Assessment of Household Food Waste as a potential source for energy generation

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EXTENDED ABSTRACT

The UK's Waste and Resources Action Programme (WRAP) defines food waste as all food and drink discarded throughout the entire food chain[1]. Food waste constitutes one of the largest components of the waste stream around the world. Based on recent study the percentage breakdown of EU-27 food waste arisings is: 42% from households, 39% from manufacturing, 14% from food service/catering sectors and 5% from wholesale/retail[2]. As it can be observed Household Food Waste (HFW) constitutes the highest percentage, estimated to be 37.7 Mt for the EU-27, which accounts for approximately 76 kg per capita per year[1] and this can partially explain the increasing interest in European level towards prevention of HFW as underlined by a number of recent studies[3,4,5] as well as campaigns e.g. *Say No to Food Waste*[6] and *Love Food Hate Waste*[7]. Moreover, there is a tendency towards quantification and recording of qualitative characteristics of HFW since such data are really missing throughout European countries with some exceptions such as in UK, Sweden and Italy. Moreover, WRAP has also disaggregated HFW into two types of waste: **avoidable waste** and **unavoidable waste**. Particularly, based on WRAP, **avoidable food waste** is the food that has been discarded because it is no longer wanted or has been allowed to go past its best. The main reasons for ending up with avoidable HFW include: (a) prepared, cooked or served too much and subsequently disposed of; in the vast majority of cases, this is because too much food was 'processed' in the home, but it also covers cases where food was damaged during this processing (e.g. burning) and (b) not used in time either because it has passed a date label (e.g. use by, or best before date) or has gone mouldy, rotten, looked, smelt or tasted bad. On the other hand, **unavoidable food waste** includes waste arising from food preparation that is not, and has not been, edible under normal circumstances, e.g. meat bones, egg shells, pineapple skin etc[1,3].

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[1] ***WRAP*** *(2008): The Food We Waste.*

[2] ***BIO Intelligence Service*** *(2010): Preparatory study on food waste across EU 27.*

[3] ***WRAP*** *(2009): Household food and drink waste in the UK.*

[4] ***WRAP*** *(2011): New estimates for household food and drink waste in the UK.*

[5] ***WRAP*** *(2013): Household Food and Drink Waste in the United Kingdom 2012.*

[6] *http://saynotofoodwaste.org/about*

[7] *http://www.lovefoodhatewaste.com/*

The objective of the present research was twofold i.e. the recording of qualitative and quantitative primary data of HFW produced in Greece and the assessment of the potential of HFW for biogas production. It was in the scope of the present research to study the diversity of the composition of HFW. At the same time, quantitative conclusions on the production of HFW waste per household as well as data on the possibility of preventing the creation of waste were drawn. For the purposes of the research, a kitchen-waste-diary was prepared and circulated to the participants i.e. five (5) two-member families (H1, H2, H3, H4 and H5) of Attica Region. The participants recorded the weight of the type and state (avoidability) of HFW they produced for 28 consecutive days during winter. Drinks and other special waste including tea bags, espresso capsules, yogurts and blood residues were excluded. The completed diaries were gathered and a thorough and extensive analysis was executed. In order to categorise the data and further interpret the results, the following household food waste groups were determined: 'Fruits', 'Vegetables', 'Meat and Fish', 'Bread and bakery', 'Cooked Food' and 'Miscellaneous'. Based on the results of the dairy keeping, twenty (20) laboratory samples were prepared (4 weekly samples per households). In **Figure 1** the prepared samples are illustrated. The samples were analysed for physicochemical characteristics in the laboratory of the Unit of Environmental Science and Engineering of the School of Chemical Engineering of National technical University of Athens. The physicochemical parameters analysed were: TS%, VS%, pH, conductivity, TC, TOC, TN, TKN, NH4, Metals (Cu, Mn, Ni, Cd, Pb, Cr and Zn) and minerals (K, Na, Ca and Mg) and P. Also, the potential of biogas generation from HFW was examined in all samples through the performance of BMP (Biochemical Methane Potential) tests, which were executed at the laboratory of Biochemical Engineering and Environmental Technology of the Institute of Chemical Engineering Sciences (ICE-HT/FORTH) in Patras.

In **Figure 2** diagrams presenting the composition of each HFW weekly sample, are provided. As it is illustrated for all HFW samples Fruit and Vegetable waste amounted more than 64%. In **Figure 3** the average composition (% weight) of all HFW samples is presented in which 'Fruit' and 'Vegetable' waste constitute the main waste types of HFW since they account for 90% of the total HFW composition. Based on the results of the inventory, category 'Fruit' participates in the largest proportion with 52%, followed by 'Vegetables' with 38%. Most waste generated from 'Fruits' (75%) and 'Vegetables' (78%) categories is unavoidable waste (**Figure 4**), i.e. waste that it is not, and has not been, edible under normal circumstances such as peels, seeds, husks etc. On the other hand, 'Bread and Bakery' and 'Cooked Food' categories are characterised by high avoidability constituting 100% and 81%, respectively by both waste types. In total 30% of the waste quantity recorded was avoidable and 70% unavoidable. **Table 1** presents the variety of the recorded waste types. Oranges, lemons, mandarins and apples comprise 97% of the total fruit waste. 'Vegetable' waste group is characterised by many different waste components with the predominant to be the potatoes (14.6%), onions (12.8%), cucumbers (9.9%), broccoli (7.5%) and carrots (7.6%).

***Figure 1**: HFW samples*

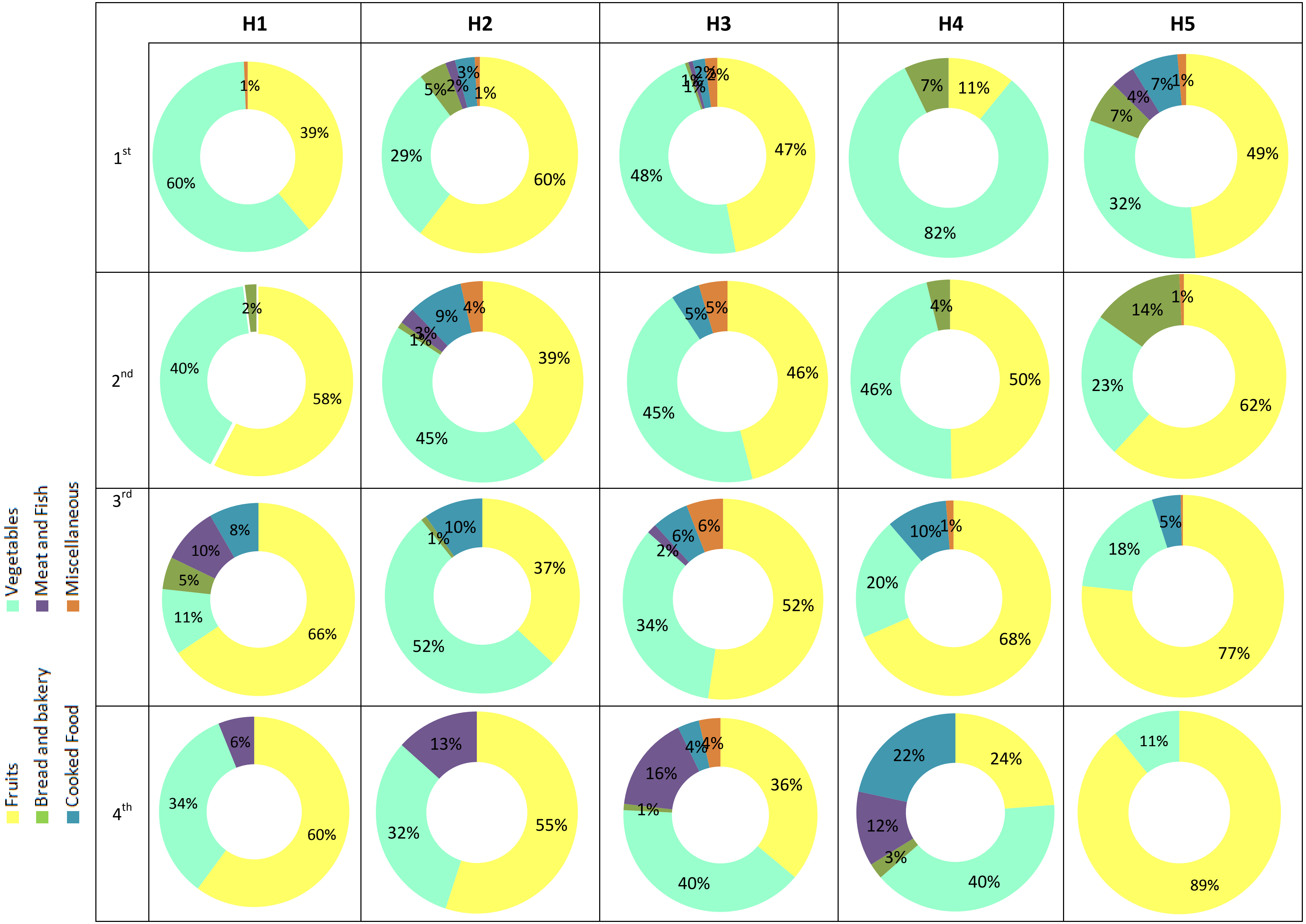

Figure 2: *Composition of HFW samples per waste category (% w/w)*

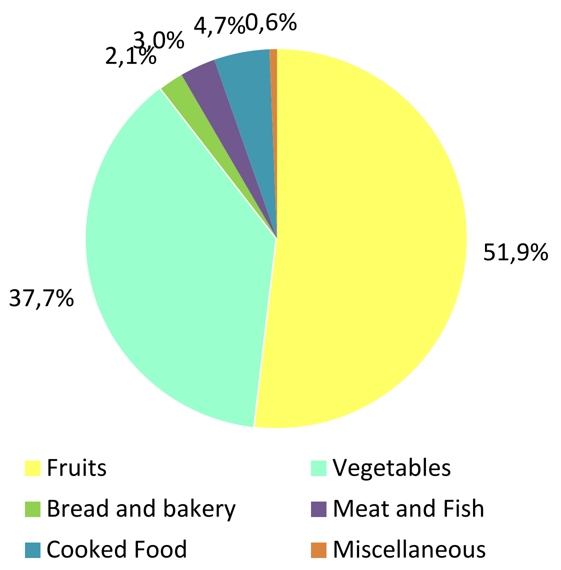

Figure 3: The average composition *(% w/w)* of all HFW sample

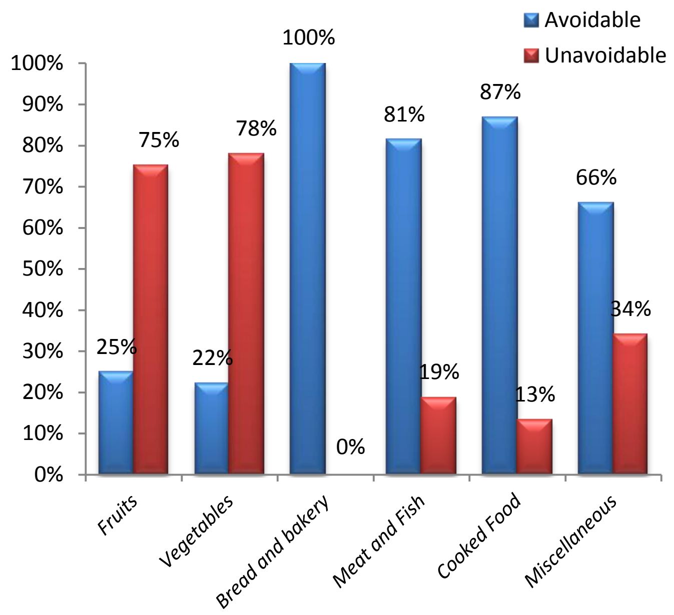

Figure 4: Avoidability *(% w/w)* per HFW category from all samples

Table 1: Percentage of weight per household food waste category

Fruits	***51,9%***	***Vegetables***	***37,7%***	***Bread & bakery***	***2,1%***	***Cooked food***	***4,7%***
Oranges	49,9%	Potatoes	14,6%	Bread	100%	Rice	29,8%
Lemons	7,2%	Lettuce	13,9%			Spaghetti	33,9%
Mandarins	17,3%	Onions	12,8%	***Meat & Fish***	***3,0%***	Mashed potatoes	15,5%
Apples	9,3%	Cucumbers	9,9%	Deli meats	46,5%	Fresh Beans	6,1%
Bananas	13,4%	Broccoli	7,5%	Chicken	24,6%	Souvlaki pita	5,2%
Kiwis	0,5%	Carrots	7,6%	Fish	18,7%	Mixed Salad	6,4%
Strawberries	1,1%	Leafy salad	3,5%	Meat	1,8%	Lentils	3,1%
Pears	1,2%	Leeks	5,8%	Sausages	8,4%		
		Spinach	5,6%			***Miscellaneous***	***0,6%***
		Cabbages	2,7%			Olive	384
		Rocket Salad	4,8%			Cheese	71
		Parsley	2,8%			Eggs	12
		Peppers	3,1%				
		Tomatoes	2,2%				
		Beans	2,3%				
		Mushrooms	0,5%				
		Dill	0,4%				

Based on other studies, the same trend was observed concerning HFW qualitative synthesis. In particular according to *Malamis et al. (2014)*[8] on three waste analysis campaigns of at source collected biowaste, which were executed to the mechanical biological treatment of Athens in Greece, prior to the composting unit by appropriately trained personnel, the largest amount is 'Fruit' waste (33%, 48% and 41% w/w in 1st, 2nd and 3rd campaign, respectively) followed by 'Vegetables' category

[8] ***Malamis D., Moustakas K., Bourka A., Valta K., Skiadi O., Stamatopoulou E., Sotiropoulos A., Panaretou V., Margaritis M., Papadaskalopoulou C., Loizidou M.*** *(2014): Compositional analysis of food waste from study sites in Greek municipalities. Athens 2014 International Conference, 2014, Athens, Greece.*

(28%, 28% and 22% w/w in 1st, 2nd and 3rd campaign, respectively). As in the present study, also in the study of *Malamis et al.* (2014), the proportion for 'Meat and Fish' and 'Bread and Bakery' biowaste categories, remained constant between 2 to 3% w/w, in all waste analysis campaigns with the exception of the 3rd campaign where no 'Bread and Bakery' waste were recorded.

According to **Figure 5** the daily per capita HFW production of the households studied lies between the range of 181g to 346g and the average production is 263 g.

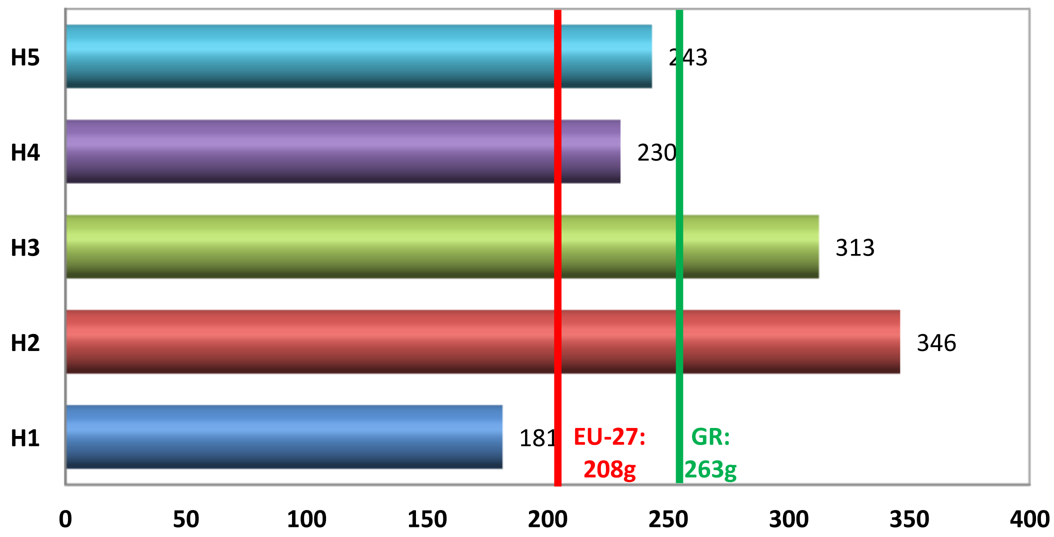

Figure 5: Average Daily amount of HFW generated per person (per household)

Based on *FUSION (2013)*[9], the food waste diary method can provide precise and accurate data and thus enable researchers to determine quantities as well as disposal routes. A potential disadvantage of the application of that methodology might be that during record keeping period, people can be more focused on food waste, and might thus not provide representative data from the collection period[9]. Another reason is that the topic is sensitive and the people can be ashamed to waste so much food and report according to the "social norm" habit which can lead to underestimation too[9]. Despite that, the recorded average value is higher than the value provider by EC.

As far as the results of the physicochemical parameters are concerned, the initial moisture of the samples ranged from 70% to 86% (**Figure 6**), which constitute typical for food waste. The pH values fluctuated at low levels from 3.48 to 4.95 (**Figure 7**) while large variation recorded in conductivity values (806mS to 4340mS) (**Figure 8**). The values of the volatile solids (VS %) were for all samples high (84.5% to 95.1%) (**Figure 9**). The same applies to the values of Total Organic Carbon (47.9% - 55.6%) (**Figure 10**). Both VS and TOC values were high which is attributed to the organic content of the samples. Total Nitrogen values ranged to relatively low values from 0.94% to 2.8% (**Figure 11**). In **Figure 12** total phosphorous values are given for all samples.

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[9] **FUSION** (2013): *Report on review of (food) waste reporting methodology and practice*.

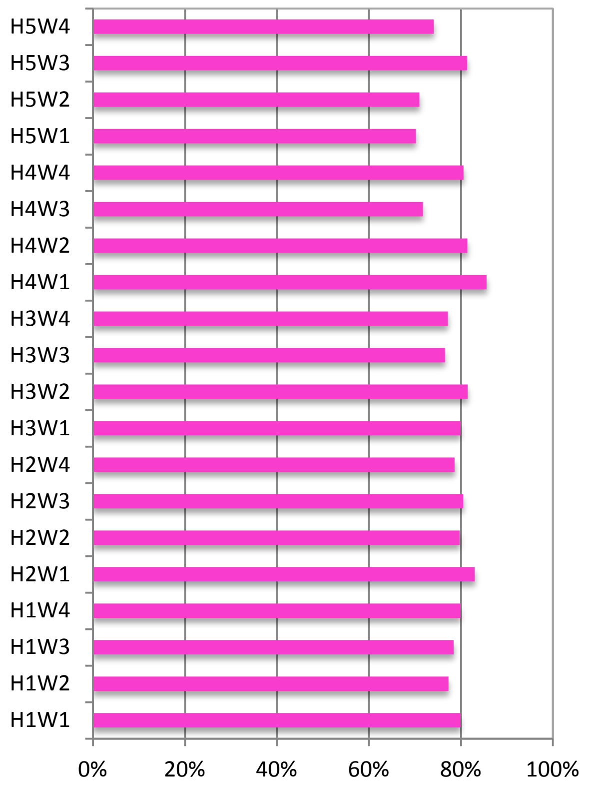

Figure 6: Humidity of the HFW samples

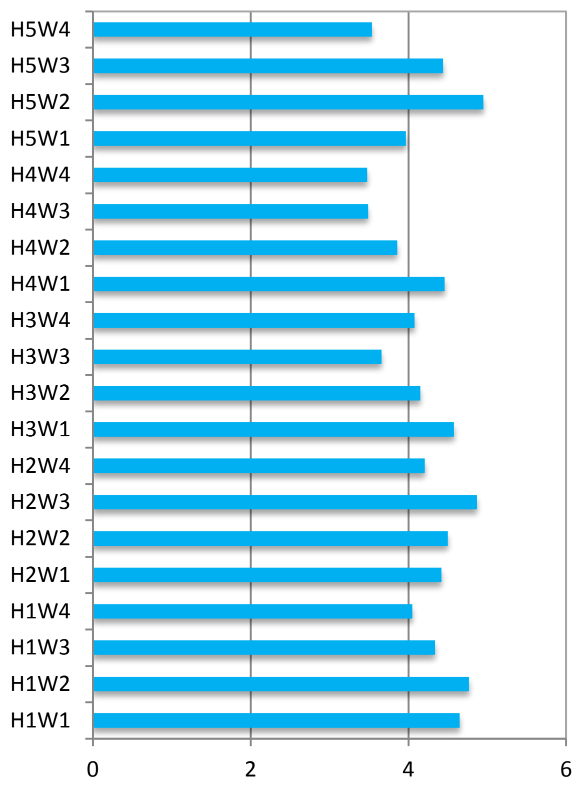

Figure 7: pH values of the HFW samples

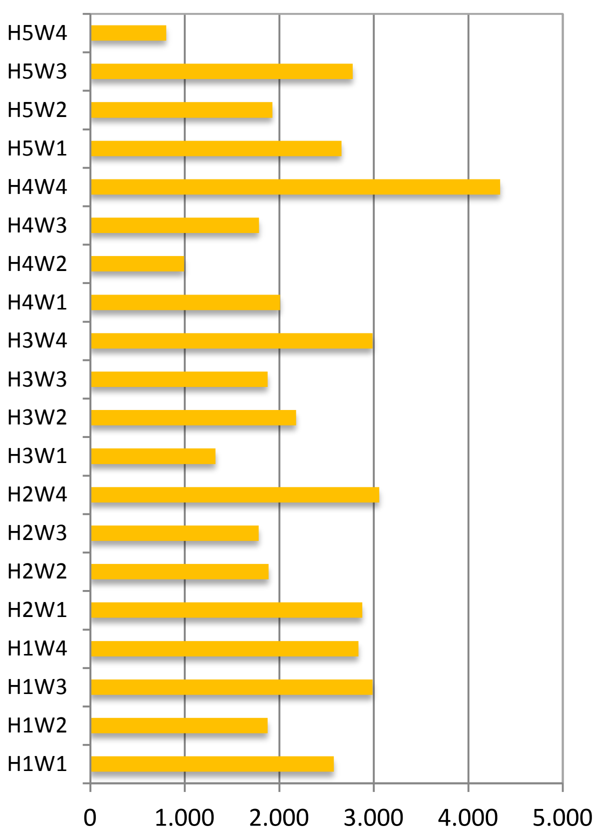

Figure 8: Conductivity values (μS/cm) of the HFW samples

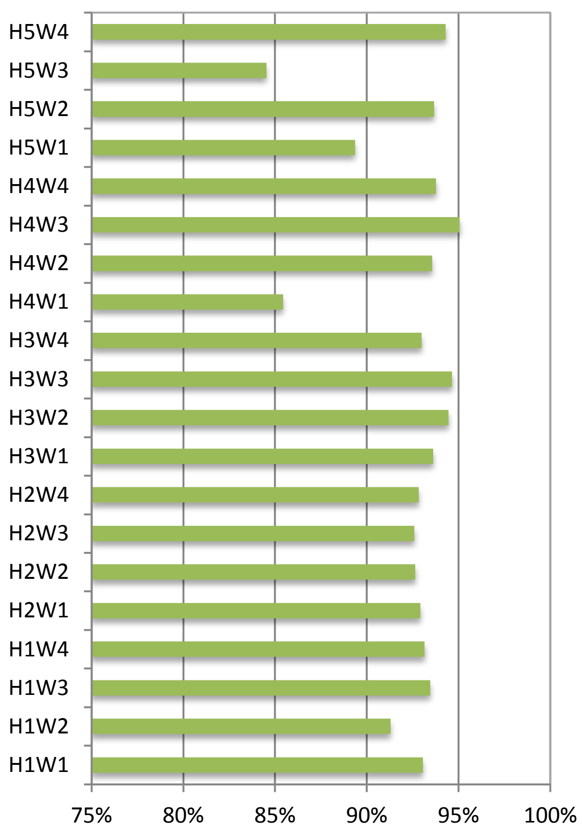

Figure 9: VS% *in dry basis* of the HFW samples

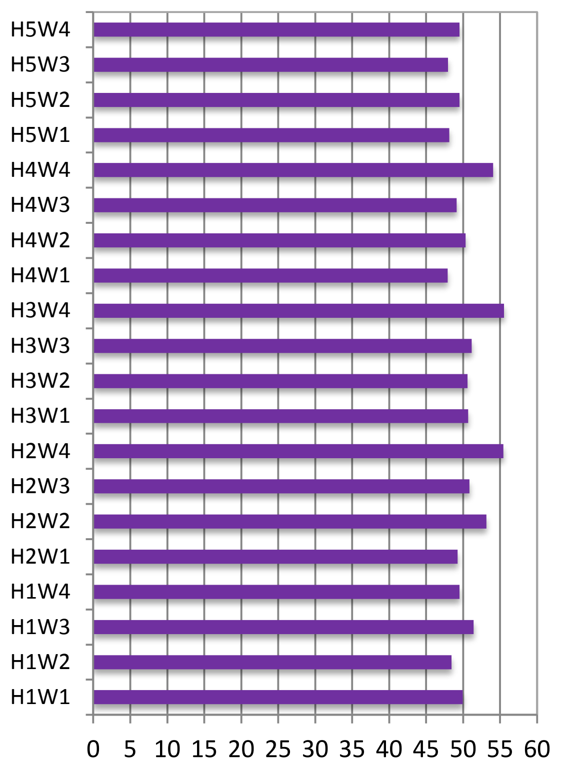

Figure 10: TOC % *in dry basis* of the HFW samples

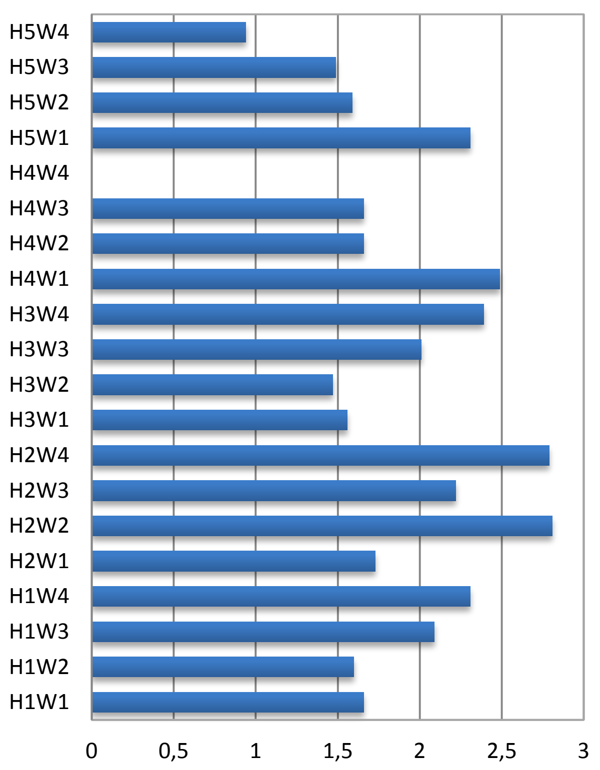

Figure 11: TN % *in dry basis* of the HFW samples

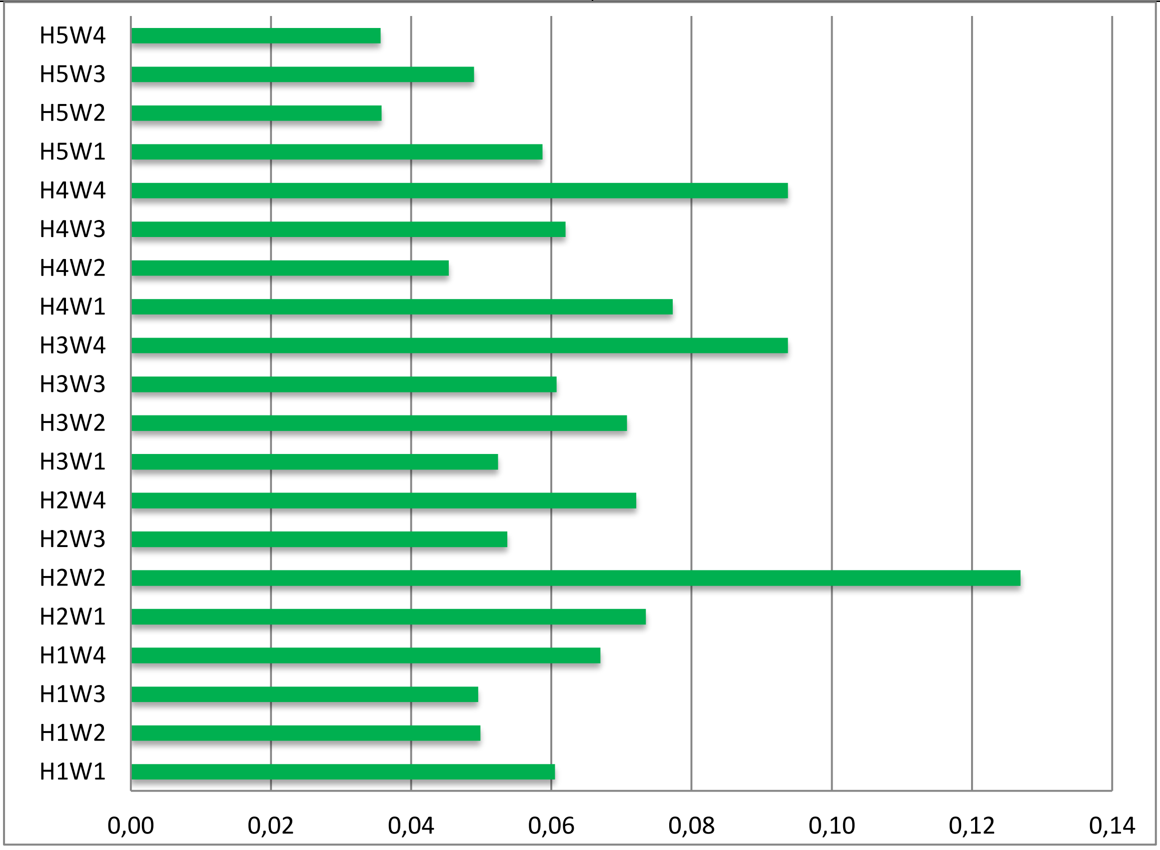

Figure 12: TP % *in dry basis* of the HFW samples

Concerning metals (Cu, Mn, Ni and Zn) and minerals (K, Na, Ca and Mg) of HFW samples, fluctuations were observed between the different weekly samples. Cd, Pb and Cr were not detected in any of the sample. Moreover, differentiations between replications of the same samples were also recorded. Metal concentration values as well as minerals values are presented in **Table 2** and **Table 3**.

Table 2: Metals Concentration (mg/kg) *in dry basis* of the HFW samples

	Cu mg/kg	Mn mg/kg	Ni mg/kg	Cd mg/kg	Pb mg/kg	Cr mg/kg	Zn mg/kg
H1W1	1,72 ±1,23	16,90±2,66	*0,00*	*0,00*	*0,00*	*0,00*	22,61±7,14
H1W2	1,42±0,58	18,15±1,72	*0,00*	*0,00*	*0,00*	*0,00*	14,76±1,44
H1W3	0,53±0,93	8,48±3,22	*0,00*	*0,00*	*0,00*	*0,00*	20,51±3,34
H1W4	3,55±0,98	12,12±0,02	*0,00*	*0,00*	*0,00*	*0,00*	22,65±3,76
H2W1	0,55±0,16	19,73±0,12	*0,00*	*0,00*	*0,00*	*0,00*	12,11±10,50
H2W2	1,25±0,18	14,50±0,37	*0,00*	*0,00*	*0,00*	*0,00*	26,20±8,65
H2W3	3,60±0,27	17,94±1,03	*0,00*	*0,00*	*0,00*	*0,00*	17,29±0,96
H2W4	0,06±0,07	6,85±0,34	*0,00*	*0,00*	*0,00*	*0,00*	12,48±11,23
H3W1	*0,00*	9,72±0,56	*0,00*	*0,00*	*0,00*	*0,00*	16,80±2,44
H3W2	*0,00*	7,55±0,99	0,00	*0,00*	*0,00*	*0,00*	19,80±2,01
H3W3	*0,00*	6,92±0,37	*0,00*	*0,00*	*0,00*	*0,00*	14,12±12,28
H3W4	*0,00*	13,12±2,60	*0,00*	*0,00*	*0,00*	*0,00*	18,01±2,26
H4W1	14,34±1,65	22,02±1,43	*0,00*	*0,00*	*0,00*	*0,00*	83,34±52,99
H4W2	3,38±0,46	14,24±0,66	*0,00*	*0,00*	*0,00*	*0,00*	11,56±11,01
H4W3	0,57±0,59	8,06±0,23	*0,00*	*0,00*	*0,00*	*0,00*	14,68±0,64
H4W4	0,06±0,11	9,40±1,63	*0,00*	*0,00*	*0,00*	*0,00*	48,98±8,86
H5W1	0,09±0,12	12,03±0,40	*0,00*	*0,00*	*0,00*	*0,00*	9,09±7,89
H5W2	*0,00*	6,63±1,53	*0,00*	*0,00*	*0,00*	*0,00*	8,16±1,68
H5W3	3,08±5,33	21,35±4,24	*0,00*	*0,00*	*0,00*	*0,00*	29,12±11,86
H5W4	*0,00*	2,58±0,49	*0,00*	*0,00*	*0,00*	*0,00*	6,86±5,94

Table 3: Minerals Concentration (mg/kg) *in dry basis* of the HFW samples

	K mg/kg	Na mg/kg	Ca mg/kg	Mg mg/kg
H1W1	19.476 ±2.016	1.988±349	8.978 ±1.188	2.818±913
H1W2	20.907 ±1.783	3.776 ±289	7.298 ±2.420	2.409±496
H1W3	11.573 ±3.107	3.695±898	2.859 ±507	807±190
H1W4	11.994 ±847	4.818±41	3.441 ±445	1.668±119
H2W1	8.775 ±284	6.556±225	4.623 ±260	1.707 ±43
H2W2	13.298 ±1.768	3.692±258	3.930 ±258	1.214 ±61
H2W3	14.349 ±914	2.452±75	6.820 ±250	1.431 ±71
H2W4	7.435 ±592	7.288±640	4.043 ±244	866 ±58
H3W1	12.105 ±879	1.413±79	4.793 ±250	1.179 ±59
H3W2	11.676 ±539	961±36	4.592 ±134	926 ±38
H3W3	11.409 ±3.345	835±265	4.844±1.463	851±249
H3W4	8.476 ±1.615	6.121±1.032	4.229 ±643	961±178
H4W1	14.762 ±1.047	4.141±162	4.173 ±231	1.709±114
H4W2	11.023 ±923	2.025±490	6.167±1.632	1.404±438
H4W3	9.491 ±406	2.024±94	3.501 ±168	763 ±63
H4W4	14.578 ±2.581	4.798±212	3.896 ±3.022	1.248 ±359
H5W1	12.834 ±526	6.111±1.135	20.011 ±2.575	2.914 ±995

	K mg/kg	Na mg/kg	Ca mg/kg	Mg mg/kg
H5W2	5.042 ±903	4.335±654	17.066 ±3.988	1.734 ±280
H5W3	15.882 ±453	2.234±860	36.997 ±4.716	2.159 ±864
H5W4	7.144 ±347	2.136 ±501	12.259 ±1.240	2.358 ±566

Finally, in **Table 4** results derived from BMP tests are illustrated.

Table 4: Methane production (L CH_4/kg TS, L CH_4/kg VS) of the HFW samples

	L CH_4/kg TS	L CH_4/kg VS
H1W1	362±7.9	389±8.6
H1W2	367±25.5	402±27.9
H1W3	413±0.5	442±0.5
H1W4	444±10.1	490±10.8
H2W1	459±59.1	493±63.6
H2W2	445±46.8	480±50.5
H2W3	287±10.6	308±11.4
H2W4	519±60.8	559±64.3
H3W1	265±12.1	283±12.8
H3W2	449±2.1	475±2.5
H3W3	441±2.5	466±2.7
H3W4	459±1.7	494±1.8
H4W1	366±1.4	429±1.5
H4W2	304±64.7	325±72.4
H4W3	368±19.7	386±21.0
H4W4	442±11.7	471±13.9
H5W1	408±4.3	456±4.6
H5W2	433±8.0	460±8.6
H5W3	334±25.5	395±27.9
H5W4	386±0.5	410±0.5

As it can be observed from the above values, methane production ranges from 265 to 519 L CH_4/kg TS confirming that HFW can be utilized as a substrate for anaerobic digestion. Results from the BMP tests could not be directly correlated with the physicochemical parameters which can be attributed to both the heterogeneity of the solid samples and to the intrinsic difficulties related to the implementation of the BMP tests.

Concluding, 'Fruit' and 'Vegetable' waste constitute the main waste categories of HFW recorded, accounting for almost 90% of the total amount generated. For both waste types approximately 30% could have been avoided while the 'bread and bakery' and most 'cooked food' waste could have been saved if they had been managed better. In other words these amounts could have been prevented. Although variations exist, the average daily per capita production of HFW as revealed from the results is slightly higher to the one estimated for the EU-27. In order to investigate in depth the compositional analysis and the average daily production of HFW, the survey shall include a larger sample of households and shall be conducted for different seasons i.e. autumn, spring and summer. Apart from the potential of prevention which constitutes the first priority in European level, HFW can be successfully utilized as a biogas source.