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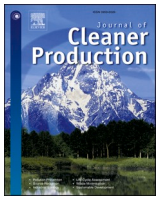

Do meal boxes reduce food waste from households?

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ABSTRACT

Household food waste is determined by a complex set of routinized behaviors, and disruption of these routines may allow for a decrease in this vast amount of food waste. The current study examines such a disruption of household routines: the meal box. The potential of meal boxes to diminish different types of household food waste is investigated for the first time, across different countries. After providing a framework comparing the effects of different types of meals on food waste, we subsequently examine the effects of subscription-based food supply (i.e., meal boxes) on total meal waste as well as on the different types of food waste: preparation, cooking, and plate waste. Our dataset contains 8747 meal observations from 955 households in six countries. Results from a Bayesian multilevel hurdle-lognormal model with random intercept show that, overall, meal boxes reduce total meal waste in comparison to traditionally cooked dinners (38% reduction). Meal boxes especially lower the occurrence and amount of pan-and-pot food that is wasted (i.e., cooking waste), and also lower the amount of meal preparation waste, yet lead to a higher occurrence of both preparation and plate waste compared to traditional meals. This shows how differences between meals affect household food waste, something that has received little prior research attention. Furthermore, whereas most prior research has focused on overall household food waste, our study illustrates that distinguishing between different types of household food waste can provide important new insights.

1. Introduction

Over the past years, the discourse on sustainable nutrition has gained immense attention (Speck et al., 2020; Lukas et al., 2016). Within this context, food waste has emerged as a key issue and important target for the Sustainable Development Goals (FAO, 2019). Food waste has high ecological and economic impacts as well as ethical implications in view of world hunger and rising global food demand (Papargyropoulou et al., 2014; Venkat, 2011; Xue et al., 2017). Globally, food wasted at the retail and consumption level amounts to 931 million tons in 2019, and 61% of this occurs in households (Forbes et al., 2021). Food waste can only be tackled by understanding the complexities of everyday food management (Goebel et al., 2015; Quested et al., 2013). Although the number of studies examining food waste in households has increased sharply (see the review by Schanes et al., 2018), studies examining the impact of interventions are still scarce (Reynolds et al., 2019; Stöckli et al., 2018; Nikravech et al., 2020) and only few studies examine household food waste across multiple countries (e.g., Heng and House, 2021; Secondi et al., 2015; van Geffen et al., 2020).

Prior research has identified drivers of household food waste by focusing on differences between households in attitudes and awareness, lifestyle, skills and knowledge, and demographic factors, as well as factors related to the socio-cultural and retail environment (Hebrok and Boks, 2017; Principato et al., 2021; Roodhuyzen et al., 2017; Schanes et al., 2018). These have been summarized as micro individual-level factors, meso household-level factors, and macro-level factors (Boulet et al., 2021). What has been mostly overlooked, however, is the effect of the meals themselves. Yet, as shown by Roe et al. (2020), an

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investigation at the meal level (in their study focused on whether leftovers were included in the meal) can provide relevant insights. Specifically, different types of meals may lead to different amounts of food waste, as the current study sets out to examine. Moreover, research on interventions that diminish food waste is at its infancy (Reynolds et al., 2019). The current study aims to provide relevant insights regarding these two gaps in prior research, by examining the effect of subscription-based food supply (i.e., meal boxes), as an intervention that disrupts food management routines and has the potential to diminish household food waste. Meal box schemes are subscription business models in food service, where a company sends consumers pre-portioned ingredients and recipes to prepare homecooked meals.

So far, the ability of meal boxes to reduce household food waste has not undergone systematic study. To examine this, meal boxes can be compared to the most relevant and often-occurring alternative meals: traditionally prepared meals (i.e., home-cooked meals with ingredients bought at a shop) as well as convenience meals (i.e., semi-/fully prepared meals that often only require heating at home). A priori, it is not clear whether meal boxes will result in less food waste compared to traditionally prepared meals (due to e.g. simplified planning, standard portion sizing) or in equal or even more food waste (due to e.g. less tailoring to households' needs and tastes, less familiar recipes). Recent in-depth interviews and ethnographic studies on how consumers use meal boxes have emphasized that meal box schemes, although relieving pressure on meal planning, can be difficult for consumers to incorporate in existing routines, because these are unattuned with unexpected events and difficult to adjust (Heidenstrøm and Hebrok, 2022; Hertz and Halkier, 2017).

Our study has three main objectives. First, it aims to show that meal-level variability in food waste is substantial, and that differences between meal types should be taken into account when investigating food waste. Second, we want to quantify the differences in reported food waste for different meal types and test whether meal boxes can diminish dinner waste. Third, our study aims to distinguish waste in different states (i.e., before or after preparation and plate waste, based on van Herpen et al., 2019a), to explore whether meal types affect these types of waste differently. The study is based on an international sample across six countries to ensure that results are generalizable.

2. Theoretical background

Food waste refers to food items (including ingredients and leftovers) intended for human consumption that are not consumed but thrown away (cf., Stefan et al., 2013; van Herpen et al., 2019a). Unused ingredients, partly used ingredients, and leftovers from meals are not considered food waste when these are stored for later consumption unless these are later discarded. Furthermore, we distinguish between edible and inedible food waste. Edible food waste is food that was at one point fit to be eaten, while inedible food waste was never edible (e.g., bones, egg shells; Hanssen et al., 2016; Van der Werf and Gilliland, 2017). In line with prior research, only edible fractions of food products are encompassed in our definition of food waste. In this study, we examine food waste resulting from dinner, taking the amount of food waste from one dinner meal as the examination unit, and disregarding food waste that occurs outside of the dinner context. Inspired by prior research (van Herpen et al., 2019a), we split total dinner waste into different stages, leading to three types of waste: preparation, cooking, and plate waste. Preparation waste is comprised of ingredients that were intended to be included in the meal but were thrown away. Cooking waste is discarded food that remained in pots and pans after dinner, while plate waste is discarded food left on plates.

In private households, food waste occurs during the stages of planning, acquisition, storing, preparing, eating and managing leftovers (Block et al., 2016; Roodhuyzen et al., 2017; Schanes et al., 2018), referred to as the *household food waste journey* (Principato et al., 2021). Several reasons for household food waste have been identified in prior research (see Principato et al., 2021 and Schanes et al., 2018 for an overview), which has mainly focused on traditional home-cooked meals. Yet, some of the food management and provisioning stages are omitted or altered when consumers use meal boxes (Halkier, 2021). Table 1 provides a description of how traditional cooking and meal-box cooking differ, and how this may affect the types of dinner waste (i.e., preparation, cooking, and plate waste). It is important to note that mistakes in earlier stages of the food management process may lead to multiple types of food waste. For instance, excessive buying of food may lead to preparation waste, but also to cooking and plate waste when the purchased food is cooked and served.

Table 1
Determinants of food waste in traditional cooking, and differences for meal boxes.

Stage	Traditional cooking	Meal boxes	Expected effect of meal boxes on types of waste
Planning	Inadequate control over food (overview of stocks, meal planning) in the home and inadequate communication between household members.	Choice of meals rather than ingredients simplifies planning.	–
Shopping	Overbuying due to oversized packaging, good provider identity, impulse purchasing.	Standardized portion sizes limit overbuying.	Less cooking waste and possibly less plate waste.
Storing	Inappropriate storing routines.	Less long-term storage.	Less preparation waste.
Preparation	Inadequate/ incomplete use of ingredients. Over-preparation of food due to inadequate anticipation of the amount needed. Lack of cooking skills.	Ingredients are provided in appropriate amounts. Step-by-step cooking instructions to mitigate issues of unfamiliar recipes.	Less preparation and less cooking waste.
Eating	Unpredictable eating patterns. Oversized portions.	Meal boxes provide appropriate portions, but not tailored to individual differences. Unpredictable eating patterns remain.	Possibly less plate waste.
Managing leftovers	Lack of knowledge on how to store and cook with leftovers. Lack of willingness to eat leftovers.	Fewer leftovers due to more appropriate portion sizes.	–

As indicated in Table 1, planning issues in traditional cooking can arise due to a lack of control on food in the home (e.g., not making a shopping list or not checking inventory before shopping; Principato et al., 2021; Schanes et al., 2018; Stefan et al., 2013) or a lack of communication between household members (van Geffen et al., 2020). Planning for meal boxes is different: meal boxes allow one to choose meals rather than ingredients, which simplifies the planning process, although issues of communication between household members remain. This should mainly affect the amount of food wasted that is not linked to

specific meals, though, and not the types of food waste we are examining here.

In the shopping stage, buying in excessive amounts is a main driver of food waste (Evans, 2012) and could result in cooking and plate waste later on. There is less opportunity for this when consumers use meal boxes, because dinner ingredients are provided in appropriate amounts for the number of household members.

Inappropriate storing routines are another source for food waste (Farr-Wharton et al., 2014; Hebrok and Boks, 2017; Roodhuyzen et al., 2017), due mostly to the discarding of parts of (especially fresh) ingredients that have lost their freshness at preparation stage. Insofar as households cook the meals from the meal box within only a few days after receiving it, and follow the storing advice that is provided, storing may be less of an issue. Moreover, as ingredients are in appropriate quantity for the household size, there is a lower likelihood of leftover ingredients that need to be stored for a prolonged time period.

In the preparation stage, consumers frequently over-prepare the quantity that is needed (Schanes et al., 2018). Sometimes this is done on purpose (batch-cooking and storage of portions for later days), but over-preparation also occurs because consumers have difficulties estimating portion sizes and predicting whether household members will be home for dinner (Evans, 2012). Although the meal box provides ingredients in quantities that are appropriate for the number of eaters, it is an empirical question whether these portion sizes are indeed better tailored to household needs. After all, home-cooked meals can be tailored to individual differences whereas meal boxes use generic portion sizes. The inherent difficulties that accompany changing schedules in who is eating dinner at home will remain for meal boxes as well. Another issue in the preparation stage can be a lack of cooking skills (van Geffen et al., 2020). Meal boxes may contain recipes that are unfamiliar to consumers, making it harder for them to prepare the food properly. This issue is mitigated by accompanying recipes in the meal boxes containing step-by-step instructions and pictures. All in all, we still expect that the portion sizing in the meal boxes will be helpful to reduce preparation and cooking waste.

Other sources of food waste can be tracked to the eating stage. Of importance here are unpredictable eating patterns, especially of children (Schanes et al., 2018; Langen et al., 2015). Prior research in canteens has shown that portion size reductions can reduce plate waste (Lorenz-Walther et al., 2019). Likewise, meal boxes could help through providing accurate portion sizes, but cannot overcome the inherent difficulties associated with changes in appetite, dislike for unknown food items and recipes (which may be higher for novel dishes in a meal box), and spontaneous decisions to eat out. The extent to which meal boxes can thus lead to less plate waste may be limited.

Finally, managing leftovers properly can be challenging for households and lead to concerns about food safety (Principato et al., 2021; Schanes et al., 2018). Eating leftovers is sometimes seen as a sacrifice, as consumers appreciate fresh food and variety in meals (Farr-Wharton et al., 2014; van Geffen et al., 2020). Although meal boxes do not address this directly, the predetermined quantities of ingredients in the box should lead to fewer leftovers.

Based on these differences between traditional meals and meal boxes, we expect that using meal boxes for dinner results in fewer food leftovers as well as less food waste than a traditional dinner. Specifically, we expect that both the occurrence and the amount of preparation, cooking, and plate waste will be less for meal boxes than for traditional meals. The effects may be relatively small for plate waste, as this type of waste depends most on individual differences in appetite and meal liking. Moreover, as the effects indicated for meal boxes generally also apply to convenience meals, we expect that these will have a similar (low) amount of food waste.

3. Materials and methods

3.1. Sample description

Recruitment was done by e-mail among customers of HelloFresh who had ordered at least three boxes in the past six months, and who had chosen to switch between recipes at least once in their total purchase history. The latter ensures that we targeted engaged households, who did not just take the default box. The number of recruitment e-mails send ranged between 2387 (the Netherlands) and 9000 (US), and signup of participants ranged between 12.2% (Germany) and 19.0% (Canada). Next, a sample ($n = 1583$) was randomly selected from the households that applied, and a subset of these dropped out (e.g., for not responding to emails). Respondents were filtered out if they reported household size as zero (448 households) or 100 (1 household). In the end, 914 households participated in the study (81% female, 53% between 25 and 39 years old). The sociodemographic profile of respondents is available in Appendix A. Respondents were relatively often female, part of a two-person household, and between 25 and 45 years old.

3.2. Data collection procedure

The survey was programmed in the online survey tool SurveyMonkey. It had a tripartite structure (introductory, daily, and feedback questionnaire), with a pre-announcement and a thank-you-mail at the end. We framed the questionnaires as being about general food practices to ensure that the focus on food waste appeared less dominant.[1] The pre-announcement contained information on the study, detailed instructions, and a checklist. A prerequisite for participation was owning a kitchen scale, to allow respondents to weigh food waste in grams.

The survey was conducted from November 4 to December 5, 2019, in the US and from November 16 to December 16, 2019, in all other countries. The earlier launch in the US allowed us to review responses and to make small adjustments (e.g., emphasizing some instructions). Communication messages were discussed and agreed upon among the project partners and sent out by HelloFresh.

Respondents filled out an introductory questionnaire with general statements about eating habits and attitudes towards food waste and towards HelloFresh, as well as demographic questions at individual level (filled in by the contact person for the HelloFresh meals, who is thus in charge of at least part of the household food management) and at household level. Shortly afterwards, they received daily questionnaires in which they indicated what type of dinner they prepared, how much and what kind of leftovers they had (in grams) and how these were handled. Depending on dinner type, the daily questionnaire took on average between 2:44–6:59 min to complete (see Appendix B). The daily questionnaire was initially planned with a time period of two weeks, and extended by another two weeks due to requests from respondents for more opportunities to submit reports (to fulfill the requirements to obtain a free meal box as a gift).

3.3. Survey design

The study was conducted in collaboration with HelloFresh, a provider of meal boxes, in six countries (USA, Canada, UK, Germany, Belgium and the Netherlands) and followed the ethical guidelines of the Social Sciences Ethics Committee of Wageningen University. A self-report survey was developed and translated into the official languages of the countries. Two languages were used in Canada (English and Canadian French) and Belgium (Dutch and French). The self-report survey was based on a recently developed and validated food waste questionnaire (van Herpen et al., 2019b), which has been shown to correlate well

[1] Questionnaires were constructed in collaboration with HelloFresh and their US non-profit partner ReFED, and the process was led by Wuppertal Institute.

with other types of waste measurements. Advantages of using s survey to measure food waste include the low costs, relatively low participant effort, and the opportunity to use large samples (Withanage et al., 2021). Yet, self-report measures such as surveys and diaries substantially underestimate the amount of food waste (van Herpen et al., 2019a; Quested et al., 2020), and we need to keep this into consideration. To keep underestimation small, we asked respondents to weigh their food waste. As an alternative to self-report measures, waste composition analysis has been used, which is more accurate yet requires direct access to the food that is wasted in households, and this is not feasible in the current study.

Respondents filled in the survey during or shortly after consuming the meal so they were able to make gram- and day-specific statements, keeping memory gaps and retrospective estimations to a minimum. Rather than relying on subjective estimates of food waste amounts (as done by van Herpen et al., 2019a), we asked respondents to weigh the food waste, to mitigate potential social desirability of responses and have consistency in the measurements. Although frequent surveys can be effortful for respondents, in this case the burden was kept relatively low because they only reported on dinner.

As an incentive to participate, respondents received a free meal box for the study period as well as a second one as a thank-you-gift, if they reported at least five times. Participants received daily reminders to fill in the survey, and were free to report for more than five times, which many did.

3.4. Converting leftover information into waste measurements

Leftovers were classified into five categories (see Table 2 and WebAppendix). Our interest is with preparation, cooking, and plate leftovers. Unused food and inedible food items were reported separately so that these would not contaminate our main measurements. During data cleaning, cases were encountered in which respondents either made a textual input like “twenty grams” or used other units of measurement than gram, even though an indication in grams was explicitly asked. These cases were recovered manually.

Respondents indicated what percentage of the leftovers in each of the categories was dealt with in specific ways (e.g., fridge, trash, compost), taking into account country-specific differences in disposal options (i.e., participants only saw answer options that were present in their country, such as sink disposal in the US and ‘bio bin’ in Germany; see Appendix C). We subsequently calculated the amount of food waste. Leftovers that were discarded (fed to animals, composed, put in sink, trash, or otherwise) were taken up as waste. For leftovers that were stored in fridge or freezer, we assumed that a percentage would eventually be discarded. The percentage was calculated based on information from the feedback questionnaire (see WebAppendix questions 15 and 18), in which participants indicated the share of food stored in the fridge and freezer that they regularly threw away. In case of non-response on this question, the country specific mean was imputed (see Appendix D).

Table 2
Leftover categories.

Category	Description
Preparation leftovers	Food that was supposed to be prepared for dinner that day but was not prepared
Cooking leftovers	Food that was prepared but not served on a plate and remained in the pan/pot/bowl
Plate leftovers	Food left on the plate uneaten
Unused food	Food that respondents had kept for a dinner occasion but threw away that day (not associated with dinner on that day)
Inedible food items	Food that was not intended for consumption

3.5. Reported meals

At the beginning of each daily questionnaire, respondents reported which type of dinner they had (see Table 3 for details; for several meal types plate waste was assessed, as the other types of waste were not applicable). To avoid inaccuracies due to memory errors, we took only those meal observations into account that were made on the same evening as the meal was consumed, which reduced the dataset by 2601 observations. Furthermore, observations were removed in which the categories for handling leftovers added up to over 100% (25 observations). To check for potential effects of respondent fatigue in filling out daily reports, we compared the amount of food waste of the first and last meal reported by each household using a Wilcoxon signed rank test with continuity correction. Results show that the amount of food waste did not significantly differ ($p = .388$), so we find no evidence of fatigue. Furthermore, we removed four households (41 observations) who provided identical answers to a series of questions in the introduction questionnaire (straight-lining).

Reported food waste was in some cases exceptionally high. We therefore carried out a data cleaning procedure to identify outliers via Box-Whisker-Plots, and excluded individual observations of waste types (preparation, cooking, plate) when waste was higher than the 3rd quartile plus 1.5 times the interquartile range. Since the data contained a large number of observations without food waste,[2] only those cases that reported food waste were considered for the identification of outliers (note that these cases were kept in later analyses). In total, 230 observations were removed as outliers (see Appendix E for boxplots). This left 8747 meal observations in the dataset. The average food waste amounts per meal after removing outliers are comparable to previous studies that considered food waste per meal in the food service sector (Beretta and Hellweg, 2019) and plate waste estimates for restaurants are comparable to previous findings as well (Visschers et al., 2002).

Table 3
Types of dinner.

Dinner type	Description	Types of waste	Occurrence	Analyses
Meal box	Dinner made from HelloFresh meal box	Preparation, cooking, plate	35%	Included
Traditional meal	Meal cooked from scratch with store-bought ingredients	Preparation, cooking, plate	29%	Included
Convenience meal	Semi-prepared, ready-to-cook, fully prepared, or frozen meal	Preparation, cooking, plate	9%	Included
Restaurant meal	Meal from delivery service, restaurant or take-out	Plate	10%	Included
Leftovers	Leftovers from another meal	Plate	7%	Included as “other meal”
Not at home	Dinner not eaten at home	Plate	8%	Included as “other meal”
None	No dinner eaten at all	Not applicable	3%	Not included

[2] Zero food waste was reported for 50.3% of all observations and 14.5% of households report zero food waste on all occasions. None of the variables differ significantly between the two groups (see Appendix F).

Table 4
Reported leftover handling by meal types and leftover types (in %).

	Freezer	Fridge	Feeding animals	Composting	Sink	Trash	Other
				Meal box			
Preparation	1.4	54.8	1.0	4.8	1.7	22.4	1.2
Cooking	4.2	69.8	1.7	2.3	0.5	12.9	0.3
Plate	0.9	20.8	6.2	7.8	1.5	37.8	0.3
				Traditional meal			
Preparation	5.2	78.1	1.0	1.2	0.4	9.2	0.8
Cooking	8.7	73.8	1.8	1.3	0.4	7.5	0.3
Plate	0.7	17.6	4.5	8.1	1.4	40.9	0.3
				Convenience meal			
Preparation	10.1	81.2	0.0	0.4	0.0	4.0	0.0
Cooking	4.5	66.6	3.0	2.3	0.0	13.1	1.1
Plate	1.8	15.3	5.4	8.6	0.9	40.5	0.5
				Restaurant meal			
Plate	0.0	33.5	4.1	2.4	0.0	38.1	4.3

Note: In the survey, percentages were not required to add up to 100%, and some respondents only reported how part of the total leftovers were handled.

3.6. Variable descriptions

As described in Table 3, certain dinner types have certain types of food waste associated with it, and we analyzed four measures of food waste: preparation waste, cooking waste, plate waste and total meal waste (i.e., the sum of preparation, cooking, and plate waste associated with a specific meal, calculated for dinner types in which there was more than only plate waste to report). The reference group for dinner type was the 'traditional meal'. In addition, we provide a summary of the variables we use in our empirical model which include sociodemographic information for which prior research supported possible effects (Schanes et al., 2018), as detailed in Appendix G.

3.7. Model specification and estimation

We use a hurdle-lognormal model, which *jointly* models occasions when a household does not waste any food as well as the amount of food a household wastes, on occasions it does waste food. The hurdle component – implemented by a logistic regression – accounts for occasions when a household does not waste any food, while the log-normal component accounts for occasions when a household wastes food and predicts the amount of food it wastes. In addition, to account for the hierarchical data structure with households nested in countries and multiple observations per household (see Fig. 1), we incorporate multilevel random-intercepts at the household and country level.

Let q_{it} denote the food wasted by household i at time t. Then the probability p_{it} that household i at time t wastes zero food is given by:

$$\text{logit}(p_{it}) = \tau_H + \tau_C + \alpha + \beta DINNER\_TYPE_{it} + \gamma SOCIODEM_i \quad \text{for } q_{it} = 0, \tag{1}$$

while the quantity wasted by a household i at time t is specified as:

$$\log(q_{it}) = \tau_H^{'} + \tau_C^{'} + \alpha^{'} + \beta^{'} DINNER\_TYPE_{it} + \gamma^{'} SOCIODEM_i \quad \text{for } q_{it} > 0, \tag{2}$$

where *logit* () denotes log of the odds ratio (), log () denotes the natural logarithm, $DINNER\_TYPE_{it}$ is the type of dinner type that household i have had at time t and $SOCIODEM_i$ is the set of sociodemographic variables we observe for household i. Further, τ_H and τ_C represents the random intercepts for household and country, α represents the intercept, β represent the coefficients for dinner type and γ represent the coefficients for sociodemographic variables in the logistic regression. Similarly, $\tau_H^{'}$ and $\tau_C^{'}$ represents the random intercepts for household and country, $\alpha^{'}$ represents the intercept, $\beta^{'}$ represent the coefficients for dinner type and $\gamma^{'}$ represent the coefficients for sociodemographic variables in the lognormal regression. We use Bayesian inference to estimate our model, and implement the multilevel hurdle-lognormal model with random intercepts using the *brms* package in R (Bürkner, 2017, 2018).

4. Results

4.1. Leftover handling

Table 4 shows the reported handling of leftovers. Most of the leftovers from the meal boxes were either put in the fridge or in the trash. The same holds for traditional and convenience meals, although freezing occurred relatively more often there too. Overall, plate leftovers were more often wasted than preparation or cooking leftovers.

4.2. Amounts of food waste

The means of the amounts of food waste per dinner type and country are shown in Table 5. Most waste occurred as cooking waste. As can be expected, the amount of preparation waste was especially low for convenience meals, as preparation for these meals is (mostly) not done by consumers themselves. The relatively high amount of plate waste for dinners in restaurant, take-away or delivery service likely occurs because consumers have little or no influence on portion size in these cases. Country differences are most likely due to differences in portion and/or package sizes and in cooking habits. An ANOVA analysis showed that preparation, cooking, plate and total meal waste differed significantly for meal box and traditional meals between the countries. For convenience meals only cooking waste differed significantly between countries (see Appendix H). Food waste was highest in Canada, which is in line with the recent UNEP Food Waste Index Report (Forbes et al., 2021).

4.3. Modelling results

Results of our multilevel hurdle-lognormal model with random intercepts are provided in Tables 6 and 7.[3] We estimated two sets of models: one with only the meal types as independent variables (model 1) and the other with meal types and sociodemographic variables (model 2). In Appendix I we compared these two models to see which provided a better fit, but our results show that we are unable to choose one from the other. Thus, we provide the results of both.[4]

For model 1, we inspect the proportions of variance at each level

[3] We verify model convergence as Gelman-Rubin statistics are all equal to 1.0.

[4] Model results in Tables 6 and 7 are based on the amount of food waste per meal per household. We also ran the same model using food waste per meal per person as the dependent variable, see Appendix J. All our main findings remain the same.

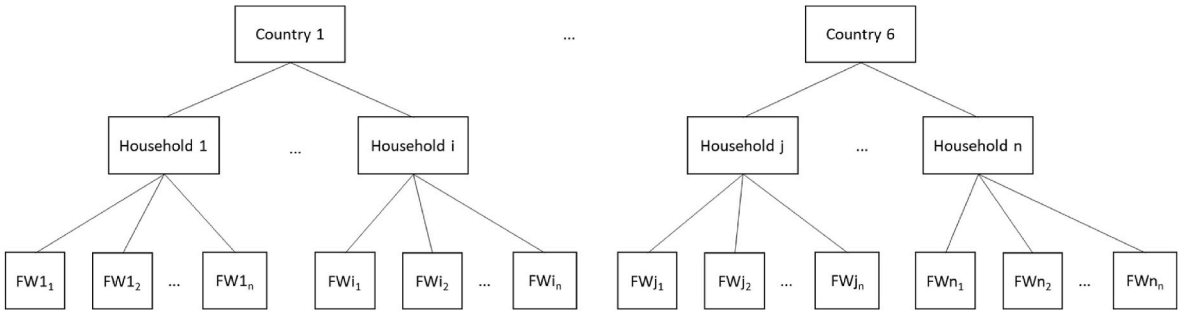

Fig. 1. Hierarchical data structure.

Table 5
Amount of food waste (mean) by meal type and by country.

	n	Preparation waste	Cooking waste	Plate waste	Total meal waste
		Meal box			
Belgium	524	10.1 (28.4)	53.8 (97.6)	15.5 (45.0)	74.2 (114.2)
Canada	458	9.6 (28.2)	75.0 (108.7)	18.5 (45.5)	102.0 (128.5)
Germany	596	2.8 (13.9)	20.4 (57.6)	9.6 (30.2)	31.8 (71.1)
Netherlands	768	14.9 (35.2)	52.5 (98.9)	17.2 (46.5)	80.7 (120.4)
UK	449	8.2 (26.4)	19.4 (47.8)	13.0 (35.5)	40.5 (74.1)
USA	372	8.0 (23.0)	39.0 (89.6)	16.3 (41.3)	61.8 (106.5)
		Traditional meal			
Belgium	466	12.6 (36.8)	57.4 (93.5)	12.9 (37.6)	82.5 (115.4)
Canada	393	14.6 (37.8)	85.8 (114.9)	10.1 (32.1)	104.9 (127.2)
Germany	444	8.4 (27.0)	33.7 (66.5)	4.5 (21.2)	44.7 (77.6)
Netherlands	757	15.0 (36.9)	69.3 (115.3)	18.7 (45.7)	102.6 (128.4)
UK	312	9.8 (28.6)	30.5 (67.7)	13.6 (35.5)	53.9 (91.0)
USA	235	10.8 (34.8)	55.7 (104.4)	12.1 (38.3)	75.1 (126.6)
		Convenience meal			
Belgium	116	2.7 (12.3)	24.9 (60.0)	9.9 (34.0)	36.1 (73.7)
Canada	115	4.8 (22.8)	33.2 (62.8)	12.6 (40.8)	47.9 (86.5)
Germany	112	4.3 (23.0)	18.5 (59.2)	6.2 (17.9)	29.0 (67.9)
Netherlands	172	1.6 (9.3)	15.2 (55.8)	11.0 (31.9)	26.5 (65.7)
UK	166	3.8 (18.9)	6.7 (38.0)	14.6 (41.8)	23.9 (62.6)
USA	80	2.2 (16.4)	19.7 (59.3)	4.8 (23.8)	26.8 (68.4)
		Restaurant meal			
Belgium	111			20.7 (49.7)	
Canada	168			9.0 (34.1)	
Germany	147			7.6 (27.9)	
Netherlands	136			15.4 (44.5)	
UK	136			10.9 (36.8)	
USA	170			12.7 (37.9)	

Note: Food waste in grams per reported meal per household, with standard deviations between brackets.

(meals, households, and countries), see Appendix K. Next to a high proportion of variance within households, this shows a large variance within meals as well, ranging from 24% (cooking waste) to 48% (preparation waste). The proportion of variance among countries is comparatively lower.

We first show the combined impact of both our model components - the hurdle and the lognormal - on food waste; we present the estimated amount of food wasted across meal types for both occasions: when there is no food wasted and when there is food wasted. To do this we use the results of our multilevel hurdle-lognormal model - without sociodemographics - and plot the marginal effects of meal types in Fig. 2. For preparation, cooking, and total meal waste, cooking from both meal boxes and convenience meals were associated with less food waste than traditional cooking. Using meal boxes was associated with a 45% reduction in preparation waste, 34% reduction in cooking waste and 38% reduction in total meal waste, when compared to traditional meals. Further, using convenience meals was associated with a 52% reduction in preparation waste, 65% reduction in cooking waste and 52% reduction in total meal waste, when compared to meal boxes. For plate waste, traditional meals was associated with a 15% reduction when compared to meal boxes, while convenience meals was associated with a 37% reduction when compared to meal boxes.

We now unpick what factors led to an increase in the odds of zero dinner food waste occurring (Table 6) and what factors led to an increase in the amount of food wasted, given that food waste occurred (Table 7).[5] Results showed that preparation waste in the home is less likely to occur for traditional meals compared to meal boxes. Yet, when preparation waste occurs, the amount of preparation waste is higher for traditional meals compared to meal boxes. This could be due to the fresh ingredients that are included in the meal boxes, which may lead to a small amount of preparation waste. For traditional meals, some meals may be prepared using preserved ingredients or pre-cut ingredients, for which preparation waste is less likely to occur. Other traditional meals may be prepared using fresh ingredients from scratch, which could lead to relatively high levels of food waste. Results comparing convenience meals and meal boxes showed that, as expected, preparation waste is less likely to occur at household level for the former. However, when preparation waste occurs, it is higher for convenience meals than for meal boxes.

[5] As we use Bayesian inference, we report 95% confidence intervals.

Table 6
Hurdle-lognormal multilevel regression model: Hurdle Model – Effects on the occurrence of zero food waste.

	Preparation waste		Cooking waste		Plate waste		Total meal waste	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
(Intercept)	1.74 [1.37, 2.08]	2.10 [1.06, 2.80]	0.55 [-0.15, 1.22]	1.21 [0.32, 2.04]	1.97 [1.50, 2.27]	2.83 [2.12, 3.56]	−0.20 [-0.68, 0.34]	0.80 [0.06, 1.58]
Meal box	−0.49 [-0.64, −0.34]	−0.48 [-0.63, −0.33]	0.29 [0.15, 0.43]	0.29 [0.15, 0.43]	−0.26 [-0.42, −0.11]	−0.28 [-0.44, −0.12]	−0.06 [-0.19, 0.09]	−0.05 [-0.19, 0.09]
Convenience meal	1.55 [1.19, 1.95]	1.58 [1.22, 1.98]	1.42 [1.16, 1.68]	1.43 [1.18, 1.70]	0.28 [0.02, 0.55]	0.28 [0.00, 0.57]	1.46 [1.23, 1.69]	1.48 [1.24, 1.73]
Restaurant meal					0.16 [-0.09, 0.42]	0.19 [-0.07, 0.45]		
Other meal					0.64 [0.40, 0.87]	0.61 [0.37, 0.86]		
Household size		0.22 [0.07, 0.37]		0.03 [-0.12, 0.18]		−0.02 [-0.16, 0.14]		0.11 [-0.05, 0.26]
Children		0.08 [-0.26, 0.40]		−0.38 [-0.70, −0.06]		−0.66 [-1.02, −0.33]		−0.31 [-0.67, 0.03]
Male		0.01 [-0.25, 0.26]		0.17 [-0.13, 0.45]		0.04 [-0.24, 0.33]		0.16 [-0.13, 0.43]
Gender nonbinary/ other		−1.24 [-3.18, 0.80]		1.53 [-1.06, 5.53]		0.55 [-1.74, 3.05]		−0.45 [-2.66, 1.68]
Age		0.02 [-0.03, 0.07]		−0.02 [-0.07, 0.03]		0.04 [-0.02, 0.09]		0.01 [-0.04, 0.07]
Parttime		−0.43 [-0.72, −0.13]		−0.02 [-0.33, 0.30]		−0.15 [-0.50, 0.19]		−0.30 [-0.64, 0.04]
Retired		−0.23 [-0.74, 0.29]		0.06 [-0.50, 0.61]		−0.56 [-1.11, 0.00]		0.01 [-0.56, 0.57]
Other employment		−0.18 [-0.48, 0.10]		−0.01 [-0.31, 0.30]		−0.07 [-0.38, 0.25]		−0.05 [-0.37, 0.25]
Suburban area		−0.02 [-0.29, 0.24]		−0.06 [-0.34, 0.23]		−0.21 [-0.50, 0.07]		−0.03 [-0.31, 0.24]
Urban area		−0.11 [-0.36, 0.14]		−0.24 [-0.51, 0.03]		−0.25 [-0.52, 0.02]		−0.30 [-0.59, −0.03]
Education level high		−0.28 [-0.81, 0.29]		−0.42 [-0.97, 0.18]		−0.21 [-0.82, 0.37]		−0.62 [-1.16, −0.05]
Education level medium		−0.04 [-0.59, 0.56]		−0.33 [-0.93, 0.29]		−0.17 [-0.81, 0.43]		−0.47 [-1.06, 0.09]
Education level other		−0.46 [-1.16, 0.29]		−0.76 [-1.52, −0.02]		−0.72 [-1.52, 0.04]		−0.99 [-1.77, −0.25]
Income level high		−0.14 [-0.55, 0.25]		−0.30 [-0.72, 0.11]		−0.46 [-0.87, −0.04]		−0.37 [-0.80, 0.04]
Income level low		−0.06 [-0.38, 0.24]		−0.01 [-0.34, 0.31]		−0.12 [-0.46, 0.21]		−0.22 [-0.55, 0.09]
Num.Obs.	5859	5693	5768	5606	7816	7603	5501	5351
R^2	.24	.25	.32	.33	.22	.24	.42	.43

Notes: 95 percent confidence interval indicated between brackets.
R-squared for Bayesian model is calculated using Gelman et al. (2019).

Both the occurrence of cooking waste, and the amount of cooking waste when it occurs, are lower for meal boxes than for traditional meals. Likewise, meal boxes lead to lower amounts of cooking waste – when it occurs - compared to convenience meals, while cooking waste is more likely to occur for convenience meals than for meal boxes. Given that cooking waste was the largest reported type of dinner waste, these findings are especially relevant.

Using a meal box increased the chance of having plate waste, but the amount of plate waste was not different for the meal boxes versus traditional meals. We will speculate on reasons for this in the general discussion. Plate waste was less likely to occur for convenience meals compared to meal boxes, but there was no difference in the amount of plate waste between meal boxes and conventional meals.

Models 2 included effects of demographic variables, and these were mostly insignificant with a few exceptions. The occurrence of preparation waste was less likely for larger households and higher for persons working parttime, while cooking waste is more likely to occur in households with children, and households with 'other' education levels and plate waste was more likely to occur in households with children and in households with higher income levels. Furthermore, the amount of plate waste was higher for larger households and for households with high and low income levels (compared to medium income). Total meal waste was more likely to occur in urban areas and for households with a high or 'other' education level, while households with children had higher total meal waste and households with 'other' employment had lower total meal waste. Although these effects need further scrutiny in future research, the occurrence of these effects for specific types of waste and not for others might explain why prior research was unable to find consistent effects of demographic variables (Schanes et al., 2018).

5. General discussion

Household food waste is determined by routinized behaviors, and disruption of these routines may allow for a decrease in this vast amount of food waste. The current study has examined such a disruption of household routines: the meal box. To assess how household food waste is affected when households use meal boxes, we examined three types of food waste: preparation, cooking, and plate waste. For *preparation waste*, we expected less food waste for meal boxes compared to traditional meals. Results paint a slightly more complex picture. Preparation waste is *more* likely to occur for meal boxes than for traditional meals. Yet, when it occurs for meal boxes, the amount is smaller. As mentioned, this could be due to the fresh ingredients in the meal boxes, which could lead to a small amount of preparation waste. For *cooking waste*, incorrect portion size estimation is key (Schanes et al., 2018) as well as buying in excessive amounts (Schanes et al., 2018; Evans, 2012), and meal boxes

Table 7
Hurdle-lognormal multilevel regression model: Lognormal Model – Effects on amount of dinner food waste.

	Preparation waste		Cooking waste		Plate waste		Total meal waste	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
(Intercept)	3.63 [3.27, 3.95]	4.01 [3.37, 4.62]	4.55 [4.23, 4.87]	4.70 [4.20, 5.20]	3.76 [3.38, 4.09]	3.65 [3.02, 4.23]	4.46 [4.10, 4.79]	4.58 [4.03, 5.11]
Meal box	−1.00 [-1.15, −0.84]	−1.00 [-1.16, −0.85]	−0.24 [-0.33, −0.14]	−0.25 [-0.34, −0.16]	−0.06 [-0.20, 0.09]	−0.05 [-0.19, 0.09]	−0.51 [-0.60, −0.42]	−0.51 [-0.60, −0.41]
Convenience meal	0.09 [-0.35, 0.54]	0.06 [-0.40, 0.52]	−0.41 [-0.59, −0.23]	−0.41 [-0.59, −0.23]	−0.04 [-0.28, 0.20]	−0.07 [-0.31, 0.17]	−0.32 [-0.50, −0.13]	−0.32 [-0.51, −0.14]
Restaurant meal					0.12 [-0.12, 0.34]	0.12 [-0.12, 0.35]		
Other meal					0.10 [-0.13, 0.32]	0.14 [-0.09, 0.37]		
Household size		0.06 [-0.07, 0.19]		−0.02 [-0.11, 0.08]		0.12 [0.01, 0.24]		0.02 [-0.08, 0.12]
Children		0.22 [-0.08, 0.51]		0.10 [-0.11, 0.30]		−0.14 [-0.40, 0.11]		0.27 [0.06, 0.49]
Male		−0.13 [-0.36, 0.09]		−0.08 [-0.25, 0.08]		0.04 [-0.17, 0.25]		−0.12 [-0.29, 0.06]
Gender nonbinary/ other		0.12 [-1.30, 1.47]		0.97 [-1.11, 2.92]		−1.34 [-3.14, 0.45]		−0.82 [-2.16, 0.47]
Age		−0.01 [-0.06, 0.03]		−0.03 [-0.06, 0.01]		−0.02 [-0.06, 0.02]		−0.01 [-0.05, 0.02]
Parttime		0.05 [-0.22, 0.33]		0.07 [-0.12, 0.27]		0.22 [-0.02, 0.46]		0.01 [-0.20, 0.21]
Retired		0.43 [-0.03, 0.88]		0.15 [-0.19, 0.49]		0.20 [-0.19, 0.60]		0.08 [-0.26, 0.44]
Other employment		−0.16 [-0.41, 0.11]		−0.17 [-0.35, 0.01]		0.16 [-0.07, 0.39]		−0.22 [-0.42, −0.03]
Suburban area		−0.02 [-0.28, 0.21]		−0.05 [-0.21, 0.11]		−0.06 [-0.27, 0.15]		0.04 [-0.13, 0.21]
Urban area		−0.01 [-0.23, 0.21]		0.00 [-0.17, 0.16]		−0.01 [-0.23, 0.18]		0.01 [-0.16, 0.17]
Education level high		−0.31 [-0.78, 0.17]		−0.08 [-0.44, 0.30]		−0.23 [-0.69, 0.23]		−0.14 [-0.53, 0.36]
Education level medium		−0.41 [-0.91, 0.09]		−0.33 [-0.71, 0.04]		−0.14 [-0.61, 0.33]		−0.25 [-0.65, 0.29]
Education level other		−0.48 [-1.10, 0.16]		−0.35 [-0.81, 0.09]		−0.24 [-0.81, 0.33]		−0.15 [-0.65, 0.42]
Income level high		0.10 [-0.25, 0.46]		0.08 [-0.17, 0.32]		0.58 [0.27, 0.87]		0.12 [-0.14, 0.38]
Income level low		−0.14 [-0.42, 0.12]		0.00 [-0.20, 0.19]		0.31 [0.06, 0.54]		−0.07 [-0.29, 0.14]
Num.Obs.	5859	5693	5768	5606	7816	7603	5501	5351
R^2	.24	.25	.32	.33	.22	.24	.42	.43

Notes: 95 percent confidence interval indicated between brackets.
R-squared for Bayesian model is calculated using Gelman et al. (2019).

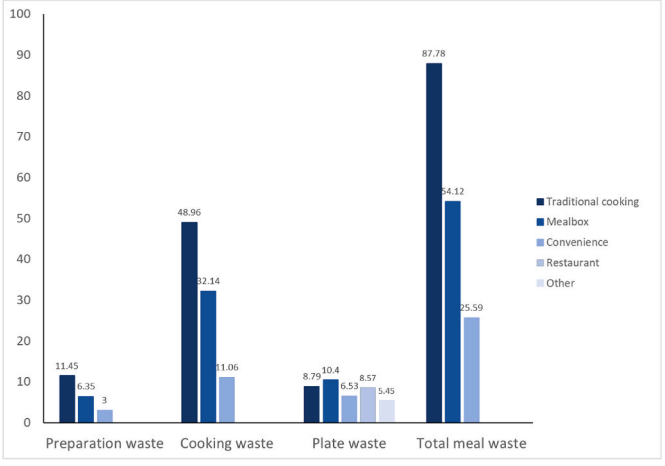

Fig. 2. Estimated amount of food waste (in grams per meal per household; model 1). *Note.* Total meal waste is calculated for those meals in which preparation, cooking, and plate waste have all been reported (no missing values for any of these).

are especially tailored to tackle this through providing appropriate quantities. Our results indicate that cooking waste is the largest type of dinner food waste that occurs within households (i.e., not accounting for upstream food waste in the supply chain). As expected, meal boxes are able to diminish cooking food waste substantially, both through diminishing the occurrence and the amount of cooking waste. Although we expected that the meal boxes might also decrease *plate waste*, we find that the chance of plate waste is higher for meal boxes than for traditional meals. This finding may be an indication that consumers sometimes do not like the taste of a particular meal box and leave food on their plate. Alternatively, the portion sizes might be relatively large for some eaters with a small appetite.

The study was conducted in six countries, which has led to several research challenges. Native speakers translated the questionnaire, taking into account the different languages spoken not only in the countries but also in different regions (e.g., differences between Belgian and Canadian French). Furthermore, we had to attune the questionnaire to differences in context (e.g., waste collection options, educational systems) and to ensure that measurement was consistent across countries (e.g., through using weighing scales). This additional effort allowed us to ensure that results are not culture-specific, and can be relied upon when extrapolating to other similar countries.

5.1. Theoretical contributions

Prior research on household food waste has focused on various types of drivers: household demographics, attitudes and preferences, skills and competencies, sociocultural factors, retail environment, etc. (Roodhuyzen et al., 2017; Schanes et al., 2018). Yet, what appears to have been overlooked are factors at the meal level: different types of meals lead to different levels of food waste. Our results indicate that substantial variance occurs at the meal level and more research attention to differences between meals thus seems warranted.

Although prior research has distinguished different stages of household food management (Block et al., 2016; Schanes et al., 2018), studies have generally focused on overall household food waste as a single measure. The current study offers an important extension and refinement of the food waste questionnaire developed by van Herpen et al. (2019b). Carefully recording of how leftover food is handled, allows for an assessment of different types of household food waste. This refined measurement has provided relevant insights in the current study, and can be used in future research as well.

5.2. Practical contributions

Our study has shown that, overall, cooking from meal boxes diminishes food waste in the household. This indicates that meal boxes may provide a promising approach towards increased sustainability of household food provisioning and should be studied further. Prior research has shown inconsistent findings regarding overall greenhouse gas emissions and energy requirements for meal boxes in comparison to traditional meals, depending on the estimates for food losses in the supply chain, single-use packaging, and consumer transportation to grocery stores (Gee et al., 2019; Heard et al., 2019). Although more research is needed on related social and economic issues to fully understand the implications of using meal boxes, our study provides insights into an important aspect of sustainability, that is, household food waste.

The success of the meal boxes in reducing household food waste can be mostly attributed to a reduction in cooking waste. This is in line with previous exploratory research that showed how leftovers are a relevant lever for food waste mitigation (Roe et al., 2020) and suggests that other ways of limiting the creation of leftovers (e.g., simplifying portion sizing, van Dooren et al., 2020, or offering smaller package sizes) may also help. Given the high proportion of household dinner waste that is cooking waste from pans and pots, intervention programs are advised to emphasize this phase, for instance by offering cooking lessons on how to reuse pot leftovers, adapt them, and how to store them.

Using meal boxes implies that certain steps in the food management process are taken out of the hands of consumers, such as the provisioning and portioning, which successfully decreases household food waste. To build on this, meal box providers could make their customers aware of the decrease in their food waste and motivate them to develop their cooking skills. For instance, given that portion sizing appears impactful, meal box providers could stimulate consumers to actively observe the portion sizes provided as an indication of what is an appropriate portion size. They could also provide indications on how to best store pots leftovers and reuse them in new dishes. Taking tasks out of the hands of consumers does not negate the importance of also increasing consumer awareness of the food waste issue and of increasing their skills and knowledge.

5.3. Limitations and future research

A main limitation of the current study is that the sample constitutes of customers of HelloFresh meal boxes. Although varied on demographic factors, this sample is not representative for the general population in all respects. Furthermore, a self-selection bias may be present, as households who are more sensitive to food waste may be more likely to participate. We attempted to diminish this bias and also attract households who are less sensitive about the issue by offering a generous compensation (free meal box) for active participation. A potential bias also holds for the sample of meals that respondents reported upon. The number of meals reported on per household varied. Moreover, customers of meal boxes may adjust their food management during weeks that they cook from a meal box, as the meal box will provide for several but not all meals of any week. Respondents also filled in daily questionnaires during weeks in which they did not receive a meal box, but this cannot completely rule out that their regular food management has been affected by being a customer of meal boxes. Additionally, self-reported data may lead to underreporting and data quality issues. Thus, future research should verify the generalizability of our results among consumers who are not currently a customer of meal boxes and using other food waste measurements, such as waste sorting.

Another limitation concerns our focus on household food waste associated with specific meals. We did not consider food losses in the upstream supply chain. Less household food waste could be offset by more food losses in the supply chain. Yet, first indications are that this might not be the case for meal boxes: although packaging impacts are higher (Gee et al., 2019), food losses and last-mile transportation impacts in the US are estimated to be lower than for traditional meals (Heard et al., 2019). Moreover, consumers also waste unused food items that they have bought without a clear intention of when/for which meal these would be used. In the current study, this type of waste has been disregarded. After all, consumers may throw out a food item bought days or weeks earlier on any given day, without there being a link to the meal of that day. Future research could assess this type of food waste specifically.

A relevant question for future research is how meal boxes affect routines, skills and knowledge of consumers. On the one hand, it has been speculated that when tasks that require skills (such as portion sizing) shift from consumers to meal box schemes, consumers might lose these skills (Heidenstrøm and Hebrok, 2022). On the other hand, meal box schemes (and the recipe instructions) may introduce new foods, handling routines, or kitchen aids to consumers (Hertz and Halkier, 2017). Rather than a decline in cooking skills, cooking with meal boxes may imply adaptational changes and adoption of new cooking skills (Halkier, 2021). Future research is needed to examine this further. In addition, it may be interesting to see if consumers of meal boxes schemes – who believe they are reducing food waste by using it – take advantage of other initiatives in food shopping aimed at reducing food waste, such as last-minute discounts by supermarkets (Mullick et al., 2021).

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CRediT authorship contribution statement

Sebastian Schuster: Data curation, Formal analysis, Methodology, Software, Supervision, Validation, Writing – original draft, Writing – review & editing. **Melanie Speck:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. **Erica van Herpen:** Conceptualization, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **Felix Buchborn:** Conceptualization, Formal analysis, Investigation, Validation, Visualization, Writing – original draft, Writing – review & editing. **Nina Langen:** Conceptualization, Investigation, Methodology, Supervision, Validation, Writing – review & editing. **Mariam Nikravech:** Formal analysis, Methodology, Validation, Writing – review & editing. **Shantanu Mullick:** Formal analysis, Software, Writing – review & editing. **Tilman Eichstädt:** Conceptualization, Investigation, Methodology, Project administration, Supervision. **Yulia Chikhalova:** Conceptualization, Investigation, Methodology, Project administration, Supervision. **Emma Budiansky:** Conceptualization, Investigation, Methodology, Project administration, Supervision. **Tobias Engelmann:** Investigation, Methodology, Supervision, Writing – review & editing. **Manuel Bickel:** Data curation, Formal analysis, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

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Data availability

The authors do not have permission to share data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.134001.

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