D4.8 A roadmap to reduce food waste in Europe

REFRESH is funded by the Horizon 2020 Framework Programme of the European Union under Grant Agreement no. 641933. The contents of this document are the sole responsibility of REFRESH and can in no way be taken to reflect the views of the European Union

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Work Package	WP4
Document Type	Deliverable
Date	June, 2019
Document Status	Final draft
ISBN number	978-94-6395-100-5
DOI number	https://doi.org/10.18174/498970

Acknowledgments & Disclaimer

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 641933.

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FSC Food Supply Chain

FW Food Waste

Executive summary

REFRESH is an EU research project dedicated to contributing to the achievement of Target 3 of Sustainable Development Goal 12, which aims to halve per capita food waste at the retail and consumer level as well as to reduce food losses along the food chain by 2030. Partners across Europe are collecting data on methods to decrease or repurpose food waste.

In developed countries an estimated 30 to 40% of food is wasted. About half of this waste stems from consumers, while the remaining part is lost through the other phases of the Food Supply Chain (FSC): farm practices, transport and processing, and the retail sector (FAO, 2011; Godfray et al., 2010).To meet target 12.3 of the Sustainable Development Goals, a better understanding of food waste drivers is needed, both at the consumer and at the retail level. More importantly, the effectiveness of tailored interventions to reduce food waste at every level of the FSC needs to be assessed.

Research on food waste faces several issues. On one side, there is large number of factors influencing the behaviour of Food Supply Chain actors, on the other side, food waste research often lacks reliable data on the amounts of food wasted along FSC. One of the possibilities to reduce food waste is the adoption of tailored innovations aiming at prevention and reduction of food waste. Currently there are many initiatives in this direction. However, there is a lack of information on effects of such interventions, since they are usually not large-scaled and have more of the local character. In this work, issues related to the complexity of the food waste phenomenon and to the lack of reliable data are tackled using a simulation approach.

This work is part of a collection of reports on household food waste prediction for EU28, Member Countries and European Regions. This collection consists of a methodological report, *REFRESH D4.8 - A roadmap to reduce food waste in Europe*, which represents the theoretical base for two additional reports, *REFRESH D4.6 Pan-European scenarios of food waste levels* and *REFRESH D4.7 A pan-European simulation of selected interventions*, where food waste scenarios for EU28 and for each European Country are presented.

Moreover, methodologies and results presented in *REFRESH D4.8 - A roadmap to reduce food waste in Europe* are based on the results of *REFRESH D4.3 Model integration - Integrated socio-economic model on food waste* and in *REFRESH D4.4 Behavioural Economics: Linking Bayesian and agent-based models to assess consumer food waste.*

This work adopts a Bayesian hierarchical mixed-effects modelling approach, based on previous REFRESH works (*REFRESH D4.3 Model integration - Integrated socio-economic model on food waste* in *REFRESH D4.4 Behavioural Economics: Linking Bayesian and agent-based models to assess consumer food waste)*, to quantify the relationships between socioeconomic and demographic indicators and household food waste. Also, the potential impact of an external intervention on food waste generated within European households is quantified.

Models are structured hierarchically using national and regional level organization specified at the EU level (European Parliament, 2003). This modelling approach may encapsulate similarities/differences between European countries and enhance our understanding of inherent variation in household food waste at multiple spatial scales.

With this approach, variations in household food waste within ten UK local government areas was analysed. Independent explanatory variables were incorporated in the model corresponding to age and sex of an individual, occupancy type and household composition (number of people living within an occupancy).

The UK regional government areas were then matched to the corresponding NUTS statistical classification and predictions of household food waste were generated. Similarities within EU statistical areas were identified through UK demographic characteristics summarised within the model. The model parameters and structure were then used predictively to generate estimates of food waste for each statistical area.

This hierarchical mixed-effects modelling approach represents a first attempt to predict food waste at the EU level using a simulation model and it had to face, among others, two important limitations in terms of data availability on food waste amounts and on impact of interventions.

To overcome the first constraint related to the availability of data in a format suitable for the development of the model, UK data derived from WRAP (2013) *Household food and drink waste in the UK 2012* has been used. This dataset has been considered as the most reliable to address the needs of the hierarchical mixed-effects modelling approach.

The underlying assumption of this choice implies a general similarity between European countries. However, considering the complexity of factors driving households' behaviour and decisions concerning food consumption and management, trends in UK data may not accurately reflect food waste household elsewhere. Food Waste behaviours are affected by several determinants concerning economic, cultural and social factors, which are often influenced by the community where consumers belong. Therefore, utilization of the UK dataset as a proxy to extend food waste data to other EU countries also represents a potential source of bias. In order to address this issue, a pan-European, standardized study design, – as also advocated by Reynolds et al (2019) - may improve generality, facilitate interpretation, and provide more robust predictions of household food waste that captures underlying socio-economic characteristics at national and regional scales.

However, beside this limitation, the model provides a set of new and interesting information regarding both the influence of socio-economic determinants and the potential impact of external interventions on food waste generation, potentially suggesting some of the targets that policy interventions might consider to prioritize.

To solve the second data weakness, the model builds on a study developed in a German university canteen (Lorenz-Walther et al., 2019) that has been used as a proxy to simulate the effectiveness of a policy intervention.

To increase the reliability of the results obtained through the roadmap, future research should focus on obtaining more consistent national data on food waste and on the impact of food waste reduction measures. Research on the impact of interventions is particularly urgent since there is a scarcity of reliable and solid quantitative data able to improve the predictive capacity of the model.

Continuing the development of such a model by ensuring more accurate food waste data at the national level and better data on the impact of interventions, would improve the predictive capacity of this tool providing decision makers with a reliable instrument for sustainable food (waste) management and planning.

1 Introduction

Previous research examining the causes of household food waste indicate that the underlying drivers are complex and often interact at multiple spatial and socioeconomic scales (M. J. Grainger et al., 2018; Schanes et al., 2018). However, existing studies do not address the underlying complexity of these interactions (M. Grainger et al., 2018). Furthermore, a precise or agreed definition of food waste has yet to be established. This makes even more difficult to obtain findings that can be interpreted in a general and straightforward manner. Additional uncertainty is also related to food waste measurement as the wide array of methodologies applied in different studies, ranging from diaries (Abeliotis et al., 2014; Giordano et al., 2018; Koivupuro et al., 2012; Stefan et al., 2013; Van Garde and Woodburn, 1987) to self-report methods (surveys and interviews) (Abeliotis et al., 2014; Falasconi et al., 2019; Gaiani et al., 2018; Koivupuro et al., 2012; Setti et al., 2018; Stefan et al., 2013; Van Garde and Woodburn, 1987) and to direct measurement and waste composition analysis (Parizeau et al., 2015; Quested and Luzecka, 2014; Wenlock and Buss, 1977), are often characterized by specific limitations that reduce their explanatory capacity (Gaiani et al., 2018; Møller et al., 2014; van Herpen et al., 2019) and their potential utilization in predictive models. To make an example, the magnitude of under-reporting is estimated to be 40% when food-diaries are utilized as the means of recording data (Reynolds et al., 2019).

Previous research has also attempted to identify and analyse behavioural factors influencing food waste. Overall food waste behavioural drivers include - at least - preferences (Sonesson et al., 2005; WRAP, 2011), habits such as the frequency of shopping (Koivupuro et al., 2012; Quested et al., 2013; Stancu et al., 2016; Stefan et al., 2013), attitudes (Grainger et al., 2018b; Parizeau et al., 2015; Quested and Luzecka, 2014; Quested and Parry, 2017; Stancu et al., 2016), social norms (George et al., 2010; Johnson et al., 2008), impact of information (Lorenz-Walther et al., 2019; Reynolds et al., 2019), knowledge and skills such as the awareness on date labels and the expertise in food preparation (Abeliotis et al., 2014; Quested and Johnson, 2012; Quested and Parry, 2017; Quested et al., 2013; Van Garde and Woodburn, 1987; WRAP, 2011), opportunities and consumer tools as local shopping options or availability of high tech kitchen appliances (Silvennoinen et al., 2012; WRAP and French-Brooks, 2012).

Indeed, household food waste has been shown to be influenced by the socioeconomic and demographic characteristics of families (Schmidt, 2016; Grainger et al., 2018). For instance, larger households are associated with increased waste. In addition, differences in overall food waste between adults and children exist. On average adults waste more food, but families with children are found to be more wasteful in overall terms. The sex of the person responsible for grocery shopping, food storage and cooking has also been found to be an important driver of food waste (Barr, 2007; Koivupuro et al., 2012; Parizeau et al., 2015; Quested and Luzecka, 2014; Wasserman and Schneider, 2005; Wenlock and Buss, 1977). However, studies that have examined the effects of variation in age and employment status on degrees of food waste are often inconsistent. Instead, differences were reported between younger and older people, and between households with retired elderly and households with young children.

Furthermore, geopolitical, socioeconomic and cultural variation within and between countries may induce heterogeneity in identifying and quantifying the underlying drivers and in detecting behaviours influencing household food waste (M. Grainger et al., 2018). In order to address issues of complexity, Grainger et al., (2018) used a machine learning approach as a means for variable reduction and feature selection. Generalised Linear models were then applied to those variables (or features) retained in an effort to quantify the effects of those key drivers selected during machine learning. An information theoretic approach was used as a means to interrogate candidate to models and model averaging undertaken to obtain estimates of the underlying effects. Findings indicated household food waste varied within and between regional government areas.

In order to encapsulate potential behavioural differences at national and regional level, multiple statistical measures that describe or summarise the socioeconomic and demographic factors, reflecting the characteristics of EU member states, were used. In addition, each European country and sub-specific region was classified according to EU Nomenclature of territorial units for statistics (NUTS) (European Commission 2003) https://ec.europa.eu/eurostat/web/regions-and-cities/overview.

All data described above are provided by Eurostat https://ec.europa.eu/eurostat/data/database. This study is based on a Bayesian hierarchical mixed-effects modelling approach to quantify the relationships between socioeconomic and demographic indicators and household food waste. Models are structured hierarchically using the national and regional level organization specified at the EU level (European Parliament, 2003). This modelling approach may encapsulate similarities/differences between European countries and enhance our understanding of inherent variation in household food waste at multiple spatial scales.

2 Methodology

2.1 Data

Data sources selection has been a fundamental step for the elaboration of the roadmap. Within this work two main data sources were analysed and tested: Van Geffen et al., 2017 and WRAP, 2013.

Van Geffen et al., 2017 is a pan-European study developed within the REFRESH project, with the aim to provide several quantified insights about in-home food waste, including the amounts wasted, households' food waste prevention (FWP) practices, and motivation, abilities and opportunities to avoid food waste. Data presented in the study were collected through a survey with 3,354 households, where the person in charge for food shopping and cooking reported the amount of food wasted by means the method described in (van Herpen et al., 2016)

On the other side, the study conducted by WRAP in 2013 offers detailed information about food and drink wasted in the United Kingdom in 2012. As reported in the document, results from research funded by UK Governments are based on three sources of data: detailed measurement of the weight and types of food and drink waste from approximately 1,800 consenting households, a week-long food and drink diary involving 950 households and a synthesis of waste data from more than 80 local authorities (WRAP, 2013).

As a strength, data from Van Geffen et al. (2017) are characterized by a regional approach, which could potentially include local differences in FW behaviour that influence the final level of households' food waste.

Moreover, Van Geffen et al. (2017) data suffer from the weaknesses due to their self-reported nature. Food waste literature highlights limitations of self-reported data, for example in Reynolds et al., 2019 and in Lorenz-Walther et al., 2019. Each study has demonstrated and discussed the implications of relying on self-reported waste as the principal source of data. Indeed, Lorenz-Walther et al., 2019discuss various forms of social bias that may drive specific behaviours that lead to under-reporting of food waste.

So, despite their potential from a territorial point of view, data from Van Geffen et al., 2017 present aspects, such as the significant presence of false positives and a certain degree of underestimation. Those aspects would have greatly affected the reliability of the roadmap's estimations, which are based on a complex statistical model where the limitations of self-reported data would have been amplified.

For these reasons WRAP was selected as the source of data to examine variation in household food waste. While (WRAP, 2013) data is UK specific, it nevertheless has the principal advantage of providing a validated measure of household food waste. Given the inherent limitations surrounding imprecision and uncertainty in estimates of self-reported food waste, and the potential implications to designing broad-scale management and intervention strategies, using WRAP generated data provides a robust foundation with which to generate important insights into consumer food waste in European countries.

2.2 Model development

Building on previous work carried out within the REFRESH project and in particular within D4.4 "Linking Bayesian and agent-based models to assess consumer food waste" (Grainger et al., 2018) a multi-phase modelling approach was developed. To develop the model variation in household food waste within ten UK local government areas was analysed. Independent explanatory variables were incorporated within the model corresponding to the age and sex of an individual, occupancy type and household composition (number of persons living within an occupancy). The UK regional government areas were then matched to the corresponding NUTS statistical classification and predictions of household food waste were generated. Moreover, UK demographic characteristics, summarised within the model, have been used to identify similarities within EU statistical areas. The model parameters and structure were then used predictively to generate estimates of food waste for each statistical area.

The subsequent model takes into account the effect of independent explanatory variables on the parameters generated by the initial model described above. National socioeconomic indicators relating to each European country: the percentage of the population obtaining a tertiary-level education, percentage of national population in employment, and a national indicator of standardised purchasing power were used to describe variation in food waste. Statistical analyses were undertaken using R statistical computing framework (R Development Core Team, 2011).

Expanded model predictions generated by these models were incorporated into an integrated data visualisation tool to illustrate variation and uncertainty in household food waste across Europe. In addition, the tools allows the users to estimate the effects of an intervention method described by Lorenz-Walther et al., 2019 that examined the effects of an information programme combined with changing the composition and size of food portions. The integrated data visualisation tool was generated using Shiny package within R Studio https://shiny.rstudio.com/.

2.3 Results

The hierarchical model illustrated in Table 1 illustrates the effect of each independent explanatory variable on estimated food waste. The reference-level corresponding to the intercept relates to female, age category corresponding to 18-24 years, household composition relating to a single individual in an owned occupancy. Bayesian P-values are also given indicating the simulated significance of the effect of age. A significant increase in estimated food waste is associated with individuals who live in rented accommodation. In addition, a significant increase in estimated household food waste was also observed while household composition increased. The age of the individual was also found to influence estimated food waste – estimates decreased steadily as age increase. There was no effect on estimated food waste relating to differences between sex. In addition, the study shows that effect on estimated food waste due to socioeconomic variables should be clarified by future research, as indicated by the values reported in Table 2.

Table 1. effect of each independent explanatory variable on estimated FW

Variable	Posterior Mean	95% LCI	95% UCI	*Pr(T (y^{rep}>T(y)|y)*
Intercept	1.311	0.581	1.918	< 6e-04
Sex: Male	-0.070	-0.256	0.105	0.453
Age categories: 25-34 years	-0.081	-0.697	0.522	0.779
Age categories: 35-49 years	-0.255	-0.892	0.335	0.409
Age categories: 50-65 years	-0.511	-1.079	0.103	0.104
Age categories: 65+ years	-0.684	-1.306	-0.062	0.027
Household Composition: 2	0.395	0.140	0.655	0.002
Household Composition: 3	0.984	0.651	1.338	< 6e-04
Household Composition: 4	1.207	0.833	1.545	< 6e-04
Household Composition: 5	1.466	1.036	1.946	< 6e-04
Household Composition: 6	1.372	0.879	1.886	< 6e-04
Occupancy Type: Rented	0.223	0.008	0.426	0.032
Occupancy Type: Other	0.035	-0.719	0.730	0.932

Table 2. Secondary model output: overall mean household food waste (kg) for European countries and the effects independent explanatory variables

Variable	Posterior Mean	95% LCI	95% UCI	Pr(T (yrep>T(y)|y)
Intercept	1.628	1.612	1.646	<6e-04
Tertiary Education	0.172	-0.130	0.468	0.272
Standardised Purchasing Power	-0.026	-0.069	0.014	0.233
Employment Rate	-0.207	-0.523	0.092	0.187

2.4 Data visualisation

In figure 1 is presented the selection interface for the choice of EU countries and data explore used to adjust socioeconomic determinants of food waste.

Figure 1. Model interface

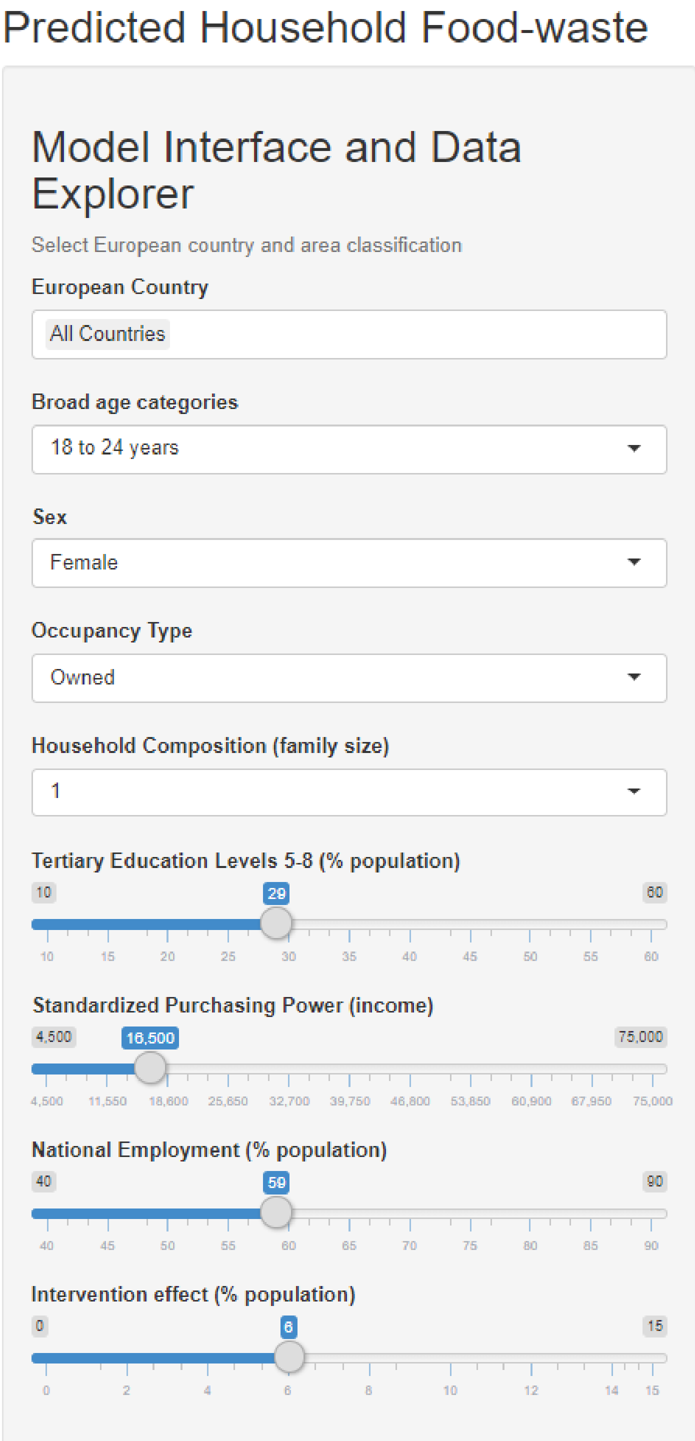
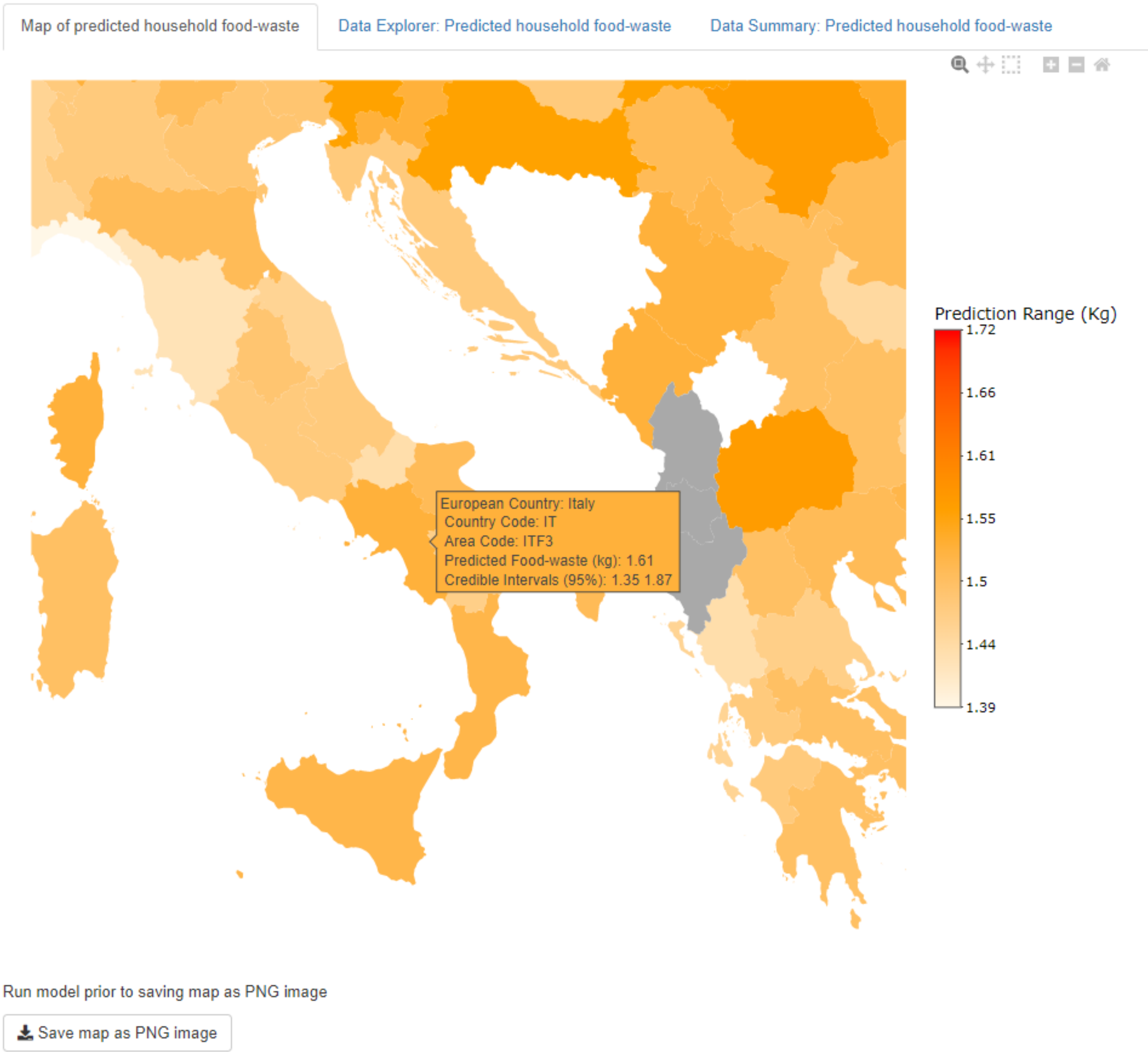


Figure 2 illustrates an example of predictive map of household food waste for Italy statistical region ITF3. Visualisation of model predictions is facilitated by the text-box. The area highlighted in grey illustrates statistical regions were data was unavailable - in this instance, no predicted values were generated for Albania. A specific area of the map can be selected using the control buttons highlighted within the figure (blue circle- top). In addition, the predictive map can also be downloaded as a PNG image.

Figure 2. Predictive map of household food waste: an example



Finally, figure 3. illustrates the data explorer and model predictions for statistical regions within Italy. Values are by Area Code however; the values can be reordered (ascending or descending) by engaging the sort-selection key highlighted (blue circle) within the figure. The data table can also be downloaded as a CSV file.

Figure 3. Data explorer and model predictions: an example

Map of predicted household food-waste | Data Explorer: Predicted household food-waste | Data Summary: Predicted household food-waste

Selected country and statistical unit: predicted household food-waste per-week (Kg) is:

Show 10 entries

Search: Italy

Country	Area Code	Predicted Household Food-waste	Lower 95% CI	Upper 95% CI
Italy	ITC1	1.46	1.22	1.7
Italy	ITC2	1.5	1.26	1.75
Italy	ITC3	1.39	1.16	1.64
Italy	ITC4	1.48	1.24	1.72
Italy	ITF1	1.48	1.25	1.73
Italy	ITF2	1.44	1.2	1.68
Italy	ITF3	1.53	1.29	1.78
Italy	ITF4	1.51	1.27	1.76
Italy	ITF5	1.47	1.24	1.72
Italy	ITF6	1.52	1.28	1.77

Showing 1 to 10 of 21 entries (filtered from 367 total entries)

Previous 1 2 3 Next

Save data as CSV file

3 Discussion and future research needs

A review undertaken by (Reynolds et al., 2019) scrutinised extant literature from 2006-2017 and identified 17 studies that implemented intervention programs in order to moderate the effects of consumer food waste. A synthesis of reviews findings indicates that studies lack robust, reproducible and quantifiable evidence in support of general efficacy of interventions and conclusions may therefore lack credibility.

At a mechanistic level, Reynolds concludes that future studies should follow a standardized protocol in an attempt to prevent structural weakness in underlying experimental design while simultaneously strengthening the evidence base available to policy-makers and stakeholders responsible for implementing decisions to prevent or reduce consumer food waste.

The proposed protocol includes a standardised intervention design that explicitly states the nature of the intervention- whether an applied intervention designed to reduce waste, or a study designed to elicit understanding of the mechanisms that drive food waste and intervention process. Similarly, a standardised means of monitoring and measuring the effects of an intervention by means of direct measurement of consumer food waste. Utilizing the direct measurement of food waste is also suggested as a means of mediating consequences relating methodologies reliant upon self-reporting (Reynolds et al., 2019). In particular, self-reporting methodologies are susceptible to under-reporting actual food waste. As anticipated, the magnitude of under-reporting is estimated to be 40% when food-diaries are utilized as the means of recording data.

The review also suggests that few studies have undertaken a critical appraisal of the deficiencies and limitations associated with self-reporting, and that the consequences of under-reporting of food waste may have serious implications for the development and implementation of cost-effective strategies for reducing consumer food waste.

While the rapid review undertaken by Reynolds provides a synthesis of existing research and affords a valuable insight into the vagaries and inherent limitations encountered within this discipline. However, (Lorenz-Walther et al., 2019) designed and implemented an applied intervention study in order to reduce the volume of food waste observed within a university restaurant. The study established an experimental-baseline to measure food waste before and after interventions were implemented. The intervention was designed to reduce food-portion size per-serving, while also implementing an education programme to in an attempt to influence attitudes towards food waste. The primary findings indicate that following the reduction in food-portion size per-serving, the percentage of plates observed to have zero food waste increased from 63% (baseline) to 78% (following intervention) and constitutes an overall reduction in observed waste. In contrast, no further reduction in food waste was observed following the implementation of the information programme. Furthermore, Lorenz-Walther et al., 2019 also demonstrated discrepancies between self-reported food waste and empirical observations. In summary, we used the 15% difference in observed waste as the effect-size for the intervention included within the modelling framework.

However, Lorenz-Walther do not include an explicit and quantitative measure of food waste, the study nevertheless implements a robustly designed intervention, utilizes observers to validate self-reported waste, while also reports findings, limitations and conclusions in the mode advocated by (Reynolds et al., 2019). These studies have proved to be highly influential with regard to the design of our own analytical framework.

Overall, this research provided a reliable tool for the estimation of food waste at a pan-European level, and raised some interesting questions and need, which could be addressed in future researches.

First of all, a more detailed analysis of the impact of socioeconomic determinants, such as income, tertiary instruction level and employment rate, is needed. As reported in section 3.3, at the moment the impact of those element on the food waste level appears to be ambiguous.

Moreover, further research should aim to improve data collection, especially concerning the quantification of food waste at the household level, in order to reduce the differences between subjective and objective quantifications of food waste. Also, the territorial aspects of data collection should be considered, with the aim of intercept the peculiarities (cultural, economic, demographic) of European States and Regions.

As a consequence of the last consideration, attention should be given to the reduction of 'false-positive' food waste self-reports, with the aim to obtain even more solid and reliable data, which would lead to broader and more precise estimation of food waste at Regional, National and European level.

Research on the impact of interventions is particularly urgent since there is a scarcity of reliable and solid quantitative data that could be used to improve the predictive capacity of the model.

Continuing the development of such a model, by ensuring better food waste data at the national level and better data on the impact of interventions, would improve the predictive capacity of this tool providing decision makers with a reliable instrument for sustainable food (waste) management and planning.

4 Limitations

This hierarchical mixed-effects modelling approach represents a first attempt to predict food waste at the EU level using a simulation model and it had to face, among others, two important limitations in terms of data availability on food waste amounts and impact of interventions.

To overcome the first constraint related to the availability of data in a format suitable for the development of the model, UK data derived from WRAP (2013) Household food and drink waste in the UK 2012 has been used. This dataset has been considered as the most reliable to address the needs of the hierarchical mixed-effects modelling approach.

The underlying assumption of this choice implies a general similarity between European countries. However, trends in UK data may not accurately reflect variations in household food waste elsewhere, considering the complexity of factors driving households' behaviour and decisions concerning food consumption and management. Behaviours related to food waste are affected by several determinants related to economic, cultural and social factors, which are often influenced by the community where consumers belong. Therefore, utilization of the UK dataset as a proxy to extend food waste data to other EU countries represents also a potential source of bias. In order to address this likely source of bias, a pan-European, standardized study design, – as also advocated by Reynolds et al (2019) - may improve generality, facilitate interpretation, and provide more robust predictions of household food waste that capture underlying socio-economic characteristics at national and regional scales.

However, beside this limitation the model provides a set of new and interesting information regarding the influence of a set of socio-economic determinants on food waste generation potentially suggesting some of the targets that policy interventions might consider to prioritize.

To solve the second data weakness, the model builds on a study developed in a German university canteen (Lorenz-Walther et al., 2019) that has been used as a proxy to simulate the effectiveness of a policy intervention.

To increase the reliability of the results obtained through the roadmap, future research should focus on obtaining more consistent national data on food waste and on the impact of interventions aiming at reducing food waste. Research on the impact of interventions is particularly urgent since there is a scarcity of reliable and solid quantitative data that could be used to improve the predictive capacity of the model.

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