



Assessment of environmental and economic aspects of household food waste using a new Environmental-Economic Footprint (EN-EC) index: A case study of Daegu, South Korea



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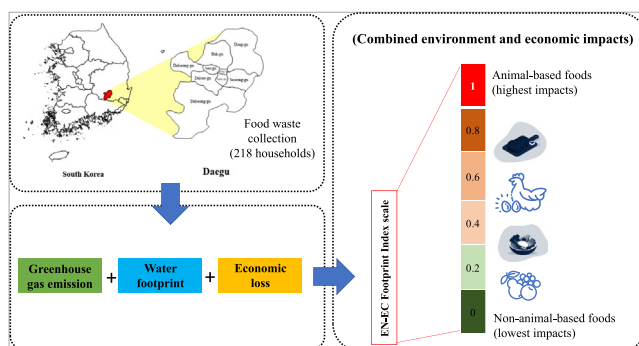
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HIGHLIGHTS

- Environmental and economic losses of 42 major food wastes were investigated.
- GHG emission, water footprint, and economic loss are the key factors of the study.
- A new EN-EC Footprint index showed the highest losses by animal-based food wastes.
- The findings may be used to mitigate the impacts caused by household food waste.

GRAPHICAL ABSTRACT



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ABSTRACT

While the global food demand has continued to increase, the enormous natural resources required for its production are limited, in addition to the accompanying environmental degradation. Despite all these, food waste generation continues unabated, especially at the household level, further compounding the environmental impacts, economic cost, and food security issues. In this study, granular primary data of edible household food waste using direct-weighing from 218 households in Daegu, South Korea was used to assess the environmental (carbon footprint, and water footprint) and economic (wasted cost) impacts associated with their wastage. For the first time, the Environmental-Economic (EN-EC) Footprint index is proposed as a single indicator for environmental and economic impacts to assess the hotspot food waste products among the selected 42 major food waste items. This study presents that the selected food products had a significant contribution to an average edible food waste generation of 0.73 ± 0.06 kg (per household/day), 0.71 ± 0.05 kg CO₂eq of GHG emissions, 0.46 ± 0.04 m³ of water footprint, and 3855.93 $\pm$ 527.27 won of economic loss, respectively. Based on the newly developed EN-EC Footprint index, we found that wasted animal-based food products had relatively high environmental and economic losses compared to non-animal-based food products. The findings of this study presented a novel method of estimating combined environmental and economic impacts associated with household food waste, which may further act as convenient guides for the waste management authorities and policymakers in addressing the mitigation of household food waste impacts.

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1. Introduction

The sustainable global food production system that would meet the growing food demands of the increasing population using the existing constraint natural resources, devoid of environmental degradation, is one of the serious challenges to be faced in the coming decades. Already, food production consumed up to 70% of the global freshwater resources and responsible for up to 10–30% of the total global emission of greenhouse gases (Garnett, 2011; Foley et al., 2011; Vermeulen et al., 2012). The demand for these resources and the associated environmental impacts are expected to go up by the year 2050 due to the anticipated population growth and increase in food production by 25–75% (United Nations, 2017; Hunter et al., 2017). Unfortunately, the demand and waste of intensive-resource foods, especially by both emerging and developed nations, have been reported to increase recently (Aschemann-Witzel et al., 2018; Blas et al., 2018; Adelodun et al., 2019).

However, addressing the inefficiency in the food production systems, readjustment of consumption patterns, and reduction in enormous food waste have been recognized as possible approaches to address the challenges of resources constraints in food production and the mitigation of accompanied environmental and economic impacts (Adelodun et al., 2020; Blas et al., 2018; Alexander et al., 2017; Chaboud and Daviron, 2017). Food waste has been acknowledged as creating a daunting challenge to achieve desired sustainable food systems (Foley et al., 2011). For instance, the Food and Agriculture Organization of the United Nations (FAO) reported an annual global estimate of 1.3 billion tonnes of food wastage with a monetary value of \$750 billion (FAO, 2015a). At the same time, the associated greenhouse gas emissions across the supply chain accounted for about 6.8% of the total global emissions (FAO, 2015b). Using the country national data from the Food and Agriculture Organization statistical database, Adelodun and Choi (2020) showed that nearly 15 Mt of food wastage was generated between 2007 and 2017 across the different supply chains in Korea, equivalent to 15 billion m³ of water resources and 20 Mt CO₂eq. of greenhouse gas emissions, and with a 13% increasing potential by 2030. Buzby and Hyman (2012) also reported an estimated economic loss of \$165.6 billion associated with food waste at both retail and consumer levels in the United States in 2008. Further, the avoidable food waste, estimated at 58% of the total food production, had an annual monetary value of \$49.5 billion in Canada (Gooch et al., 2019). All these narratives have led to progressive approaches targeting reducing the enormous food waste generation to address the resource constraints, food security, and various accompanying impacts.

As one of the global policy initiatives instituted to address the food waste issue, the Food and Agriculture Organization of the United Nations (FAO) declared an intervention themed “SAVE FOOD” in May 2011 (FAO, 2011). This initiative has been further strengthened by the recent adoption of the Target 12.3 set goals by the United Nations members on the Sustainable Development Goals. The specific set objective is to achieve the reduction of global per capita food waste by half at both retail and consumer level by 2030 (United Nations, 2015). At the country level, South Korea is implementing “Pay-As-You-Throw” to combat food waste issues at the household level. This policy mandated each household to be responsible for the cost of food waste amount generated and disposed of. The process is being implemented through the purchase of plastic bags to dispose of the household food waste or the use of a Radio-frequency Identification (RFID) machine (volume-based pricing system) that weighs the disposed of food waste and the household pays accordingly. Similarly, the United Kingdoms initiated a Waste and Resource Action Program (WRAP) with the theme “Love Food Hate Waste” as a charity program involving stakeholders such as governments, businesses, and communities on the improvement of resources efficiency of household food waste (Quested and Parry, 2017). Some countries and cities across Europe including Austria, Spain, Italy, Germany, Netherlands, and Sweden, among others, have also implemented the source-separation and Pay-as-you-throw policy on

household waste (Reichenbach, 2008; Dri et al., 2018), with reported significant reduction in food waste compared to other residual wastes (Reichenbach, 2008). Morlok et al. (2017) attributed the reduction of 84 kg/capita/year residual waste to pay-as-you-throw policy in Aschaffenburg, Germany, between the years 1995 and 2000, with increasing recycling rates of food waste. Dahlén and Lagerkvist (2010) also reported about a 20% reduction in household waste generated from the households with a pay-as-you-throw scheme compared to the households that do not implement the scheme in Sweden. Despite these tremendous efforts on the reduction of food waste, household food waste represents a considerable 35% proportion of the total generated food wastage across the supply chain (Chalak et al., 2016; Lipinski et al., 2013). This figure is more pronounced in the developed and industrialized countries due to their improved gross domestic product and economy (Xue et al., 2017). The household food waste reported at the European level reached about 42% of the total food produced (Monier et al., 2011), while the United Kingdom households generated a whopping 7.3 Mt of food waste in 2015 (Quested and Parry, 2017).

Although there are growing studies that investigate household food waste in terms of weight (Jørgen et al., 2016; Edjabou et al., 2016; Delley and Brunner, 2018; Abeliotis et al., 2019; Ilakovac et al., 2020), the attributed impacts such as the environmental and economic cost are often ignored. Only a few studies have been attempted to estimate the environmental and economic impacts of household food waste generation (Aldaco et al., 2020; von Massow et al., 2019; Garcia-Herrero et al., 2018; Nahman et al., 2012). While to the best of our knowledge, no study has attempted to use a singular index that can serve as an indicator for combined environmental and economic impacts of household food waste. Meanwhile, a singular indicator for both environmental and economic impact assessments is of utmost importance considering that the expensive food items might not necessarily be the ones with high environmental impacts, making the identification of targeted hotspot food items that could address both impacts indispensable. Moreover, a single indicator eliminates the difficulty and bias that comes with a trade-off in a decision-making process (Vázquez-Rowe et al., 2020; Garcia-Herrero et al., 2018).

This study assesses the environmental and economic impacts associated with household food waste in Daegu, Korea, based on the granular primary data of edible household food waste sampled via direct-weighing. Further, a new Environmental-Economic (EN-EC) Footprint index to identifying the wasted hotspot food products with combined significant environmental and economic impacts as a singular indicator was proposed. The developed footprint index provides an informed insight into the targeted food waste items that could address the environmental and economic impacts associated with their wastage.

2. Material and methods

2.1. Description of the study area

The study was conducted in the Daegu metropolitan city (Fig. 1), the third-largest city in Korea, and one of the leading cities on sustainable solid waste management, including food waste (Lee, 2020). The city is located in the southeastern part of Korea, with 979,852 households (2.5 million population) and a total area of 883.5 km² in 2019 (Table 1) (KOSIS, 2020). It is one of the representative metropolitan cities with the integration of rural and urban areas and their characteristics (Kim et al., 2020). The permission to conduct the food waste sampling was sought from the waste management department at the Buk-gu district office in Daegu, Korea.

2.2. Study design and household food waste collection

The food waste samples were captured daily before entering the waste stream in the food waste garbage from 218 households for two weeks in four seasons (July 2019–May 2020). The participants were

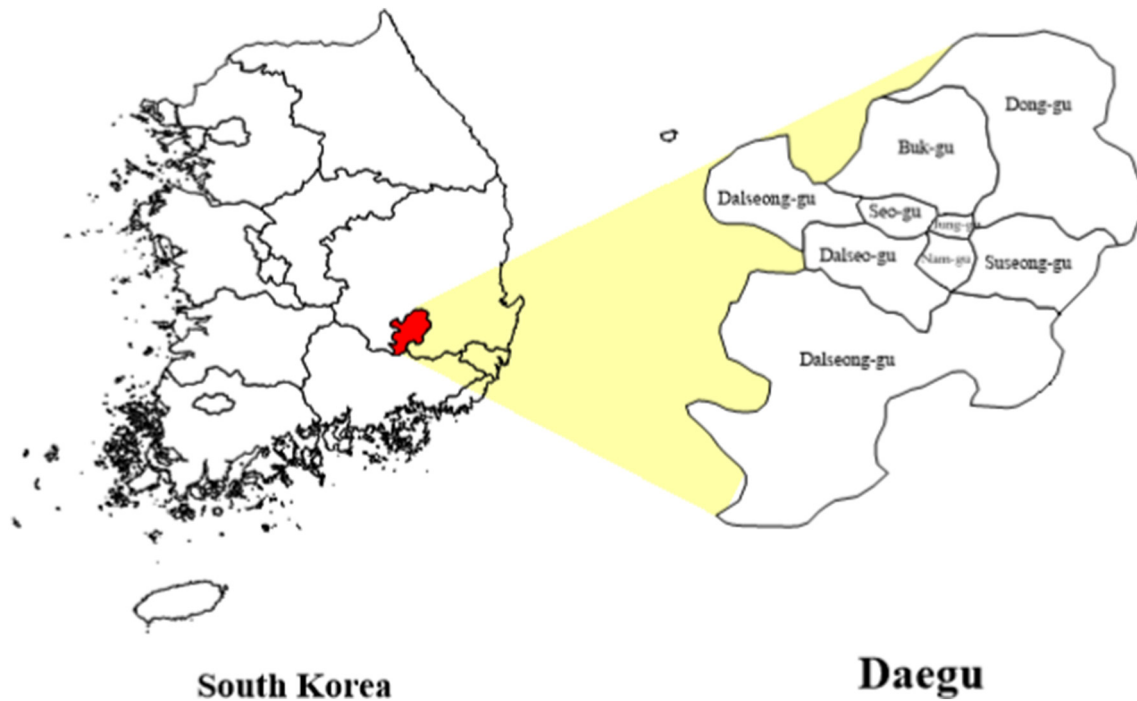


Fig. 1. Map view of the Daegu district of South Korea.

recruited with the assistance of the department in charge of waste management at the Buk-gu district office in Daegu, South Korea. Among the 218 households considered in this study, only 85 households submitted the complete details about the demographic/socio-economic information including, occupation, income, family size, and marital status, as this information was termed sensitive by the remaining 133 households (Adelodun et al., 2021). Nevertheless, since this information is beyond the scope of this study, we, therefore, considered a total of 218 households for this study.

The composition analysis of household food waste was conducted based on the direct weighing method to obtain highly granular data. The items considered as food waste in this study are any food items that are fit for consumption or allow to expire or spoil, whether knowingly or unknowingly, and are discarded into the waste stream as defined by the Food and Agricultural Organization of United Nations (FAO, 2014), and also in line with the cultural definition of food waste in Korea (Ju et al., 2016). However, inedible food wastes such as shells and bones, including food packages and drinks and beverages, were excluded. The sampled food wastes were characterized in situ and daily to avoid physical compaction and chemical degradation due to transportation and/or a further delay between disposal and characterization (Elimelech et al., 2018; Edjabou et al., 2016; Langley et al., 2010). All

the food waste was measured three times with the average value taken using a standard electronic weighing scale of 10 kg capacity with a standard error, $e = 0.005$ kg (Model number: C-05-12, A&D KB-10K, Korea).

2.3. Data analysis

2.3.1. Calculation of wasted food in the household

The weight of food waste items was converted to raw food material equivalent and then to the agricultural product following Wang et al. (2018) and based on the conversion coefficients from the literature (Cao et al., 2014; USDA, 1992; Chappell, 1954). The average weight of wasted food in the Korean household equivalent of an agricultural product disposed of daily and its standard error of the mean was calculated using Eq. (1).

$$FW_H = \frac{\sum_i^n FW_i \times C1_i \times C2_i}{n} \quad (1)$$

where FW_H is the daily average of wasted food in the household (kg/day/household), FW_i is the daily average wasted amount of food item i per household (kg), n is the total number of identified wasted food items (Table 2), $C1_i$ is the conversion coefficient of wasted food item i (kg) to raw food item due to change in water content and cooking loss; $C2_i$ is the conversion coefficient of raw food equivalent item i (kg) to the agricultural products due to value chain losses (Table 2).

2.3.2. Environmental impact analysis of household food waste

The environmental impacts of wasted food items were assessed using the carbon footprint and water footprint indices, as indicated in Eqs. (2) and (3).

$$CF_{FW} = \frac{\sum_i^n (FW_i \times C1_i \times C2_i \times GWP_i)}{n} \quad (2)$$

$$WF_{FW} = \frac{\sum_i^n (FW_i \times C1_i \times C2_i \times WF_i)}{n} \quad (3)$$

where CF_{FW} and WF_{FW} are the average greenhouse gas emission (measured as kg CO_2eq) and water loss (measured as m^3) of wasted food in

Table 1

Description of the study area (Daegu, South Korea) and its districts.

District	Number of households	Population	Food waste generated (tonnes per day) ^a
Jung-gu	34,523	74,662	445.00
Dong-gu	139,879	334,898	1803.04
Seo-gu	75,067	171,891	967.61
Nam-gu	68,768	145,655	886.42
Buk-gu	176,876	439,084	2279.93
Suseon-gu	158,648	412,809	2044.97
Dalseo-gu	228,034	561,077	2939.36
Dalseong-gun	98,057	249,772	1263.95
Total	979,852	2,389,848	12,634.87

Data source: KOSIS (2020), KEA (2020).

^a Computed for this study.

Table 2
Conversion coefficients from wasted food to agricultural product.

Food category	Food items (wasted food)	Conversion coefficient (C1)	Raw food material	Conversion coefficient (C2)	Agricultural product
Rice	Rice and rice products	0.45	Rice	1.48	Paddy
Wheat and other grains	Bread, pizza, pastry and products, noodles, Tofu/cheese, soybean, corn	0.53	Wheat, potato, soybean, corn	1.49	Wheat and other grains
Vegetables	Onions, radish, cabbage, carrot, garlic, lettuce, broccoli, ginger, leafy vegetables, cucumber, tomato, mushroom, spice, potatoes	1.05	Onions, radish, cabbage, carrot, garlic, lettuce, broccoli, ginger, leafy vegetables, cucumber, tomato, mushroom, spice	1.50	Vegetables
Fruits	Watermelon, apple, orange/mandarin, oriental melon, banana, persimmon, lemon, plum/peach, aubergine, grape, apricot, Asian pear, kiwi, strawberry, pumpkin, pineapple, jujube	1.05	Watermelon, apple, orange/mandarin, oriental melon, banana, persimmon, lemon, plum/peach, aubergine, grape, apricot, Asian pear, kiwi, strawberry, pumpkin, pineapple, jujube	1.20	Fruits
Eggs	Eggs	1.05	Eggs	1.18	Eggs
Pork	Pork	1.33	Pork	1.63	Slaughter pigs
Poultry	Poultry	1.37	Chicken	1.49	Slaughter poultry
Beef	Beef	1.40	Beef	2.11	Slaughter cattle
Aquatic products	Aquatic products	1.10	Fish	1.18	Fish

Source: Wang et al. (2018) with modification.

the household, respectively; GWP_i is the global warming potential of each food item i ($\text{kg CO}_2\text{eq./kg}$) (Clune et al., 2017); WFi is the water footprint for the production of each food item i (m^3/kg) (Lee et al., 2015; Yoo et al., 2014).

The greenhouse gas emission is an indicator of global warming potential (GWP) and climate changes. The carbon footprint of wasted food items is based on the associated carbon dioxide equivalent of GHG emissions ($\text{kg CO}_2\text{eq./kg}$) from the life cycle assessment study of food items from production to retail store and distribution system boundaries (Clune et al., 2017). Similarly, the estimated water loss of wasted food items was based on the water footprint concept (m^3/kg) of country-specific crops and livestock productions in Korea (Lee et al., 2015; Yoo et al., 2014). These two indices are essentially and frequently used to evaluate the related environmental impact of both food production and food waste (von Massow et al., 2019).

2.3.3. Economic impact analysis of wasted food at household

The economic cost associated with the wasted food from the sampled Korean households was estimated based on the cost of the agricultural product commodity items, the amount required for the waste disposer, and the inconvenience cost of source separation of food waste from other household wastes by the household. The retail price of each agricultural product was obtained from the Korea Agriculture, Fisheries, and Food Distribution Corporation database (KAMIS, 2020). In some cases where particular food items were not listed on the database, the G-market (www.global.gmarket.co.kr), one of the largest e-commerce companies for online shopping in Korea, was used. The average cost of food waste disposal, popularly referred to as “Pay-As-You-Trash,” which is paid per household, was obtained from the Korean waste management department (RCD, 2020). Lastly, the inconvenience cost attributed to the source separation of wasted food by the household was based on an earlier study by Lee et al. (2017). The economic cost of wasted food was estimated using Eq. (4):

$$EC_{FW} = \frac{\sum_i^n (FW_i \times C1_i \times C2_i \times RP_i)}{n} + C_x + C_y \quad (4)$$

where EC_{FW} is the average economic cost of wasted food in Korean won; RP_i is the retail price of each of the wasted food items (Korean won/kg); C_x is the average cost of food waste disposal per household (Korean won) (RCD, 2020), C_y is the inconvenience cost of source separation of food waste by the household (Lee et al., 2017).

2.3.4. Combined environmental and economic impact analysis

To investigate the combined impact hotspots of food waste items due to the potential variations in environmental and economic impact

perspectives among the food items, this study used a newly developed normalized index called the “EN-EC Footprint Index,” which combined environmental and economic impacts of household food waste. In this, we considered water footprint (m^3) and greenhouse gas emission factor (GHG: $\text{kg CO}_2\text{eq}$; Clune 2017) as environmental impacts variables, while the household food waste generated (kg in agricultural products) and economic cost (Korean won) of each food type as economic impact variables.

The above data was normalized in a range of 0 to 1, where 0 presented minimal while 1 presents the highest level of environmental and economic impacts associated with selected food waste products. We transformed the data by taking the sum of environmental and economic data and then dividing them by 100. In this, the data of economic impacts were further normalized by taking some of their logarithms since the values are very high and hard to understand at first sight. For this, the following Eq. (5) was employed to calculate the EN-EC index of the selected food types:

$$\text{EN-EC Footprint Index} = \frac{\sum (WF + GWP) + \text{Log}(W + C)}{100} \quad (5)$$

where EN-EC Footprint index was the combined environmental and economic loss associated with particular food waste type, WF and GHG were the water footprint (m^3) and greenhouse gas emission ($\text{kg CO}_2\text{eq}$; Clune 2017), W was the converted agricultural products (kg) and C was the waste cost (won) of food type, respectively.

2.4. Software

In this study, we employed Microsoft Office 2016 (Microsoft Corp., USA) software for various calculations of the environmental and economic indices, while OriginPro 2020a (Origin Corp., USA) software was used for graphing. The level of the confidence interval was 95%. The data were analyzed using linear regression (R^2), Pearson's correlation coefficient (R), and coefficient of variation (CV) tests. Besides this, Surfer 16 (Golden Software, LLC, USA) software was used to create a map of the study area.

3. Results and discussion

3.1. Wasted food products in the sampled Korean households

The average daily weight of wasted food (edible) among the 218 sampled Korean households was 0.73 ± 0.06 kg, which corresponds to an average annual of 266.45 ± 21.9 kg per household. This result is in line with a study by Kim and Lee (2020), where it was reported

that an average Korean household discharged less than 1 kg of food waste daily. Similar results were also reported in other countries for an average annual household food waste despite the varying culture, food waste definitions, geographical conditions, and data and collection methods, among which are 270 kg for United Kingdoms (Quested et al., 2011), 297 kg for USA (Koester, 2013), and 217 kg for Canada (Parizeau et al., 2015). The common attribute among these countries is their status as high-income countries, which have been previously reported to influence the generation of household food waste (Xue et al., 2017; Thyberg and Tonjes, 2016). The distribution of food waste items is presented in Fig. 2. Among the 42 food waste items identified in this study, leafy vegetables and watermelon accounted for the largest shares of 10% and 9% of the total weight of the food items, respectively. However, the wastage contribution of some food items was less than 2%, among which are kiwi (0%), broccoli (1%), and lettuce (1%). The contributions of animal products, including beef (4%), pork (3%), poultry (3%), fish (2%), and egg (1%), summing up to 13% of the total wasted mass.

The wasted food items among the sampled Korean households showed considerable variability, which can be attributed to integrating rural and urban characteristics in the study area (Kim et al., 2020). However, the low standard error of mean values showed a good confidence interval i.e., 95% (low uncertainty level). The observed largest share of leafy vegetables to the total wasted mass is due to the Korean traditional dietary habits that are characterized by an immense contribution from vegetable-based foods, which are fragile and prone to spoilage compared to other food items (Lee, 2018; Kim et al., 2014).

Similarly, the considerable mass of wasted food items like rice and some fruits such as apple and oriental melon can be attributed to the high consumption rates of the items (Song et al., 2015). The correlation between high intake and perishability of plant-based food products and their significant wastage compared to animal-based food products was also confirmed by González-García et al. (2020). These results are consistent with some other studies on the composition of household food waste in similarly developed countries, where vegetables and fruits were reportedly contributed the most percentage of wasted items (Ilakovac et al., 2020; Elimelech et al., 2018; Jørgen et al., 2016; Edjabou et al., 2016). The mass of edible wasted food items is in agricultural product forms for a reliable impact estimate since the impact coefficients for environmental and economic analyses are derived based on the agricultural products rather than cooked food or raw food waste.

3.2. Environmental impacts of household food waste

3.2.1. The carbon footprint of household food waste

Table 3 showed the environmental impact results of 42 food waste types identified among the sampled Korean households. The median value of the global warming potential for each food item was obtained from Clune et al. (2017), which contained an extensive list of 168 food products to ensure the uniformity of estimations of embedded GHG emissions of all the 42 edible food products in this study from the same data source. The average daily estimate of the carbon footprint

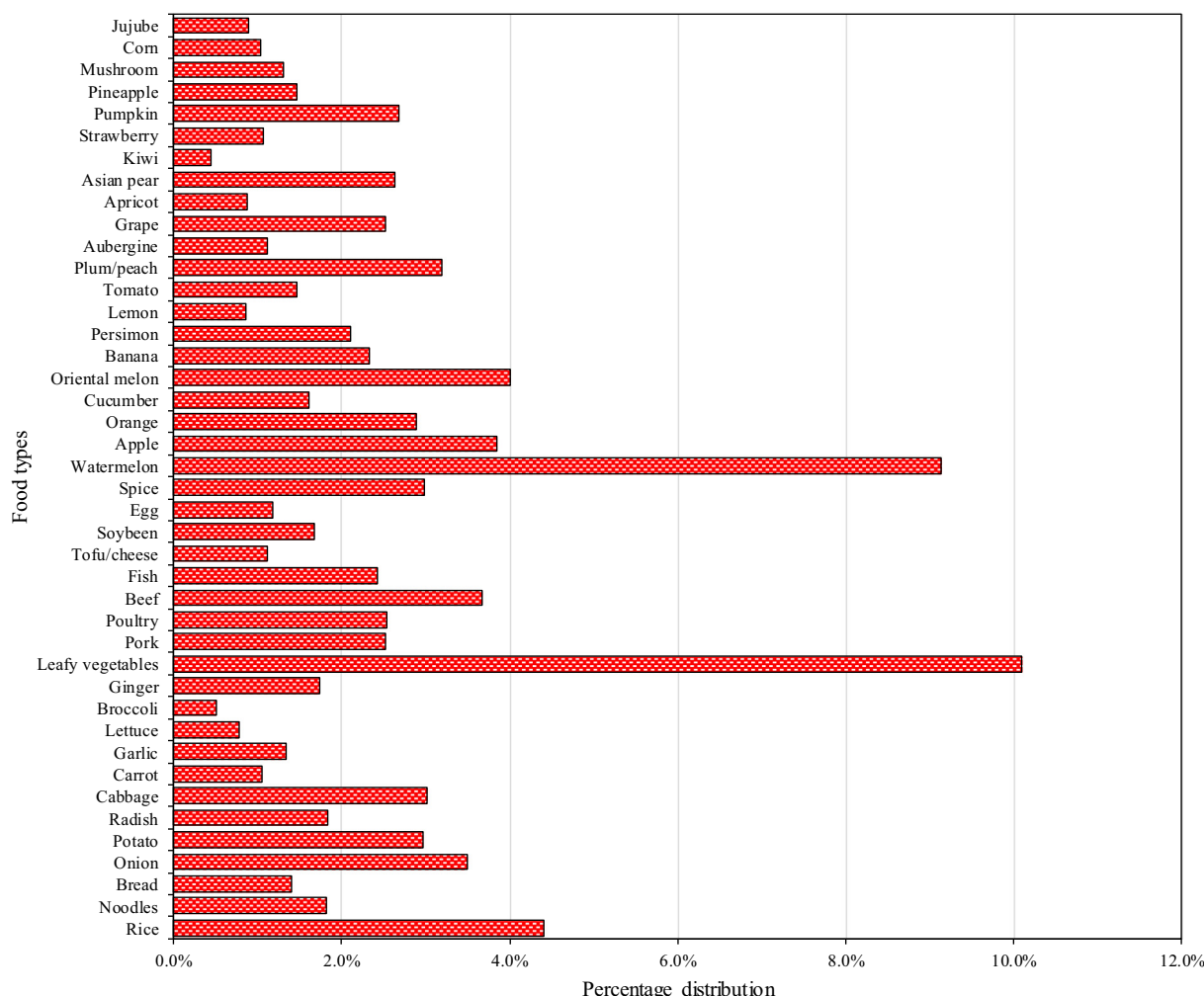


Fig. 2. Percentage distribution of food waste items (weight basis) generated from Daegu, South Korea.

of household food waste was 0.71 ± 0.05 kg CO₂ eq. per household, which is equivalent to an average annual of 259.15 ± 18.25 kg CO₂ eq. This estimate is lower than the reported 0.88 kg CO₂ eq. and 0.83 CO₂ eq. of per capita avoidable household food waste in the United Kingdom (Cooper et al., 2018) and Canada (von Massow et al., 2019), respectively. However, the amount was higher than the annual average of 148 kg CO₂eq. per household reported for Chinese households using national survey data (Song et al., 2015).

The beef was responsible for more than half (52%) of the total carbon footprint associated with household food waste, followed by pork (8%), rice (6%), tofu/cheese (5%), and poultry (5%). The wasted proportion of beef by weight (4%) was at variance with its remarkable GHG emission estimate (52%), which can be explained by the large global warming potential coefficient resulted from the production of animal feeds and other energy expended at different trophic levels for beef and other livestock production (Sun et al., 2018). Since the global warming potential (GWP) indicates the amount of emission that could result in global warming and change in climate, which is measured in carbon dioxide equivalent (Cakar et al., 2020), the use of GWP serves as an indicator of the life cycle climate change impact of food waste (Clune et al., 2017). Apparently, this implies that the wasted animal-based food, irrespective of the amount, has far-reaching adverse impacts on the environment (Adelodun and Choi, 2020). Reducing the waste of food items of animal origin would translate to a significant reduction in the environmental impact associated with such food items.

On the other hand, despite the combined significant contributions of all the vegetables and fruits (31 food items altogether) to the total weight of the wasted food products (72%), the emission proportions were less than 18% of the total carbon footprint of the wasted food. These results are in agreement with a recent study by Aldaco et al. (2020), where red meat was the major contributor of over 30% of the total GHG emissions related to food waste despite contributing only 4% by weight. There is a need to eliminate or reduce the wastage of hotspot food items to achieve any meaningful reduction in the carbon footprints associated with household food waste (Springmann et al., 2018; González-García et al., 2018).

3.2.2. Water footprint of household food waste

The average daily associated water loss of household food waste reached 0.46 ± 0.04 m³ per household, equivalent to 167.9 ± 14.6 m³ per annum (Table 3). This implies that a daily average of 460 l of water was used by a household on food not consumed. This amount represents 20% of the per capita water footprint of food consumption in the country (Yoo et al., 2016), which is, however, higher than the annual estimated 19 m³/capita of water loss associated with food wastage along the supply chain for industrialized Asia (Kummu et al., 2012). The possible explanation for this variance is the continuous dietary change from cereal-based to westernized meat-based food, among many other factors (Adelodun and Choi, 2020; Yoo et al., 2016). Nonetheless, this amount is very significant for a country that persistently faced with water scarcity, drought and largely depends on food importation to meet the increasing demand, especially the livestock products such as beef and pork, which are water-intensive to produce (Bae et al., 2019; Herh, 2019).

The estimates from other countries and regions indicate that the average annual per capita of water loss due to food waste was 66 m³

for Chinese households (Song et al., 2015), 47.7 m³ for Spanish households (Blas et al., 2018), 42 m³ for North America (Kummu et al., 2012), 106 m³ for United Kingdoms (Chapagain and James, 2011), 44 m³ for Oceania (FAO, 2013), and 27 m³ for a global estimate (Kummu et al., 2012). Evidently, these estimates varied widely due to a range of factors such as the study scopes, system boundaries, dataset, and methods employed in the studies; hence, they are found to be incomparable.

In terms of food products, just like GHG emissions, beef accounted for 52% of the total water footprint of wasted food, followed by pork (9%), poultry (5%), and rice (4%), despite their low waste contribution by weight, except for rice that had 4% of the total weight of food items. Many other food items, especially plant-based products like lettuce, ginger, cucumber, tomato, and mushroom, had relatively low water loss due to their wastage (<1%). These results indicate that animal-based food accounted for 66% of the total water footprint of household food waste despite their low wastage contribution of a combined 13% of the total wasted mass. These results are consistent with other studies asserting the significant amount of water loss due to wastage of animal-based food products notwithstanding their low wasted amount by weight, and also than the water footprint of wasted plant-based food products (Adelodun and Choi, 2020; González-García et al., 2020; Blas et al., 2019). Consistently adhering to the traditional Korean diet, which is highly riched in vegetables and fruits, could significantly improve water savings potential at both production and consumption sides by giving less desiring to animal-based products that are resource-intensive to produce.

3.3. Economic impacts of household food waste

The economic cost of house food waste reached an average amount of ₩3855.93 $\pm$ 260.48 (Korean won) per household per day (\$3.41 at 1129.60 exchange rate), taking into account the price of the food products, disposal cost, and associated inconvenience cost of food waste separation by the concerned household (Table 3). This amount represents about 32% of the average household expenditure on groceries and non-alcoholic beverages (Kim and Lee, 2019). This implies that an average of ₩1.4 million cost savings can be achieved by the household from food waste prevention in a year. Similarly, considering the water rate of 914.3 won/m³ for the total unit cost in Korea (MOE, 2018), the average cost of water loss to household food waste was ₩420.58 per day and ₩153,510.97 per year, respectively. The estimates of economic loss of food waste that was earlier reported reached \$936 per household per annum for 297 kg of wasted food (the equivalent of \$2.56 per day of 0.8 kg of food waste) in the United States, which also represents 10% of the average expenditure on food in 2008 (Buzby and Hyman, 2012). Also, the economic loss of avoidable food waste in Canadian households was estimated at \$936.52 per annum, representing 16% of the average expenditure on food bought by Canadian households in 2017 (von Massow et al., 2019).

Beef and fish represented the largest proportions of 21% and 13%, respectively, of the total economic cost of household food waste despite their small relative waste percentage of the total weight (combined of 6%). In contrast, the vegetable and watermelon with the highest waste proportions only represent 10% and 5% of the total economic cost, respectively. Other food items such as corn, lettuce, kiwi, broccoli, egg, carrot, and lemon had an insignificant economic impact (< 1%) associated

Table 3
Edible household food waste characteristics and impact results of 42 food items.

Characteristics	Value per day	Value per annum	Unit
Average edible food waste generation rate	0.29 $\pm$ 0.02	107.31 $\pm$ 8.03	kg per household
Average edible food waste as converted to agricultural products	0.73 $\pm$ 0.06	266.45 $\pm$ 21.9	kg
Carbon footprint (GHG emissions)	0.71 $\pm$ 0.05	259.15 $\pm$ 18.25	Kg CO ₂ eq
Water footprint	0.46 $\pm$ 0.04	167.9 $\pm$ 14.6	m ³
Wasted cost	3855.93 $\pm$ 527.27	1,407,414.45 $\pm$ 192,453.55	₩ (Korean won)

Data presented as means followed by the standard error.

with their waste proportion by weight. Meanwhile, only meat responsible for about 15% of the total household expenditure on groceries and non-alcoholic beverages in 2018 (Kim and Lee, 2019). von Massow et al. (2019) reported an economic cost of \$18.01 per week for avoidable household food waste in Canada, with meat and fish accounted for a significant proportion of the total cost (up to 13%). Buzby and Hyman (2012) reported that meat, poultry, and fish had a considerable 75% of the total consumer food waste. Similar results were also reported by Garcia-Herrero et al. (2018), where the economic wastage of meat and animal fat reached €144 per capita per year, which is equivalent to 39% of the total cost of food waste.

3.4. Hotspot impact analysis of household food waste results

The developed EN-EC Footprint index was helpful to derive combined environmental and economic impacts of selected food types. However, the combined impact of wasted fish items was not considered due to the unavailable country-specific water footprint data and; therefore, unsuitable for the index calculations. The calculations from the EN-EC Footprint index affirmed that animal-based food types showed relatively high environmental and economic losses than non-animal-based food types (Fig. 3). In this regard, beef showed maximum values of 0.30, followed by pork (0.08) and poultry (0.06) on a scale of 0 to 1, where 0 refers to the lowest impacts, and 1 shows the highest impact. However, the lowest EN-EC Footprint index values were represented by corn and lettuce (0.02), while all other food types exhibited a moderate level ranging from 0.03 to 0.05, respectively. The data generated by the new index was also verified by the individual environmental

and economic impacts, which showed a good relationship between the actual and computed values. In this, the general linear relationships between environmental (EN: GHG emission + water footprint), economic (logarithm of wasted cost), and EN-EC Footprint indices were illustrated in Fig. 4. It was evidenced from the linear regression and Pearson correlation analyses that environmental data had a good and positive relationship with EN-EC Footprint index (R^2 : 0.9773 and R : 0.9886) compared to economic data (R^2 : 0.2518 and R : 0.5018), accordingly. However, the linear relationship between environmental and economic data showed an R^2 value of 0.1338 and an R -value of 0.3658, respectively. Therefore, the new index can be efficiently used to assess the hotspot food waste products with combined associated environmental and economic impacts for effective food waste management and prevention strategies in the face of associated impacts. The applicability of the combined impact footprint index of household food waste in other settings such as cities or countries would require adjusting the formula as per the currency considering since this is one of the major variables in the index computation and may affect the calculated values. Previously, no study has been done using the proposed footprint index; therefore, we were unable to compare our results with available literature.

3.5. Future consequences and mitigation strategies

The current state of household food waste generation and management has shown to encompass significant environmental and economic impacts, which can potentially increase in the future as the population increases. As revealed in this study, there are considerable associated impacts of household food waste, which are often excluded while

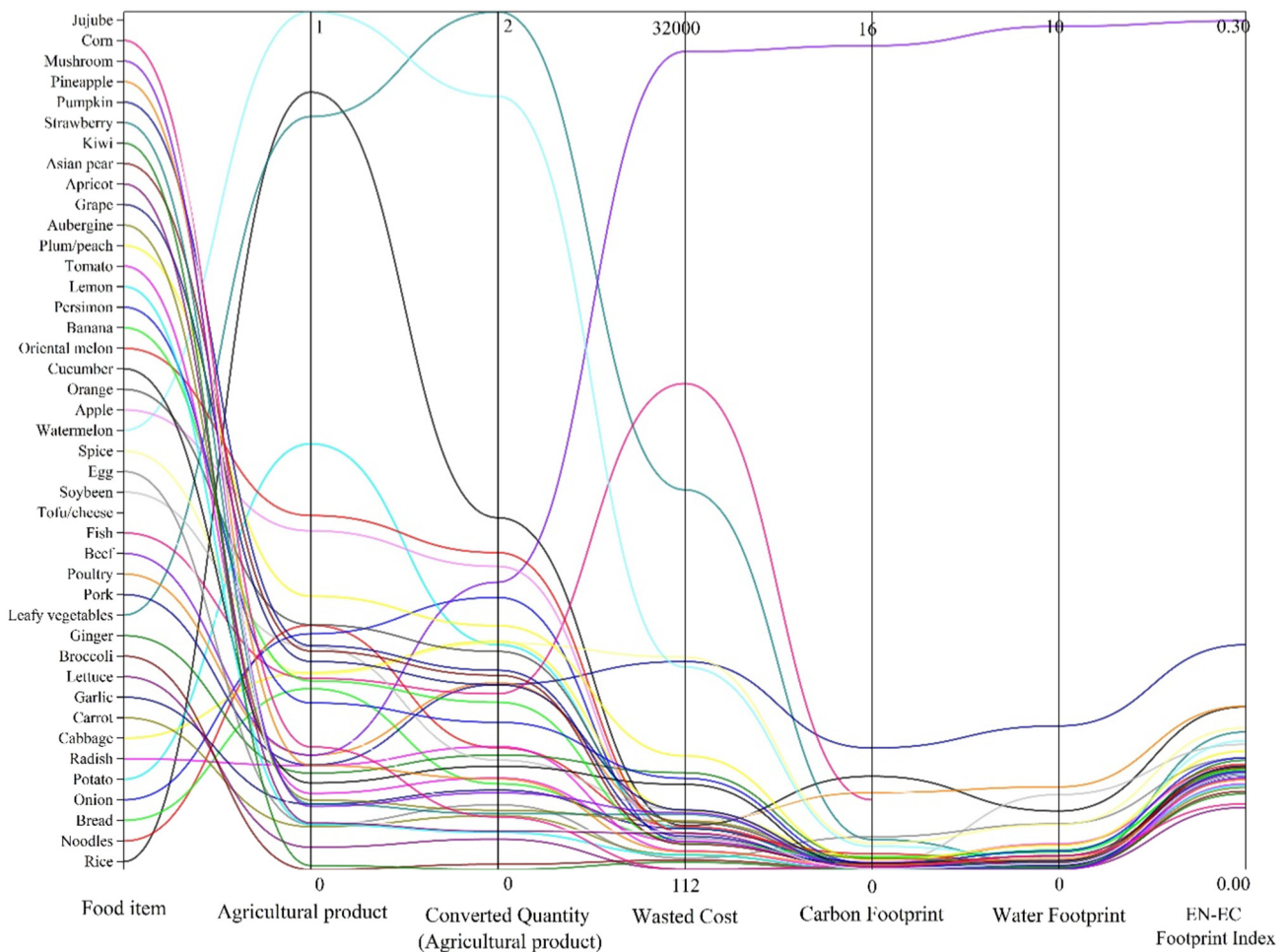


Fig. 3. EN-EC Footprint index of household food waste products (colored lines passing through different axes represent different characteristics of respective food type).

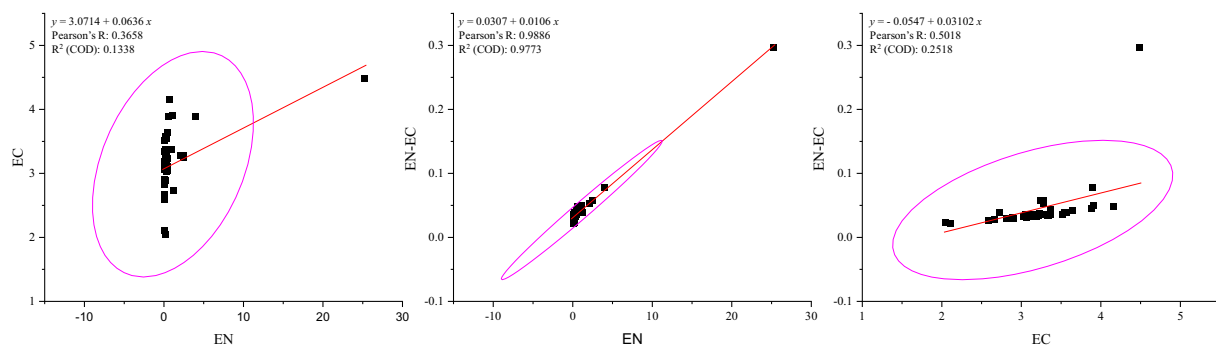


Fig. 4. General linear relationship between environment (EN: GHG emission + water footprint), economic (logarithm of wasted cost), and new EN-EC Footprint index (circle represents confidence interval at 95%). COD is the Coefficient of determination.

making recommendations on the food waste reduction strategies but rather based on the quantity (weight) of the wasted food. This approach has limited the awareness of danger portends in the household food waste generation rates as it does not consider the different food items that have different embodied environmental and economic impacts. The current study has highlighted the implications of household food waste in its composite forms and not only in terms of weight but also on the environmental and economic impacts. Although cultural and socioeconomic predisposition on household food waste and associated environmental and economic impacts could vary across the cities, countries, and regions, the previously reported success on the reduction of household food waste through the policy intervention of volume-based food waste fee system popularly called “pay-as-you-thrash” in Korea (Park and Lah, 2015), can be further strengthened by incorporating the environmental and economic impacts of food waste awareness through the involvement of various stakeholders, in a similar form to “Love Food Hate waste” under the WRAP program, which resulted to household economic cost savings of £60 per month (WRAP, 2018). The incorporation of household food waste footprint impacts in the food waste awareness programs to achieve both the reduction of household food waste and the mitigation of accompanied impacts cannot be overemphasized (Zamri et al., 2020). The environmental and economic impacts, along with social impact, have been re-emphasized as part of the proposed framework to be included in the hierarchy measures of prevention, re-use, recycling, recovery, and disposal of food waste prevention and management (Papargyropoulou et al., 2014).

4. Conclusion

In conclusion, significant environmental and economic impacts of the selected food types were observed in Daegu, Korea. Furthermore, the new EN-EC Footprint index also confirmed the impact levels of contributing to food waste products. Often, the environmental and economic impacts of household food waste are excluded when recommending appropriate measures and policies to address household food waste issues. However, this study indicates a significant variance of attributed impacts among the wasted food products, in which the hotspots among them were identified using the EN-EC Footprint index. Therefore, incorporating the impact footprints assessment can provide appropriate measures to mitigate the total environmental and economic impacts of household food waste while reaching the prevention and/or reduction target of household food waste. It is recommended that consistently adhering to the traditional Korean diet, which is generally rich in plant-based food products, and vegetables and fruits, in particular, could significantly lead to a reduction in environmental impacts and household economic cost savings at the consumption side by giving less desiring to animal-based products that are resource-intensive to produce. This study provides useful insights into the progressions of food waste generation along with their efficient management to minimize environmental and economic impacts.

CRediT authorship contribution statement

Bashir Adelodun: Conceptualization, Investigation, Data curation, Formal analysis, Methodology, Software, Visualization, Writing – original draft. **Sang Hyun Kim:** Data curation, Visualization. **Golden Odey:** Data curation, Visualization. **Kyung-Sook Choi:** Visualization, Resources, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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