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Reducing environmental pressures produced by household food waste: initiatives and policy challenges

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Abstract: In this study, an environmental approach is used to reveal pressures on natural resources caused by food waste and depicted through water, land and energy footprints. The purpose is: 1) to quantify food waste in households in the Metropolitan District of Quito; 2) to determine the environmental pressure of food waste on energy, water and land. Finally, an analysis of some initiatives for reducing food waste and policies applied to the supply chain of the products selected was performed. To that end, an online survey was carried out, and the responses were classified through a descriptive analysis to establish categories of food and the energy, water, and land footprints of rice and potatoes. The results and information presented here are expected to be valuable for generating or rethinking policies to make improvements in the food system to achieve Sustainable Development Goals.

Keywords: household food waste; environmental pressure; Sustainable Development Goal 12.3; potato; rice; reduction initiatives.

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1 Introduction

Food waste (FW) is a major concern globally. It is estimated that nearly 570 million tons of food were wasted at the household level in 2019 (United Nations Environment Programme, 2021). When food is wasted, more than a source of nutrition is lost. Land, water, and energy, the resources needed to produce, process, and distribute food, are also lost. For example, it is estimated that 0.9 million ha of land and 306 km^3 of water are needed to produce the 1.3 billion tons of food wasted annually worldwide (FAO, 2014). While environmental effects accumulate during every phase of the production, distribution, and consumption of food, the most significant effect is that occurring when consumers waste food. Emerging economies increasingly face the FW problem (FAO et al., 2020). Consequently, this issue is included among Sustainable Development Goals (SDGs) (Target 12.3), according to which FW in homes and retail establishments should be halved by 2030 (United Nations Development Programme, 2015). Different approaches, including environmental, economic, and social, have been studied to deal with the food loss and waste issue (Principato, 2018; Thyberg and Tonjes, 2016; Wunderlich and Martinez, 2018). FW leads to waste of resources, including inputs used for food production, such as fertilisers, herbicides, pesticides, and water, as well as resources used in food processing and transportation. Therefore, resources that are wasted along the food supply chain (FSC) due to food loss and waste represent losses in energy and water resources (Hannibal and Vedlitz, 2018).

Water and energy are closely interconnected with food; this synergy is associated with trade-offs, which are represented by the water-energy-food (WEF) nexus (Kaddoura and El Khatib, 2017). The concept emerged in response to climate change, population growth, globalisation, and economic growth, phenomena that put pressure on water, energy and food resources (Endo et al., 2017). According to the FAO, the WEF nexus is an approach that takes into account the interdependence of water, energy and food security (Asghar et al., 2020). This framework identifies and addresses the complex interdependencies, synergies, constraints, and trade-offs among water, energy and food (Midgley et al., 2019). The WEF nexus concept has included other components, especially land/land-use (Midgley et al., 2019). The importance of FW in the WEF nexus is that when food is wasted, the water and energy used along the FSC are also wasted (Hannibal and Vedlitz, 2018). Therefore, the efficient use of resources is critical to avoiding problems related to food, energy and water shortages. To address the complex FW issue, Kibler et al. (2018) "proposed a food-waste-systems approach to optimize resources" within the FEW nexus; that framework can be applied to develop strategies, for example, to reduce edible FW and to promote efficient use of energy and water in the food production process.

There are different definitions of FW. FAO (2011) states that FW, or loss, "refers to the decrease in edible food mass along the food supply chain." According to FAO (2019c), food loss is the reduction of the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, as well as by retailers, food service providers and consumers. On the other hand, Food Use for Social Innovation by Optimising Waste Prevention Strategies (FUSIONS) defines FW as the fractions of "food and inedible parts of food removed from the FSC" to be recovered or disposed of Stenmarck et al. (2016). What is noteworthy here is the absence of consensus on the definition of FW, as is the lack of consensus regarding FW quantification, that is, there is no standardised method to measure it. As a result, studies reporting waste quantification come up with widely varying results (Chaboud, 2017; Corrado et al., 2019; Delley and Brunner, 2018; Joshi and Visvanathan, 2019). The same tendencies in results have been found in quantifying water, land and energy footprints. It is, thus, impossible to compare studies. The methodologies most often applied and, thus, responsible for the high variability in results, include the life cycle assessment (Cakar et al., 2020), input and output analysis (Reynolds et al., 2015), and calculation of waste to crop yield relations (Sun et al., 2018). For example, to quantify FW, Abeliotis et al. (2019) measured FW volume and composition in households in Greece. For this purpose, their methodology involved asking Greek householders to weigh the food they wasted and to keep 'waste collection diaries'. Their resulting total per capita FW estimate in Greece came to 76 kg/capita/year.

Studies on quantifying FW also present inconsistencies in how the FW problem is analysed (Chaboud and Daviron, 2017), including the definition and methodology applied. Research carried out at the global level, such as the Swedish Institute for Food and Biotechnology (SIK) studies requested by the FAO, establish that one-third of the world's edible food is lost or wasted annually, amounting to about 1.3 billion tons per year globally (FAO, 2011). At the regional level, it is estimated that, in Europe, approximately 100 million tons of food are wasted annually (Pagliaccia et al., 2016); at the country level, the estimated annual figure for China comes to around 60 million tons of food (Meng et al., 2015). Researchers who quantify FW in households have applied various methodologies. For example, a study of Hungarian households measured both quantitative and qualitative waste. This work followed the methodological recommendations of FUSIONS (Szabo-Bodi et al., 2018). In New Zealand, household waste research used macro-economic data and aggregated waste data (Reynolds et al., 2016). A study of Finnish households estimated amounts of FW using diaries and weighing (Silvennoinen et al., 2014). In Serbia, an online survey was applied (Djekic et al., 2019). In Lebanon, researchers conducted face-to-face interviews (Mattar et al., 2018). And, as indicated, in Greece households were asked to weigh FW and record the results in diaries (Abeliotis et al., 2019).

In estimating FW, the authors cited have in mind common objectives, such as creating awareness of waste in their cities and contributing to databases in order to establish strategies to decrease FW. Quantification of FW is also important to guide authorities in planning policies aimed at reducing FW.

According to Van Herpen et al. (2019a), attempting to compare FW studies amounts to comparing apples and oranges, given the multiplicity of methods applied in measuring household FW and the little that is known about their validity. Their conclusion was based on an examination of five methods. One of them applied a survey on FW over the course of a week, a method that seems to be appropriate for measuring large quantities of FW while also indicating how much of that waste is produced by each household. Concerning the effect of FW on land, water and energy, a study by Kummu et al. (2012) determined that around one-quarter of the food supply is lost along the FSC. This included "24% of total freshwater resources used in food crop production, 23% of total global cropland area, and 23% of total global fertilizer" used. Guzmán-Luna et al. (2021) have calculated "the footprint of tilapia aquaculture in Mexico and compared the footprints of fish and meat." They conclude that it is not more sustainable to replace livestock with tilapia because tilapia requires more fresh water than beef, pork, and poultry and pollutes greater quantities of water. As regards energy and land, the footprints are comparable. In Japan, the effects of FW on land and water resources were calculated during the processing, distribution, and consumption phases. It was found that 1.23 million hectares of cropland were used to produce food that was wasted, and 413 million m^3 of water resources were wasted in agricultural production (Munesue and Masui, 2019).

The multiple effects of household FW were evaluated by Von Massow et al. (2019). According to a study by the Commission for Environmental Cooperation (CEC), Canadian households waste 85 kg of food per person annually. Subsequently, an observational study of household FW found that calculated weekly avoidable FW per household was equivalent to \$18.01, 3,366 calories, and 23.3 kg of CO_2. In addition, the rice's blue, green, and grey water footprint from production and consumption perspectives is a concern expressed by Chapagain and Hoekstra (2011).

The last FW index report shows a lack of information about FW in developing countries. Together with policies compatible with SDGs, more studies about FW in these countries are needed. To date, no household FW studies have been reported in developed countries aiming to identify areas for improvement in existing initiatives or to generate new initiatives. In this sense, Cattaneo et al. (2021) indicated that any actions on food chain phases can affect previous or subsequent phases, a matter that needs to be taken into account. Evans (2014) indicates that one of the strategies aiming to reduce the FW is to understand the factors that are leading to this result, taking into account that household FW is a complex issue.

In 2020, the Metropolitan District of Quito (MDQ) was Ecuador's largest city, with more than 2.7 M inhabitants, according to the Instituto Nacional de Estadísticas y Censos (INEC, 2017) and in terms of contribution to national GDP. Top industries in Quito's larger metropolitan area include textile and metal manufacturing and agriculture, while Ecuador's major exports are coffee, sugar, cacao, rice, bananas and palm oil. The MDQ produces 2,000 tons of solid waste per day, which is disposed of in a landfill. Nearly 60% of this is organic waste, which is not separated and ends up in the landfill, emitting great amounts of methane and contributing to climate change (Center for Clean Air Policy, 2018).

This paper aims to analyse household FW at a value supply chain level, taking into account not only FW but also external forces. For this purpose, a quantification of FW and the resulting environmental pressure on energy, water, and land was performed. Possible factors related to FW generation were assessed. Finally, some initiatives for reducing FW and policies applied to the supply chain were evaluated, aiming to provide a broad vision of household FW. Our study is focused on the MDQ, the results and information presented here is expected to be valuable for generating or rethinking policies for reducing FW.

2 The case study: MDQ

For the present study, the MDQ was chosen since it is the capital of Ecuador. According to the latest population projection by the INEC, in 2020, the MDQ had 2,781,641 inhabitants, making it the country's largest city (INEC, 2017). The MDQ occupies 4,235.2 km^2 and is divided into eight zonal administrations made up of 32 urban and 33 rural parishes (Municipality of Quito, 2012). Food supply for the MDQ comes from sierra, coastal and Amazonian provinces. The agri-food production of these provinces is mainly destined for Quito's wholesale market (48%); the rest is sent to local businesses and fairs (23%). The inhabitants of the MDQ buy their food in markets, supermarkets and neighbourhood stores (Secretariat for Productive Development and Competitiveness, 2018). It is estimated that the MDQ is highly food dependent on national production, imports, and food entering illegally, since local production in the MDQ supplies only 5% of its requirements (Andino et al., 2021). In 2019, Quito's public sanitation company, Empresa Pública Metropolitano de Aseo de Quito (EMASEO, 2021), collected around 722,560 tons of household solid waste in the MDQ. It is estimated that 63% of household solid waste is FW and waste from pruning (ASAMTECH, 2019).

3 Methods and materials

3.1 Methodology

The current study applied the methodology proposed by Chaboud (2017) for evaluating and reporting FW.

3.2 Data collection

In the current study, the sample design was adapted to health emergency conditions (COVID-19). For computational purposes, the following assumptions were considered: overall population of the MDQ and availability of databases. An online survey was applied to study subjects whose contact details (e-mail) were obtained from databases of institutions participating in the research. A validated questionnaire proposed by Van Herpen et al. (2019b) was applied online during the third week of November 2020. A total of 343 participants from the MDQ were interviewed and 189 fully completed questionnaires were processed. The Google Forms platform was used to design the online questionnaire.

In applying the questionnaire, care was taken to comply with "privacy procedures, a pre-announcement, application method, and the calculation of household food waste in grams based on reported units." The questionnaire consists of the following sections: general introduction, a list of food categories, an explanation of FW states, and follow-up questions for those food categories with insufficient information.

In addition, the questionnaire procedure involved the following:

1 A section in the first part of the questionnaire provides information on respondents' demographic characteristics.

2 Household FW was separated into categories, or units, and measured in grams. Measurement of meat, fish, and chicken units was based on the meat substitute category. Bread units were based on the average weight of the different kinds of bread consumed in Ecuador (Freire et al., 2014). Milk was measured as a non-alcoholic beverage unit. The units described above were suggested by nutritionists and based on the typical Ecuadorian diet.

Weight conversion factors were applied to certain cooked foods, such as potatoes, potato products (fries), pasta, rice, meat, chicken, fish, and bread, to obtain the weight of raw FW (Freire et al., 2014; Ministry of Health of Peru, 2014; Hamelman, 2017).

3.3 Limitations of the study

The database involves a portion of the population; data was scarce in some zones and for some food categories; thus, FAO (2011) made a series of assumptions when estimating percentages of loss and waste. Nevertheless, various authors take these estimates as the best currently available globally, and therefore a good basis for calculations (Kummu et al., 2012). The period during which interviews were conducted could also be improved. It would be interesting to take a sample during different periods in the course of a year or during a number of years to determine whether this affects results. Waste analysed across the food chain is also a major topic requiring further research. For instance, food chain insights can reveal that part of FW can be used for other purposes, such as animal feed and biofuel production. Thus, although FSC waste is not used directly by humans, the portion utilised for other purposes is not wasted.

Another factor to be considered is possible calculation errors. As stated in Section 3.4, imported products were not included in calculations, as most of the rice and potatoes consumed in Ecuador is produced here. Importation can be a problem for calculations, according to Kummu et al. (2012) because, in many cases, this is not easy due to factors such as re-exporting. Specifically, this might introduce an inconsistency in the final freshwater calculations, as the blue water footprint varies among countries. When importation is considered, the external (i.e., imported) blue water footprints account globally for approximately 23.7% of the global blue water footprint (of all agricultural products) (Mekonnen and Hoekstra, 2011). This simplified method has an effect on all calculations, including consumption waste calculations. However, if a country's calculations are based mostly on national products, as they are in this study, the potential error is very small, while in countries relying on imported food, the error might be larger.

3.4 Statistical analysis

Descriptive methods were used to present socio-demographic information. Then, an exploratory data analysis (EDA) of the collected variables was done. A well-known randomisation-based method (Friendly and Meyer, 2015), that is, association analysis through a Pearson chi-square statistical dependence test, was carried out among categorical variables related to the characterisation of the sample. The main categorical variables were associated with socio-economic characterisation. In cases in which dependence existed, Pearson's residuals analysis was performed to define outstanding relations among levels of the categorical variables analysed.

Additionally, a variance analysis was carried out independently to determine the relation between the FW declaration and family size and age of members. This analysis was performed using the statistical software R. On the other hand, to analyse the spatial differences among sectors and neighbourhoods related to FW production in the MDQ, a statistical dependence test was developed; no statistically significant differences were found, considering a 5% significance level. In this context, the MDQ was considered as a unit for the expansion factor computation.

The classical chi-square statistical dependence analysis, mentioned above, was carried out between general administrative location reporting and the sum of relevant FW categories.

A complementary analysis was carried out to determine the potential spatial behaviour of the quantity of household FW through a spatial statistics approach. First, the Global Moran's I statistic (Gimond, 2021) was computed. For this purpose, a shapefile with general administrative boundaries was obtained and the cumulative sum of the relevant FW categories was joined with the spatial data file. Mainly, the R packages used for these tasks were the sf (Pebesma, 2018) and spdep (Bivand and Wong, 2018). Additionally, a Monte Carlo approach (Bivand, 2013) (599 simulations) of Moran I statistic computation was carried out.

A factor of expansion was applied in calculating FW, taking into account the following information: the last population census in Ecuador was carried out in 2010. According to projections (INEC, 2012), by 2020 the MDQ will be Ecuador's most populous city, with 2,781,641 inhabitants. Another population estimate, based on household water consumption, with an average water consumption per capita of 4 cubic metres, and including an outliers analysis, resulted in 3,122,192 inhabitants (unpublished study). Thus, the FW quantity results were recalculated using the average of the two population estimates, household size (3.9), and the annual average waste of food categories. These were analysed for a one-year period. Another consideration was the number of answers obtained.

3.5 Environmental pressure of FW on energy, land and water resources

Average FW figures calculated according to the method described were used to analyse environmental pressures on land, energy and water.

The land footprint was calculated using an equation proposed by Sun et al. (2018) and applied by Jin et al. (2021):

$$LF = Fw / Yc \tag{1}$$

where the land footprint (*LF*) is equal to the quotient of the food wastage (*Fw*) and crop yield (*Yc*) in kg/ha.

Then, methodologies to calculate each footprint were applied. Thus, the methodology used to determine the water footprint in m3/ton for the crop, suggested by Sun et al. (2018), involves the following equations:

$$Wg = Fw \times WFg \tag{2}$$

$$Wb = Fw \times WFb \tag{3}$$

$$Wgy = Fw \times WFgy \tag{4}$$

where

Wg green water footprint

Fw food wastage

Wgy grey water footprint

Wb blue water footprint.

The energy footprint was calculated according to an equation developed by Yuan and Peng (2017) and Kashyap and Agarwal (2019). This method involves grouping items by energy as related to human labour (MJ/h) and the energy consumed by machinery and the application of pesticides (MJ/Kg). The information was transformed into energy equivalents and the following equation was used to calculate energy:

$$E = \frac{Tw}{Tp} \times Te \tag{5}$$

where

E energy footprint

Tw total wasted

Tp total produced, by hectare

Te total energy required for production, by hectare.

Inputs and quantities used in calculations were taken from a database of the Ecuadorian Ministry of Agriculture and Livestock.

4 Results and discussion

4.1 Sample characterisation

The sample characterisation was carried out through the methods described in Section 3 of this article.

4.1.1 Socio-demographic information

Table 1 presents the socio-demographic information of respondents; variables considered were age, household size (number of members), occupation, marital status, gender and education level. Socio-demographic characteristics of respondents include an average age of 35 years and an average household size of four persons. Among respondents, 29% said they were public employees, 55% of respondents were single, 53% were female, and higher education had been obtained by 43%.

4.1.2 Relation among socio-demographic variables

Among the 343 persons who responded to the survey, 189 reported FW. Statistical tests were performed on this dataset. To understand the possible relation between socio-demographic variables and FW, an EDA was applied composed, principally, of three methods. The first was an association analysis using the Pearson chi-square statistical test, the second was the Pearson standardised residuals analysis, and finally, a variance analysis was applied.

Table 1 Socio-demographic characteristics of respondents

Variable	n = 343	
Age (mean/SD)	34.71/12.98	
Household size (mean/SD)	3.92/1.62	
	Absolute frequency	*Relative frequency*
Occupation		
Public employee	98	28.60%
Private employee	63	18.40%
Manual labourer	1	0.30%
Self-employed	43	12.50%
Unpaid household worker	16	4.70%
Domestic worker	7	2.00%
Unemployed	52	15.20%
Retiree or pensioner	5	1.50%
Student	58	16.90%
Marital status		
Co-habiting	9	2.60%
Single	187	54.50%
Married	121	35.30%
Divorced	23	6.70%
Separated	3	0.90%
Gender		
Female	179	52.20%
Male	164	47.80%
Education level		
Primary education	3	0.90%
Secondary education	122	35.60%
Higher education	146	42.60%
Postgraduate	72	21.00%

4.1.2.1 *FW, education level, parish type*

Table 2 provides the results of the dependencies analysis between, on the one hand, education level and parish type and, on the other, FW.

The study indicates a dependency between education level and household FW (P-value less than 5%), but no dependency between parish type (urban/rural) and household FW (P-value greater than 5%).

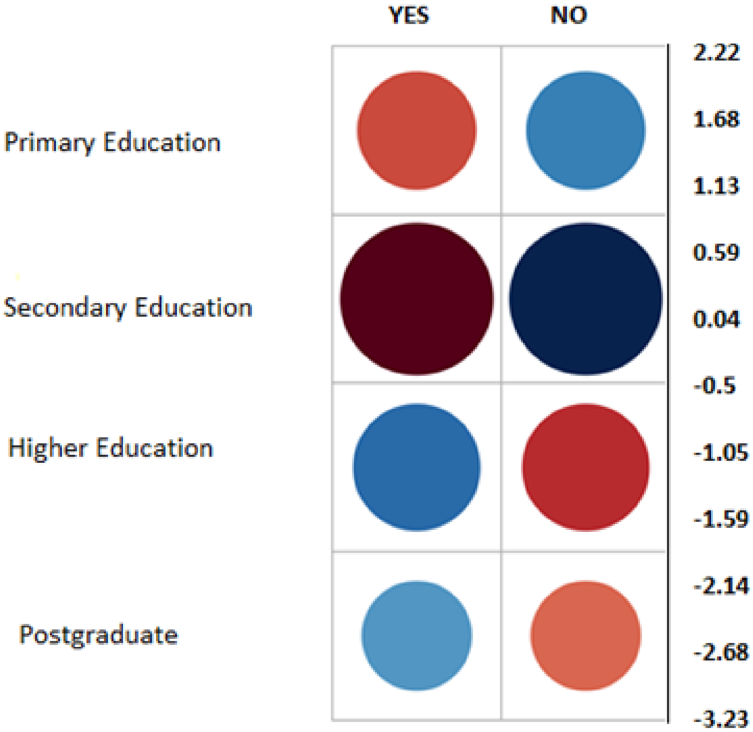
Table 2 Education level and parish type dependencies analysis

Variable	*X-squared*	*df*	*P-value*
Education level	15.856	3	0.001213
Parish type (urban/rural)	20.001	1	0.1573

4.1.2.2 FW and education level

Figure 1 indicates the relation between education level and FW, assessed by Pearson's standardised residuals.

Figure 1 Pearson standardised residuals: education level and FW (see online version for colours)



Note: Positive residuals are in shades of blue, negative residuals, in shades of red.

In Figure 1, blue positive residuals determine attraction, indicating a positive association. On the contrary, red negative residuals reveal repulsion, indicating a negative association. There was a strong association between respondents who reported no FW and a secondary education level, and a weak association between respondents who reported FW and a secondary education level.

Regarding education level and generation of household FW, respondents with a higher education level tended to discard more food than respondents with a lower education level. In contrast, research conducted in Serbia by Djekic et al. (2019) showed consumers with lower education levels reporting more FW than students and citizens with higher levels of education. Thus, the role of education level in food wastage is not clear. Research carried out in Croatia indicated that education level was not related to food wastage (Ilakovac et al., 2018). A study of Finnish households by Silvennoinen et al. (2014), as well as one of Swiss households Visschers et al. (2016), reported similar results.

According to our results, parish type (urban/rural) was not correlated with the amount of food wasted; these results are similar to other studies (Koivupuro et al., 2012). This result could be due to the dietary characteristics of Ecuador's urban and rural areas, where consumption of 5 of the top 10 products is the same (INEC, 2013). However, in Norway, Hanssen et al. (2016) found that households in the urban region generated more edible FW than those in rural areas. The opposite results were found for households in Hanoi through self-reported FW generation: 1,192 g/day/household in urban areas, and 1,694 g/day/household in rural areas (Liu and Nguyen, 2020).

4.1.2.3 Relation between FW and family size and age of members

In Table 3, variance analysis was performed to detect statistical differences between the means of the family size and age variables on the one hand, and the declaration of FW on the other.

Table 3 Family size and age variance analysis

Factor	*Dependent variable*	*Df*	*Sum sq.*	*Mean sq.*	*F value*	*Pr (> F)*
Family size	Waste	1	6.2	6.245	2.397	0.122
	Residuals	341	888.3	2.605		
Age of family members	Waste	1	69	69.06	0.409	0.523
	Residuals	341	57,509	168.65		

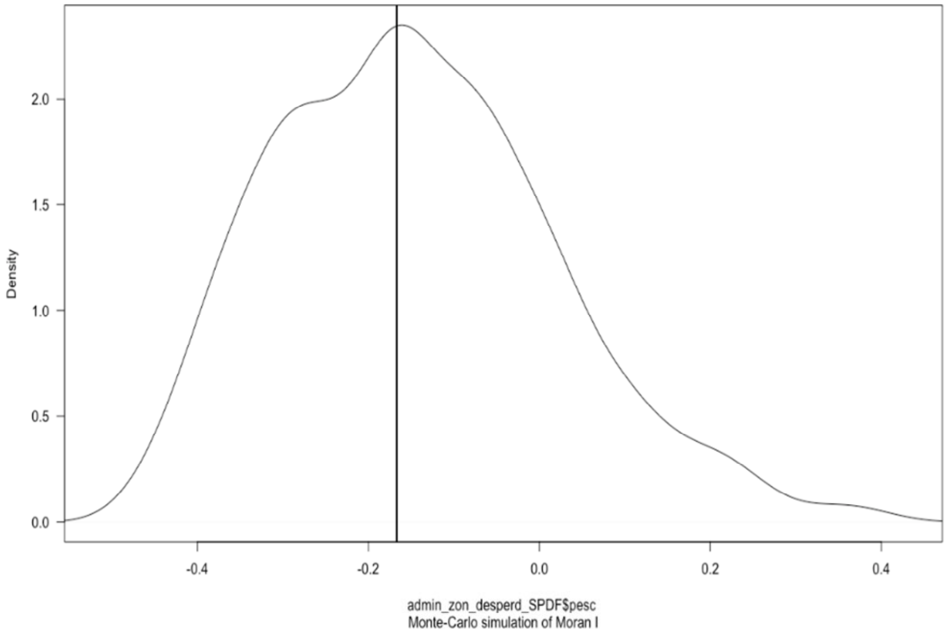
Family size and age of members obtained a P-value > 0.05, which means that the FW declaration had no significant relation with said factors (Table 3). These results contrast with information reported by other authors who found a significant relationship between family size and FW. Hence, a number of authors (Jörissen et al., 2015; Stancu et al., 2016; Giordano et al., 2019; Abeliotis et al., 2019) showed that in larger households, more food is discarded. However, the Waste and Resources Action Programme (WRAP, 2009) states that families with four members generated half of the FW produced by single person households (Chalak et al., 2016). On the other hand, other studies found that the age variable is significantly correlated to FW. Older people tend to be more careful with FW than younger consumers (Quested et al., 2013; Ilakovac et al., 2018). However, research by Falasconi et al. (2019) found the opposite. So, there is no consensus about generation of FW related to age (Schanes et al., 2018).

4.1.2.4 Relation between FW and spatial behaviour

The potential spatial behaviour of the quantity of household FW, performed through a spatial statistics approach, determined that in all cases analysed through hypothesis testing, the P-values obtained were above the significance level defined (in this case 5%); in addition, the Monte Carlo approach obtained a similar conclusion for each relevant FW category. As an example, Figure 2 shows the density plot of Moran I for the fish waste food category and the mean value of the Moran I statistic (–0.16687).

The null randomness hypothesis (attributed values are randomly distributed across the study area) cannot be rejected (autocorrelation absence) because a P-value of 0.5267 was obtained. In conclusion, the variable household FW amount for this study, in general terms, cannot be considered a regionalised variable. For this reason, an additional analysis of local indicators of spatial association is not feasible.

Figure 2 Monte Carlo simulation of Moran I (fish waste food category)



4.2 Household FW characterisation

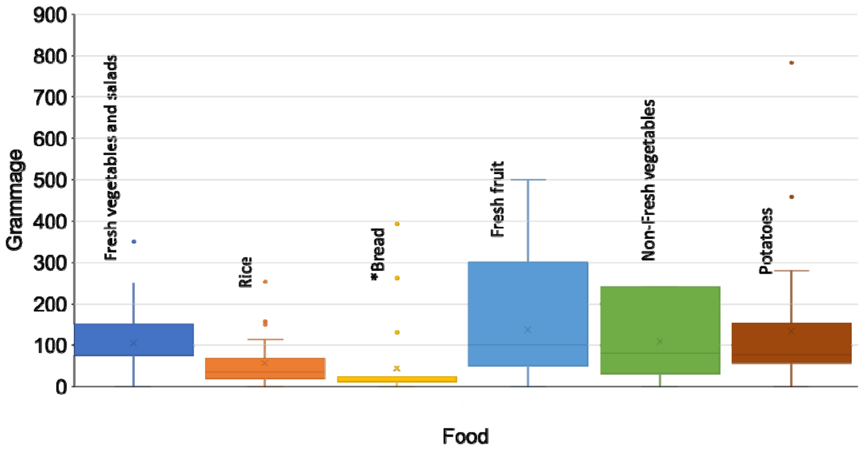
Analysis of FW information obtained through the online survey provided the following results.

4.2.1 FW categories – observations distribution

Figure 3 presents the products for which FW was quantified. Some food categories had a low median, and their quartiles were very concentrated, with a value equal to or less than 100 g of waste. This is the case of bread and rice. Products with a relative medium dispersion, with approximately 150 g, were fresh vegetables, salads and potatoes. Products with values higher than 200 g were fresh fruit and non-fresh vegetables (processed vegetables). Also notable is the higher waste of potato products, reaching 800 g. Concerning the waste of non-fresh vegetables and fresh vegetables, the concentration of the answers in the quartiles, evidenced in Figure 3, could be partly explained by respondents' food preferences and partly by the higher cost of these goods (Ilakovac et al., 2018).

According to WRAP (2013), households generate waste for several reasons. Food may not be used before it spoils; it may be prepared, cooked, and served in excess; it may not satisfy personal preferences; it may be accidentally spoiled. The study also mentions reasons for not using food on time, including purchase of excessive quantities or in large packaging sizes, confusion in interpreting food expiration labels and suboptimal storage practices (Jeswani et al., 2021). These factors may be affecting waste generation in the case of potatoes.

Figure 3 Boxplot of FW by categories (see online version for colours)



As noted by Abeliotis et al. (2019), the products more susceptible to waste are fresh fruits, vegetables, and dairy. Results for fresh vegetables and fruit, calculated with the median and presented in Figure 3, are not comparable to those for the study mentioned, or to research by Elimelech et al. (2019) and Delley and Brunner (2018), among others.

On the other hand, the mean, standard error and median (in grams) for major household FW categories are shown in Table 4.

Table 4 Mean, standard error and median (in grams) of relevant FW categories

Food waste category	*Mean (grams)*	*Standard error (grams)*	*Median (grams)*
Fish	99.75	9.36	126.00
Chicken	151.36	21.87	126.00
Fruits	138.89	16.32	100.00
Appetisers	82.50	7.50	90.00
Meat	160.71	49.93	90.00
Processed fruits	109.58	13.22	80.00
Potatoes	85.61	10.88	76.50
Rice	56.84	4.85	33.75

4.2.2 Quantification of FW categories

Table 5 shows FW production in the MDQ per food category (number of responses > 50). Since the median is a robust figure (less sensitive to outliers), it is also presented. As a general result, the weekly average of FW was 0.13 kg/person, and the annual average was 7 kg/person.

In Table 5, this study presents the more representative solid FW per category (number of responses > 50): fresh vegetables and salads, rice, processed vegetables, bread, fresh fruits, and potatoes (potatoes and potato products) were often discarded.

Bread, rice, and potatoes are very important in the diet of Ecuadorian households (Egas et al., 2018; Freire et al., 2014; FAO, 2019a). In Ecuador, the total estimated annual expenditure for all households on bread consumption was more than

USD 34 million, the greatest food expenditure nationwide, followed by rice, accounting for more than USD 33 million; expenditures on potatoes ranked 15th, accounting for more than USD 10 million. When analysing the differences in consumption of the products mentioned, between the Ecuadorian households with the lowest income and those with the highest income, it was found that the first group spends 10.2% of food expenditures on rice, a greater percentage than that found for the highest income group. For bread and potatoes, household consumption is similar for both groups. On the other hand, analysis of fruits shows that households with higher incomes spend 14.4%, more than double the expenditure for Ecuadorian households with lower incomes, which spend 7.1% on this category. Regarding vegetables, legumes, and tubers (potatoes), the poorest households spend 15.2% while households with the highest income spend 13.5% on these products (INEC, 2013).

Table 5 FW production

Food waste category	*Number responses*	*Total waste (kg)/week*	*Weekly average waste kg/hs*	*Median (g)/week*	*Total annual waste kg**	*Quito annual average (t)/hs***
Fresh vegetables and salads	100	10.40	0.10	75.00	540.80	4,093
Rice	88	5.00	0.06	33.75	260.10	2,237
Processed vegetables***	87	7.95	0.09	75.00	413.40	3,596
Bread	81	3.56	0.04	22.98	185.12	1,729
Fresh fruit	54	7.50	0.14	100.00	390.00	5,466
Potatoes	53	4.80	0.09	102.00	249.51	7,309
	Weekly average waste kg			*Quito annual average (t)***		
Total waste/hs	0.53			0.027		
Average waste/person[b]	0.13			0.007		

Notes: *Total calculated, 52 weeks/year, **average calculated with the expansion factor and ***processed vegetables. [a]Sum of the six food categories, [b]division of the total average waste (sum of all sixcategories) by the number of households and the number of members per household in Quito, and hs: household (3.9 members).

Household FW data are compiled using heterogeneous methodologies and definitions (Spang et al., 2019). The lack of a standard methodology in quantifying generates incomparable results (Withanage et al., 2021). Nevertheless, some studies show results similar to those of this study. Households in different parts of the world waste fresh fruits and vegetables more than any other product (Parfitt et al., 2010; Abeliotis et al., 2019; Edjabou et al., 2016; Hanssen et al., 2016; Schott and Andersson, 2015; Ammann et al., 2021; Fiore et al., 2017). In the investigation by Aschemann-Witzel et al. (2019) of Uruguayan households, waste was determined as follows: vegetables 14.6%, fruits 8.7%, and bakery products 8.1%. Similarly, in the city of Tehran, Fami et al. (2019) found that food items wasted at the household level were fresh fruits at 10.53% and fresh vegetables and salads at 8.66%. A study of Czech households reported that vegetables represented 26.40% of food wasted, bakery 22.52% and fruit 13.05% (Novakova et al., 2021).

Estimates of household FW need to be taken with care. According to estimates of the specific categories of FW in MDQ households, average annual potato waste is 7,309.46 t, while rice comes to 2,237.14 t. When comparing these figures with Ecuador's rice production, the estimated amount of rice waste is equivalent to 21.7% of rice production (in husk) for the year 2019 from El Oro Province, one of the country's main rice-producing provinces. Regarding potatoes, the waste estimate is equivalent to 8.5% of potato production in Chimborazo Province for 2019 (Ministry of Agriculture and Livestock, 2019b).

Wheat, the principle raw material in bread, is not produced in sufficient quantities in Ecuador to cover internal demand (Ministry of Agriculture and Livestock, 2019a). Therefore, the country depends on wheat imports. Wheat is used in making flour for bread, pasta, cakes, cookies, etc. Wheat imports are currently exempt from tariffs and duties (Foreign Trade Committee, 2019); therefore, the waste of bread (wheat) is not only a waste of natural resources but also an economic loss.

According to the Ecuadorian food balance sheet for 2019 (Ministry of Agriculture and Livestock, 2019a), available supplies per capita of rice, wheat, and potatoes are as follows: rice 51kg/year – 139 g/day, wheat 48kg/year – 132g/day, potatoes 26 kg/year – 71 g/day. If the annual waste in the MDQ for these three products were avoided, there would be enough rice available for approximately five people (260 kg per year/51 kg per year), bread (wheat) for four people (185 kg per year/48 kg per year) and potatoes (249 kg per year/26 kg per year) for ten people.

The FW index indicates that the average waste for the Latin American and Caribbean region is 69 kg/capita/year, while the global FW index report for households is 74 kg/capita/year. According to this report, households in Ecuador waste around 72 kg/capita/year, or 1,258,415 t/year (United Nations Environment Programme, 2021). According to this study, households in the MDQ discard, on average, 0.13 kg/person/weekly and 7 kg/person/yearly.

4.2.3 Environmental pressures due to FW

Annual average FW information was used as raw material in equations for calculating environmental pressures on water, land and energy, indicated in Table 6.

As shown in Table 5, the total waste associated with rice is slightly higher than the waste associated with potatoes. This tendency changes when average household waste is calculated, leading to higher average potato waste. According to interview information, this is due to the fact that most households recognised rice waste while more than half indicated potato waste. But in households that waste potatoes, the quantity wasted was higher, on average, than that for rice. Thus, in order to calculate environmental pressures due to wastage of rice and potatoes, the annual average was used; results are presented in Table 5.

Total annual waste indicated is consistent with greater rice consumption in Ecuador (Freire et al., 2014). One of the factors contributing to this is related to the price of potatoes. According to the Instituto Nacional de Investigaciones Agropecuarias (INIAP, 2002), potatoes have greater nutritional value, their sensorial characteristics are more valued, and they are considered more expensive than other tubers by Ecuadorian consumers. This last suggests that people able to consume potatoes, on average, waste more. This pattern is in agreement with the consumer waste patterns analysed by Verma et al. (2020). Their study suggests that consumer FW follows a linear-log relationship with consumer affluence and starts to emerge when consumers reach a threshold of approximately $6.70/day/capita level of expenditure. Although in this study economic value has not been determined, the pattern seems to be similar.

Table 6 Environmental pressures of food wastage on energy, land and water resources

Food	*Waste*	*Energy*		*Water footprint* m^3*/ton*				*Land footprint*
	*t/year**	*MJ/t***	*MJ/h*	*W green loss*	*W blue loss*	*W grey loss*	*W foot total*	*Ha*
Rice	2,237.19	1,403.42	204,673.95	2,771,167.78	1,135,396.92	301,025.09	4,207,589.80	499.64
Potatoes	7,309.46	2,320.84	288,798.98	2,332,890.56	1,567,275.3	972,851.2	4,873,017.06	313.98

Notes: *Waste calculated with the expansion factor.
**Fertilisers are not considered since energy equivalent information is not available.

The agricultural water footprint of FW has the highest values, with a total of 4.2 million m^3 and 4.8 million m^3 of water/t/year for rice and potatoes, respectively. Green water, that is, water entering soils from precipitation, had the highest value. However, the green water environmental impact is smaller than the blue water-based irrigated agricultural systems because it does not change the distribution of water resources (FAO, 2013). The second highest values are for energy, specifically, the energy involved in pesticides applied during production. Finally, the land footprint has a relatively low value. These data are annual footprints per household. A number of other studies confirm the major concern regarding these effects.

Thus, it is estimated that three-quarters of the water footprint produced by food loss and waste is due to cereals, fruits and vegetables (Mekonnen and Gerbens-Leenes, 2020). On the other hand, in Turkey, the FW water footprint measured 6.2×10^9 m^3 of water/year, and the energy footprint represented 13.5×10^4 TJ/year (Cakar et al., 2020). Sun et al. (2018) have shown that, in China, food wastage is serious. It results in a large amount of inefficient water resource consumption and environmental destruction. Hence, water resource (blue water and green water) loss caused by FW reached 60,502 million m^3, that is, more than 10% of the nation's blue water used in 2010, with the largest proportion, 45.77%, caused by cereal wastage, followed by pork (17.06%), fruit (11.42%) and vegetables (7.68%) (Sun et al., 2018). The same authors conclude that chemical fertilisers and pesticides are the main cause of agricultural non-point-source pollution. The study calculated water resources required to dilute chemicals applied to crops, such as pesticides and chemical fertilisers. These conclusions are consistent with the results for energy expressed in MJ/t in Table 6. Overall, previous studies indicate that losses related to cereals (particularly rice) and sugarcane have the highest environmental effects (Kashyap and Agarwal, 2019).

Potato waste exhibited more environmental pressure than rice, although the same tendency is present. Therefore, the highest values are for the energy and water footprints. Regarding energy consumption, Zangeneh et al. (2010), in a potato production study, mentioned that mechanisation is an important factor because a high level of technology significantly reduces energy use. Reynolds et al. (2015) evaluated the environmental effect of weekly food consumption in households at different socio-economic levels in Australia using environmental extended input-output analysis. Fruit and vegetables accounted for a high-water effect, per dollar spent, and the energy effect followed. In this study, cereals were the categories that contributed to the largest environmental effects in an average household's food consumption footprint. These results are similar to those found in this study. Reutter et al. (2017) found that the FW of Australia was AU$5.7 billion, representing 9% of total water used. The most water, 71%, was consumed at the farm level.

4.2.4 Analysis of SDG initiatives to reduce FW and other policies for the rice and potato supply chain

To suggest public policies that can be developed and implemented in the potato and rice supply chains, the following data and facts were considered:

Table 7 Initiatives and policies to reduce rice and potato FW

Initiative or policy	*Supply chain impact*	*Type*	*Objective and other considerations*	*Quantification of food waste reduction*	*Rice*	*Potato*	*Ref.*
Diakonia's Food Bank	AP	Private	Food waste reduction bridge between hungry people and producition and sales companies.	No	A	A	Technical Secretariat Plan Ecuador (2019)
Great Agricultural Minga	AP	Public	Technification of the agricultural sector through the provision of technified irrigation systems, seed kits, fertilisers and agricultural inputs.	No	A	A	Technical Secretariat Plan Ecuador (2019)
Local governments	AP	Public	Develop initiatives to collect surpluses from the agricultural sector, food manufacturers, restaurants, hotels for distribution to vulnerable communities.	No	A	A	Technical Secretariat Plan Ecuador (2019)
Minimum support price (MSP)	Direct: consumer and producer Indirect: AP	Public	"MSP, as well as a complimentary high import tariff, was meant to protect small rice producers from competition from world markets and increase their incomes. Farmers with greater productive capacity are currently receiving the highest income transfers from the guaranteed minimum rice price."	NA	A	NA	FAO (2019b)
Agrifood Pact of Quito (PAQ) Agrifood Charter of Quito (Carta Agroalimentaria de Quito)	Consumer and producer	Public	Accept recommendations of the Milan Urban Food Policy Pact in terms of food waste reduction. Four actions can be considered. The objective is to manage food waste in a more sustainable way by adopting a circular economy approach. Accept recommendations from the París Agreement.	Yes Recommended indicators: 1 Total annual volume of food loss and waste 2 Annual number of events and campaigns aimed at decreasing food loss and waste	A	A	Milan Urban Food Policy Pact (2015)
REAGROBAQ Program	Direct smallholder producer	Private	"Tackle food waste at the production level by investing time and resources in smallholder farmers" (farms less than five acres in size).	No	NA	A	The Global Foodbanking Network (2021)
City Region Food System Program	Decision makers, policy makers	International	Monitor and report advances in food programs (including food waste). The objective is to reinforce rural-urban linkages for resilient food systems.	NA	NA	NA	Andino et al. (2021)

Note: A: applicable, NA: not applicable, and AP: all phases (production, industrialisation, commercialisation and consumption).

According to FAO (2011), "per capita waste by consumers is between 95–115 kg a year in Europe and North America, while consumers in sub-Saharan Africa and South and South-eastern Asia throw away only 6–11 kg a year" per capita. This study found that, yearly, almost 7 kg/person is organic waste, a value comparable to that indicated in the report for Sub-Saharan Africa and South and South-eastern Asia. On the other hand, according to INEC (2020), rice consumption in Ecuador is approximately 50 kg/person; according to this study, annual rice waste per person is 0.75 kg. Based on these figures, almost 1.5% of all rice purchased is wasted. As for potatoes, INEC (2020) estimates a consumption of 23.03 kg/person/year in 2020; according to this study, potato (fresh and processed) waste is 1.25 kg, that is, 5.14%.

Table 7 presents initiatives to reduce FW and other policies for the rice and potato supply chain.

As indicated in Table 7, the information presented contains initiatives for achieving SDG FW reduction and other policies applied to the rice supply chain. To date, none of the initiatives presented includes quantifiable reduction indicators. The MSP policy does not have a multiphase analysis based on environmental sustainability.

Regarding potato waste, as previously mentioned, this product is not included in MSP policy. According to studies of this product, prices are extremely variable, unlike those for rice, as there are no fixed minimum market prices. This fact can lead producers to decide not to plant potatoes or not to harvest their crop because payment will not cover costs and because potato varieties, such as those produced in Carchi, cannot be stored, nor can those produced in the wet Andean highlands (Sherwood, 2009).

Policies leading to environmental sustainability that can be considered, for both producers and consumers, involve education and price incentives. In creating these policies, codes of conduct should be taken into account (FAO, 2021).

4.2.5 Analysis of SDG initiatives for energy and water management and other policies

Table 8 presents initiatives for energy and water management and other policies.

As indicated in Table 8, water use initiatives and governance are both public and private. Although there is no data related to water waste in the food supply, the use of this resource is regulated. SENAGUA's national irrigation plan affects the agricultural level, and most policies affect all sectors.

Although the initiatives and policies mentioned are leading to improvements and generating awareness about water waste, Ding et al. (2018) mention that technology is always the main way to prevent water waste. Thus, in order to obtain better results from these initiatives, water technology is a factor that should be considered.

The policies cited are, in general, thought to support a part of or the entire FSC. Another approach would provide different results. Sino et al. (2019) evaluate the knowledge and practice of household FW management in order to avoid impacts on the marine ecosystem. This is a new approach that could be taken into account when developing FW policies. Another approach would be to empower entire communities involved in the FSC based on the management of FW.

Table 8 Initiatives and policies for energy and water management and other policies

Initiative or policy	*Supply chain impact*	*Type*	*Objective and other considerations*	*Quantification of resource waste or reduction*	*Ref.*
Water Protection Fund (FONAG) or Camaren Consortium	All phases for Quito	Public and private consortium Managerial level: private trust Execution level: technical secretary	Restores and protects all the city's water sources. Programs: 1 Water management: hydrologic, climate monitoring and translating water benefits into economic profitability. Analysis of ecological flows. Support for basin governance. Use of water.	No	FONAG (2022)
Metropolitan Public Potable Water and Sanitation Company (EPMAPS)	Consumer	Public	City water authority.	No	EPMAPS (2022)
National Water Secretariat (SENAGUA)/National irrigation plan	Agricultural level	Public	Water authority, policy makers.	No	Water Secretariat (2019)
Water Regulation and Control Agency (ARCA)	All phases	Public	Water authority, controls use of water.	Yes	Water Regulation and Control Agency (2022)
Ecuadorian agricultural policy: towards sustainable rural territorial development, 2015–2025	Agricultural level	Public	Policies influencing structural factors: Promote water management and improvement of irrigation infrastructure and flood control. Promote the use of local inputs (seeds and bio-inputs) and the implementation of good agricultural practices to promote the establishment of new agricultural systems for the sustainable intensification of agricultural production.	No	Ministry of Agriculture Livestock Aquaculture and Fisheries (2016)

Note: All phases (production, industrialisation, commercialisation and consumption).

Regarding energy, as proposed in Ecuador's agricultural policy, the use of local inputs, such as seeds and bio-inputs to establish new agricultural systems, is the only element taken into account. However, the government has suggested the need for research regarding the use of local seeds and its relationship to low rice production (Jirarud and Suwanmaneepong, 2020).

5 Conclusions

This study involved quantifying household FW and determining environmental pressures produced by FW. Interest in FW in developing countries is growing due to the socio-economic and environmental characteristics of this phenomenon. We explored the influence of socio-demographic factors on household FW in the MDQ. The findings indicate a relationship between FW and educational level (P-value less than 5%): respondents with a higher educational level tended to throw away more food than those with a lower educational level. However, this study found no relationship between FW and type of urban or rural parish, family size, age of household members, and spatial behaviour (P-value greater than 5%).

In this study, FW amounts are calculated for households in the MDQ, followed by analysis of the interactions between FW and water, energy, and land resources determined by estimating the environmental pressure of rice and potato waste indicated in the water, land and energy footprints. Thus, study results indicate that the analysis of FW categories, through the boxplot, determined low medians and higher concentration of quartiles in bread and rice (< 100 g). Categories with relatively medium dispersion (approximately 150 g) corresponded to fresh vegetables, salads and potatoes. The products with values greater than 200 g were fresh fruits and non-fresh vegetables (processed vegetables). In addition, the food categories producing the most waste were fresh vegetables (10.40 kg/week) and rice (5 kg/week), while waste for potatoes was the lowest (4.80 kg/week). Regarding potato and rice waste in households in the MDQ, estimates found in this study show that the annual average for potatoes was 7,309.46 t, while rice accounted for 2,237.14 t. Environmental pressures of rice and potato waste on energy, water, and land were as follows: energy 1,403.42 MJ/t, 2,320.84 MJ/t, 204,673.95 MJ/h and 288,798.98 MJ/h. Total water footprint 4,207,589.80 m^3/t, 4,873,017.06 m^3/t, land footprint 499.64 ha and 313.98 ha, for rice and potatoes, respectively.

Study results represent a starting point, that is, for the first-time, household FW and environmental pressures have been quantified. Compliance with the SDG is a global concern; the data reported here can guide industrial sector decision-making, for instance, regarding strategies that can contribute to FW reduction. At the same time, the information provided in this study can also be used by authorities and others in generating social or production policies intended to reduce FW in compliance with SDG 12.3. Policies for reducing FW, with a social and production focus, are doubly beneficial as they help vulnerable populations access food through food redistribution mechanisms and they reduce the pressure on natural resources while mitigating the effects of FW on the sustainability of the food system.

It is noteworthy that the complexity of FW can generate different scenarios. A case requiring more in-depth analysis is bread for which the raw material is currently exempt from import tariffs and duties, a fact linked to the socio-economic level of consumers as well as its considerable waste level.

Thus, for future studies, it is recommended that researchers characterise waste according to different dimensions, including, but not limited to, the social, economic, technological and environmental. This will encourage sustainability at the consumer level and in the crafting of policies and regulations.

We suggest that policies such as MSP be analysed taking into account the consumer effect specifically related to FW. A balance between the small rural farmer's economic benefits and FW reduction at the consumer level would need to be reached. Initiatives should take into account effective indicators of FW reduction; this requires a baseline of FW quantification.

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