that need to be taken in order to make the global food system more sustainable, halving FLW would play an important and essential role in minimizing GHG emissions [1]. Halving U.S. FLW would result in an annual environmental saving of 92 million MTCO2e GHG, which is equivalent to the CO2 emissions of 23 coal-fired power plants [1]. Current scientific projections indicate that halving the global FLW could lead to a 24% decrease in total global food system GHG emissions between 2020 and 2100 [1]. This would be a reduction of 331 Gt CO2e compared to the amount of GHG emissions produced by the current global food system FLW [1]. In order to achieve this level of GHG emission reduction, minimizing FLW from the consumption stage should be prioritized. Energy usage and GHG emissions occur in each phase along the supply chain. This means that cumulative energy use and GHG emissions increase as food moves farther downstream through the supply chain [1]. Therefore, reducing the amount of FLW created during the final stage of the food supply chain, which is the consumption phase, would have the largest impact on the reduction of GHG emissions. Studies have shown that halving FLW from households, restaurants, and food

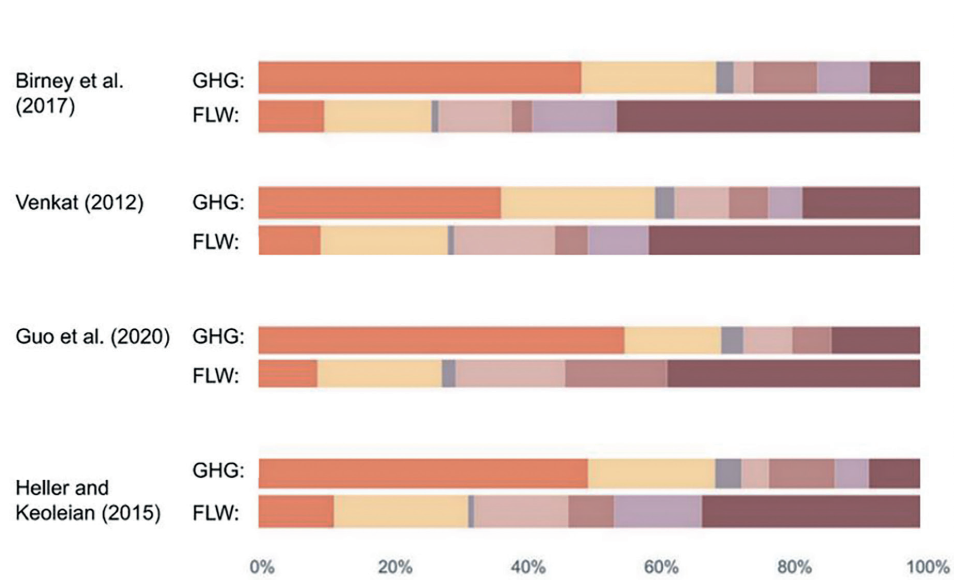


*Figure 5: Findings from previous studies on the GHG emissions by food category vs the total FLW composition based on food category [1,20-23]*

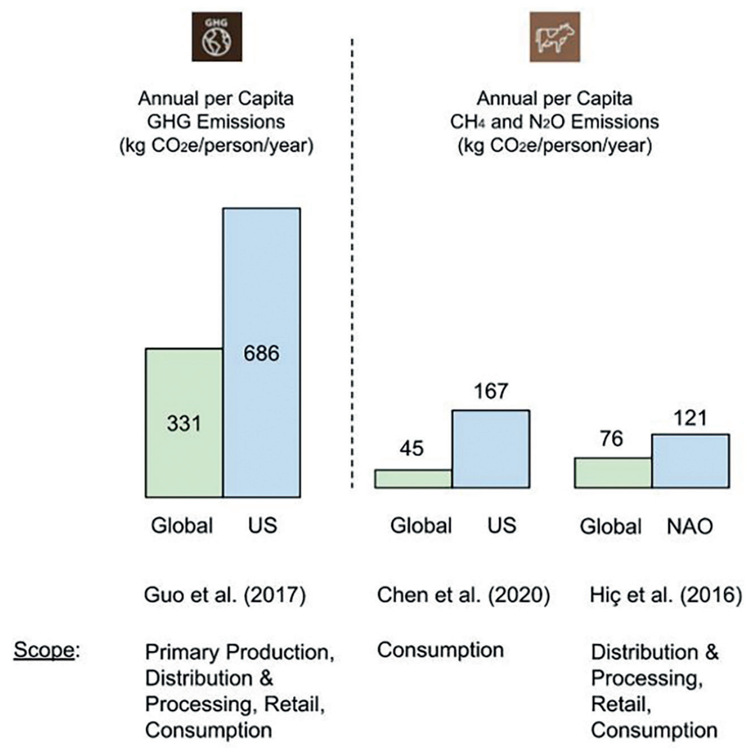


*Figure 6: Findings of previous studies on the GHG emissions produced by FLW [1,18-23]*

processing during the consumption phase would result in a bulk of the projected environmental benefits compared to other sectors [1]. Thus, it is crucial to reduce FLW in the consumption phase, especially from households, restaurants, and food processing sites.

Another factor that would reduce the amount of FLW-related GHG emissions produced is the decrease of FLW from resource-intensive foods such as animal products, fruits, and vegetables. The categories of animal products, fruits, and vegetables have consistently been found to be the largest contributors to the negative environmental impacts of FLW. Animal products, especially beef, have a very strong contribution to GHG emissions due to methane output. Although animal products make up less than one-third of the U.S. FLW, they are responsible for the largest share of phosphorus and nitrogen fertilizer usage and GHG emissions. Fruits and vegetables make up a bigger portion of U.S. FLW than animal products, and they are the second largest share of fertilizer utilization. Therefore, achieving a reduction in the FLW from the food categories of animal products, fruits, and vegetables will have more significant environmental benefits than reducing FLW in other food categories. Thus, the reduction of FLW from three food categories should be prioritized.

## Moving Forward

Options and learnings from other countries are available including those discussed above to reduce FLW-linked GHG emissions. While FLW is a dynamic issue that does not have a simple solution, addressing this concern will require action by the public as well as policy-makers. The U.S. along with many other countries adopted a national target to halve FLW per person at the retail and consumption stages by 2030, which is similar to the UN Sustainable Development Goal Target 12.3 [1 Fao 2020]. Significant progress has been made in other countries such as the U.K. and Japan. The U.K. has reduced edible FLW per person by 27% in four years since setting its target goal. In Japan, the household FLW has reduced by 13% in four years, with a majority of that progress being made in one year [1]. While these countries have successfully been making gradual improvements with reducing FLW, the U.S. is taking steps towards halving FLW by 2030. Options are available and will need to be implemented on reducing the amount of FLW generated in the consumption phase and to minimize the amount of FLW from animal products, fruits, and vegetables since these are the two main sources of GHG emissions within the supply food chain.

Continuing current research on FLW is another crucial step that the U.S. plans to take to further reduce FLW-related GHG emissions. The EPA is currently working on research projects to gain knowledge on U.S. FLW. One current project is evaluating the comprehensive net environmental footprint of U.S. FLW from cradle-to-grave. Another project that the EPA is conducting now is developing environmental indicators that track the U.S. FLW environmental footprint as time passes. These indicators would be able to track the amount of FLW produced in the U.S. as well as the FLW's corresponding inputs and environmental effects over time, starting with GHG emissions. A third current area of study for the EPA is enhancing the modelling of the U.S. food system. The EPA is collaborating with USDA, Argonne National Laboratory, and Cornell University to construct a more accurate and precise food system model that would include the generation of FLW. Projects such as these are important for advancing FLW knowledge and tracking FLW creation. The data and projections gained from these current research projects would be key for minimizing GHG emissions from FLW.

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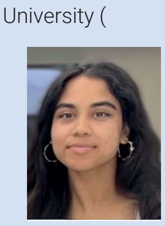

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