Cleaner and Responsible Consumption 22 (2026) 100435

Contents lists available at ScienceDirect

Cleaner and Responsible Consumption

journal homepage: www.journals.elsevier.com/cleaner-and-responsible-consumption

A bite too much: Scenario-Based analysis of simulated plate waste behaviour at a hotel breakfast buffet

Caterina Rettore [a], Larissa L. Lima [b,*], Ivan Puga-Gonzalez [b], Filippo Pini [a], Paulina Szwed [c], Patrycja Antosz [b], Matteo Vittuari [a]

[a] Department of Agricultural and Food Sciences, Alma Mater Studiorum, University of Bologna, Bologna, 40127, Italy
[b] Center for Modeling Social Systems, NORCE Research AS, Kristiansand, Norway
[c] VLTN, Antwerp, 2018, Belgium

ARTICLE INFO

Keywords:
Food waste
Behavioural interventions
Scenarios
Agent-based model
Food service

ABSTRACT

Plate waste at hotel breakfast buffets contributes substantially to food waste, yet interactions between guest characteristics, portioning decisions, and behavioural interventions remain understudied. This study conducts scenario analysis using the validated Establishment Diner agent-based model, simulating plate waste across 36 scenarios varying plate size, clientele structure, guest sustainability awareness, and buffet communication messages. The model captures guests' sequential decisions on initial portioning, refilling, and leftovers, driven by internal motives, social norms, and external constraints. Across the simulated scenarios, simulated plate waste outcomes range from 9.7 g to 277 g per guest per day. The analysis highlights how plate waste emerges from a sequence of behavioural decisions rather than from a single action. A behavioural pathway analysis of the simulated outputs indicates that interventions affecting one stage of the decision process may trigger compensatory responses that limit or even reverse their intended effects. While sustainability awareness and clientele structure shape baseline behavioural tendencies within the ABM, the simulations show that the effectiveness of interventions depends strongly on contextual conditions and guest profiles. In particular, communication messages interact with guest characteristics, producing different outcomes depending on sustainability awareness and clientele composition. These results underscore the value of scenario-based simulations for testing unintended compensatory dynamics and reactance in buffet settings that would be difficult to observe in field settings. The findings should be interpreted as simulation-based insights rather than empirical evidence and suggest that hospitality interventions should move beyond isolated nudges and instead consider how guest characteristics and behavioural pathways jointly influence waste outcomes.

1. Introduction

Food waste (FW) is a global sustainability challenge with environmental, social, and economic consequences. A significant portion of FW originates in the downstream stages of the food supply chain, particularly at the consumer and food service levels (UNEP, 2024). Food services (e.g., canteens, restaurants, and hotels) account for 28% of global FW (UNEP, 2024), with 75% avoidable hospitality FW (Oliveira et al., 2016). In parallel, the expenditure on restaurants and accommodation has steadily increased in the EU (EUROSTAT, 2025), highlighting the need to measure FW and analyse its determinants.

Within hospitality, FW occurs across planning, preparation, serving, and consumption (Oliveira et al., 2016). Determinants include prediction and procurement practices (Heikkilä et al., 2016), preparation methods, the use of prepared versus fresh ingredients (McAdams et al., 2019) and staff skills (McAdams et al., 2019; Kasavan et al., 2019). Additionally, operational practices (e.g., overproduction, excessive menu variety) contribute to the issue (Kasavan et al., 2019; Papargyropoulou et al., 2019). Strict food safety regulations around food safety and liability limit the reuse or donation of leftovers (Filimonau et al., 2020; Chawla et al., 2021), constituting recognized systemic drivers of FW. On the operational side, better forecasting, simplified menus, and staff training can reduce FW (Wu and Teng, 2022), but the most effective strategies are systematic, combining waste monitoring, corporate reduction targets, and redistribution partnerships, which also influence customers' commitment to reduce waste (Wu and Teng, 2022; Zhu et al.,

* Corresponding author.
E-mail address: lali@norceresearch.no (L.L. Lima).

https://doi.org/10.1016/j.clrc.2026.100435
Received 27 January 2026; Received in revised form 24 April 2026; Accepted 26 April 2026
Available online 29 April 2026

2025). In fact, while organizational factors shape service-level FW, consumers' behaviours determine plate waste (PW), the share of FW occurring directly on guests' plates and defined as the food served but not consumed. PW is influenced by abundant portion sizes (von Massow and McAdams, 2015; Berkowitz et al., 2016), individual preferences with respect to ingredients or preparation methods, individual attitudes towards FW (Dhir et al., 2020; Okumus et al., 2020), and social norms (Muposhi and Musavengane, 2023). In buffet settings, where guests serve themselves, usually in an all-you-can-eat mode (Juvan et al., 2018), PW is particularly relevant. The abundance of food and all-you-can-eat pricing lead guests to overserve and leave food uneaten (Juvan et al., 2021). Few studies have measured the amount of PW in hotel buffets, resulting in very different figures spanning from an average of 15.6 g (Juvan et al., 2018) to 300 g per guest (Papargyropoulou et al., 2016). Socio-demographic and cultural characteristics of guests are also a key element (Juvan et al., 2018). For example, children and first-time diners at a given buffet establishment tend to leave more food unconsumed (Juvan et al., 2021). On the other hand, no previous research has explored how different types of guest, beyond socio-demographics, may differ in their wasting behaviour due to professional identities and situational norms. While studies found that tourists' cultural backgrounds influence PW (Liu et al., 2022), research has not yet examined business and leisure guests as categories following distinct motivations, social norms, and with different behavioural constraints.

Different strategies have been tested to reduce PW. Guest-oriented interventions, such as smaller plates, informative signage, and behavioural nudges, have shown promise (Guimarães et al., 2024). Despite these efforts, PW in buffet settings remains substantial and important research gaps remain. Several of the abovementioned determinants are well established, such as the role of portion size, sustainability attitudes, and operational establishment practices, but evidence is inconsistent for others, particularly for influences related to time or social identity on guest behaviour. Additionally, existing studies usually examine individual drivers, providing limited insight into how their interactions shape portioning, refilling, and waste generation. The behavioural pathways leading from initial serving to leftovers remain understudied. These gaps highlight the need for an analysis capable of capturing interactions, compensatory dynamics, and messaging backfire, elements that are inherently difficult to observe, isolate, or manipulate in field studies, particularly when interventions operate across multiple decision stages.

To address these gaps, this study uses the Establishment Diner agent-based model (ABM) developed and validated by Puga-Gonzalez et al. (2025) to simulate PW (measured as leftovers per guest) in all-you-can-eat breakfast buffets. ABMs simulate systems composed of individual agents whose decisions and interactions produce emergent outcomes (Macal and North, 2010). ABMs are particularly valuable for capturing emergent phenomena that arise from localized interactions and heterogeneous behaviors (Bonabeau, 2002). They are suited to investigate FW determinants, as they capture heterogeneity and feedback among individuals (Puga-Gonzalez et al., 2025; Ravandi and Jovanovic, 2019; Skeldon et al., 2018; Kandemir et al., 2020; Boz et al., 2024). Moreover, ABMs enable the exploration of “what-if” scenarios that would be difficult to implement empirically (Ravandi and Jovanovic, 2019). The ABM (Puga-Gonzalez et al., 2025) integrates psychological, behavioural, and social mechanisms through the HUMAT (Jager et al., 2025) and Motivation-Opportunity-Ability (MOA) (MacInnis et al., 1991) frameworks and simulates key behavioural mechanisms relevant to PW, including portioning and refill decisions, finishing behaviour, social influence, and individual motives and opportunities. Given that PW emerges from a sequence of guest decisions (i.e., initial portioning, refilling, and leftovers generation), in this study, we adopt a behavioural-pathway perspective, examining how interventions influence each stage of this decision process.

Using this ABM, we simulated 36 scenarios combining variations in plate size, guest sustainability awareness, clientele structure, and communication strategies. The objective is not to estimate empirical effects, but to analyse behavioural mechanisms and interactions as they emerge within a controlled computational environment. The ABM is used as a virtual laboratory to generate and explore behavioural pathways under systematically varied conditions. Scenario analysis allows us to explore how these factors and their interactions shape portioning, refills, and PW in an all-you-can-eat breakfast buffet, under combinations that would be difficult to manipulate and isolate in field experiments. Importantly, all findings reported in this study derive from simulated behavioural trajectories generated by the ABM under hypothetical configurations. Through the simulated scenarios, this study addresses the following research questions (RQ).

RQ1. How does plate size influence the behavioural pathway from initial portioning to refills and PW?

Previous studies show that plate size affects portion perception and consumption norms (Wansink and van Ittersum, 2013), with large plates leading to increased PW (Van et al., 2011; Freedman and Brochado, 2010), while smaller plates may reduce waste (Kallbekken and Sælen, 2013). However, most evidence comes from isolated interventions and single-stage outcomes, neglecting potential interactions with individuals' characteristics and behavioural pathways (Freedman and Brochado, 2010).

RQ2. How do different mixes of business and leisure guests affect portioning, refills, and PW, and do they amplify or hinder the effects of interventions?

Based on social identity theory (Tajfel et al., 1979) and professional self-categorization (Ellemers et al., 2004), we assume business guests are more efficiency-oriented, with less time and greater conformism, while leisure guests behave more indulgently. In other words, we assume business guests adhere to situational social norms suggesting what is perceived as more appropriate in a certain context (Rimal and Real, 2005). Conformism matters in buffets, as guests can observe and adjust their behaviour based on what others do (Cialdini and Goldstein, 2004), and time constraints may either reduce PW by encouraging selective portioning (Cohen et al., 2016; Price and Just, 2015; Wansink, 2004), or increase it, if portions exceed finishing capacity. Empirical evidence comparing business guests and leisure guests is not available. Thus, starting from the abovementioned assumptions, we test whether business guests' efficiency-oriented motives (higher conformism, lower indulgence) amplify nudges effects, and whether leisure-dominated settings hinder them.

RQ3. Under which conditions (clientele structure, sustainability awareness) do communication messages reduce PW?

Communication studies indicate that positive/informative messages can reduce waste (Nisa et al., 2022; Cozzio et al., 2021; Chen et al., 2018), while messages perceived as moralizing may backfire due to psychological reactance (Yuan and Kuehl, 2023; Li and Shi, 2025), a motivational state occurring when one's freedom of choice is threatened (Brehm and Brehm, 1981). Reactance reduces willingness to comply with norms, decreases goal-directed attitudes, and increases the tendency towards restricted behaviour (Kavvouris et al., 2020; Sprengholz et al., 2023). Individual's characteristics have an influence on reactance (Ward et al., 2021). Therefore, testing how different messages perform and interact with individuals' characteristics is essential to prevent potential backfiring effects.

RQ4. How does sustainability awareness shape the behavioural pathways leading to PW, and how does it moderate the impact of plate size and communication messages?

Pro-environmental values and sustainability awareness are associated with lower waste (Visschers et al., 2016; Williams et al., 2012), yet their interaction with nudges and contextual factors in self-service buffets is unclear. Simulating guests with high versus low sustainability awareness helps us understand how personal values drive PW, and how these values interact with behavioural interventions along the portioning–refilling pathway.

RQ5. To what extent do changes in initial portioning induce compensatory refilling behaviour, and how do these dynamics jointly determine PW?

Portion size strongly predicts both intake and leftovers (Visschers et al., 2020; Lorenz-Walther et al., 2019), but most studies do not follow guests across multiple servings. Through the ABM, we simulate guest portioning and refilling behaviours to assess their influence on PW.

By addressing these questions, the scenario analysis moves beyond testing whether single drivers affect PW, and instead examines how interacting drivers and behavioural pathways produce waste in all-you-can-eat buffets. The contribution of this study is primarily theoretical and simulation-based. Rather than aiming to produce empirical estimates or causal inference, the ABM is used as a generative laboratory to explore how behavioural mechanisms interact and produce emergent outcomes. This supports the identification of intervention combinations that minimize PW while accounting for compensatory dynamics and messaging backfire. For hospitality actors, simulated scenarios can help identify the most effective combinations of interventions to reduce PW. From a policy perspective, scenario results can inform guidelines or incentive programs that promote sustainable consumption practices in the hospitality sector.

2. Methods

2.1. ABM overview

The Establishment Diner ABM simulates guests' daily meal choices, including portioning, refilling, and PW generation. A detailed description, calibration, and validation of the base model are provided in Puga-Gonzalez et al. (2025), where the model was calibrated using real-world hotel data on guest composition and buffet food waste. A graphical representation of the model flow and its most relevant factors for this study is represented in Fig. 1. The population consists of individuals differentiated by gender (male/female) and guest type (business or non-business). Business guests represent individuals staying for work, typically eating earlier and under time pressure, while non-business guests represent leisure visitors. During breakfast, agents decide when to eat, how much to serve, how often to refill, and how much to leave uneaten.

Individual decision-making depends on personal attributes and key internal motives: hunger, fullness, weight control, conformism, indulgence, and sustainability awareness. These interact with opportunities and abilities such as self-control and time availability. The process unfolds in stages: agents first choose portions based on internal motives, time available, and self-control. Agents are also influenced by what other agents around them are doing. The decision to leave leftovers also depends on ability, sustainability awareness, hunger level, conformism, and time.

The ABM integrates the HUMAT socio-cognitive architecture (Jager et al., 2025) and the Motivation-Opportunity-Ability (MOA) framework (MacInnis et al., 1991), enabling realistic simulation of portioning, refilling, and PW emerging from the interplay of personal and contextual factors.

2.2. Scenarios design

Scenarios were defined through a participatory co-design process involving researchers and hospitality practitioners in the context of the Horizon Europe CHORIZO project, ensuring that the tested scenario configurations reflect realistic operational conditions in hotel buffet settings. Participants were introduced to the ABM and invited to propose interventions targeting guests' behaviours and PW. The research team evaluated the feasibility and relevance of the proposals, resulting in four experimental factors combined into simulation scenarios: plate size, clientele structure, sustainability awareness, and communication strategy.

Other ABM parameters were adopted from Puga-Gonzalez et al. (2025) (see *Supplementary Table A)*. The scenarios explored in this study do not represent empirically observed interventions, but plausible configurations derived from stakeholder consultation and existing empirical literature. Scenario parameters were therefore introduced as variations within this validated model structure to explore potential behavioural dynamics under hypothetical but realistic conditions.

The 36 scenarios are defined by the unique combination of four key parameters. The first parameter is related to plate size. It affects portion choices: small plates allow small or normal portions (200-300 g), while large plates also enable large portions (400 g). In the ABM, portion decisions are guided by hunger, weight control, indulgence, fullness, and sustainability motives.

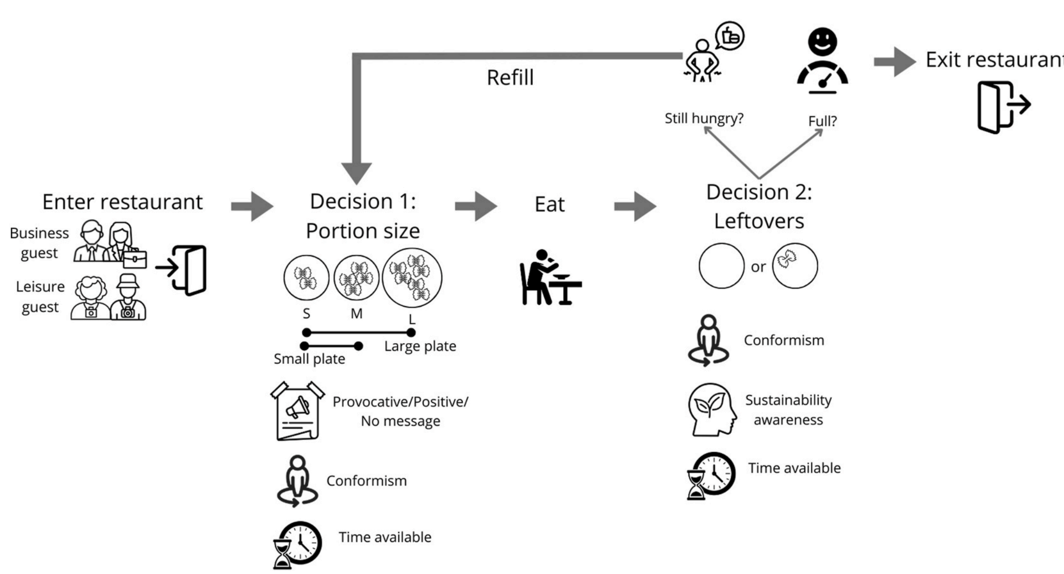

Fig. 1. Establishment Diner ABM decision steps. After the first serving, agents can decide whether to finish, leave food or go back and refill. Only factors relevant for this study are depicted, further details in Puga-Gonzalez et al. (2025).

The second parameter is defined by clientele structure. It varies across three population distributions: 70% business dominant, 50% balanced, 30% business minority. Assumptions regarding clientele structure are informed by empirical hotel datasets used in the original model calibration (Puga-Gonzalez et al., 2025). Business guests are assumed to be more conformist and less indulgent than non-business guests, based on social identity theory and professional self-categorization (see Section 1). In the model, the level of conformism determines to what extent an agent is influenced by what other agents present in the restaurant are doing.

The third parameter captures guests' levels of sustainability awareness, which influences whether they finish or leave food. Two levels are tested: high awareness and low awareness.

Finally, hotel communication strategies test the influence of messages on guests' behaviours. The implementation of messages in the model is grounded in the psychological reactance theory (Brehm and Brehm, 1981), which hypothesizes that when individuals perceive messages as threatening their autonomy, they tend to resist. In our model, this is coded as a comparison between individuals' tolerance level and the message threat degree. Reactance is thus modelled as a graded motivational process rather than a binary response, allowing heterogeneous and context-dependent reactions to the same message across individuals and guest types. Messages previously tested empirically in field experiment conducted in eight Norwegian hotels (Alonso Miquélez et al., 2024) are coded as positive, provocative, or absent. The message calibration process and data are presented in the *Supplementary materials* (*Supplementary Table B),* while details about how message influences were coded in the ABM are presented in *Supplementary materials* Section 3.

When serving themselves, agents see a displayed message. Each message has a threat potential level: positive messages are minimally threatening, while provocative ones have high threat potential (Shen, 2015). Based on Ebbinghaus' forgetting curve theory (Murre and Dros, 2015), it was assumed that, as guests are exposed to the message at the beginning of the mealtime, their reaction to the message gradually diminishes in proportion to the time between serving and finishing their meal. Individual reaction depends on their tolerance, which is influenced by their self-control: high self-control guests tolerate threatening messages better. It was assumed that self-control can moderate reactance by allowing people to approach the message with a more considered perspective (Middleton et al., 2015).

The ABM incorporates two decision routes for portioning and leftovers. Agents follow different routes depending on how their tolerance compares with the message's threat level. When the message threat exceeds an agent's tolerance, reactance occurs in the form of purposefully disobeying the communicated request (Fig. 2). If the individual does not perceive the message as threatening, they conform to what the message encourages them to do. Message effects on motives were determined through expert consensus among FW researchers, psychologists, and modelers, as no prior research existed.

Route 1 (message perceived as unthreatening): guests conform to the message by increasing conformism (follow social norms for appropriate actions) and sustainability motives, while reducing indulgence. These effects gradually decay over time, so when the agent decides how much food to leave uneaten, all three motives might already be at the initial level (or still slightly higher, depending on how much time it takes the individual to consume the portion of the chosen size).

Route 2 (message perceived as threatening): guests react with psychological reactance, disobeying the message by decreasing conformism, desire to control weight, and indulgence motives (e.g., taking larger portions despite "small portion" message) (Boukamcha, 2016). These effects gradually recover during eating, approaching but not exceeding baseline levels at the time of leaving leftovers.

Details about how message influences were coded in the ABM are presented in the *Supplementary Materials* Section 3.

Table 1 summarizes parameters and their values used in what-if scenarios.

2.3. Data analysis

Each of the 36 scenarios was simulated 150 times, yielding 5400 simulations. Because empirical calibration data are aggregated at the hotel rather than the individual level (Puga-Gonzalez et al., 2025) analyses are conducted on aggregated outputs (simulated average PW per agent per simulation). Overall scenario differences were assessed using Tukey's Honest Significant Difference (HSD) test (Tukey, 1949), complemented with heatmap visualizations and boxplots illustrating the effects of key factors.

To address RQ1-RQ5 and to interpret the simulation results in a coherent way, we analyse the outputs through a behavioural-pathway framework that reflects the sequential structure of guest decision-making in the ABM: portioning decision, refill decision, and leftovers (PW) generation. We estimated four multiple linear regression models with heteroskedasticity-consistent (HC1) robust standard errors,

Table 1
Values used for parameter variation in what-if scenario simulations.

Variable	Scenario	Value
Small_plate	Small	Max 300 g
	Large	Max 400 g
Clientele_structure	High business guests proportion	0.7
	Equal guests proportion	0.5
	Low business guests proportion	0.3
Sustainability	High	For women = 0.5
		For men = 0.4
	Low	For women = 0.2
		For men = 0.1
Message	No message	Threat level = 0.5
	Provocative message	Threat level = 0.6
	Positive message	Threat level = 0.2

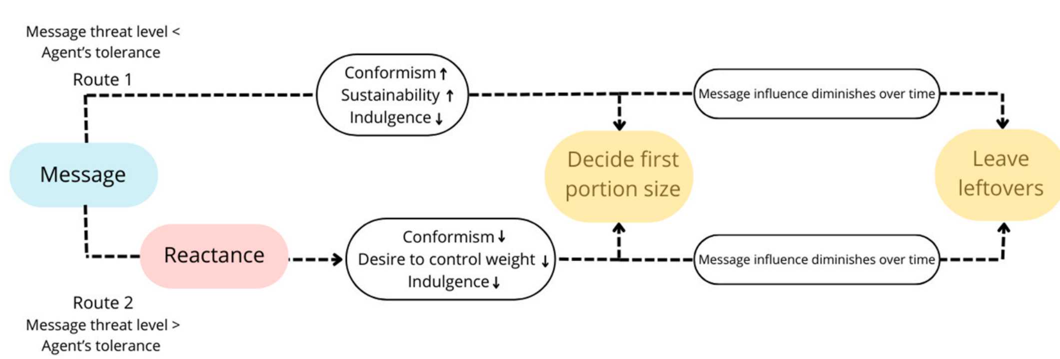

Fig. 2. Messages influence on guests' decisions through reactance.

implemented in the *sandwich* package in R (Zeileis et al., 2020). All continuous predictors were standardized to facilitate comparison across scales. Standardized coefficients represent the change in the dependent variable associated with a one-SD increase in each predictor. Interaction terms were incorporated to test for moderation effects. Analyses were conducted in RStudio, using the *lm(a)* function for estimation and the *sandwich* and *lmtest* packages for inference. The regression models do not estimate empirical relationships in real-world populations. Rather, they serve as secondary analytical models used to systematically summarize and decompose patterns generated by the ABM. While the ABM constitutes the primary generative model producing simulated behavioural results, the regression framework serves to quantify marginal effects, identify interaction patterns, and formally decompose behavioural pathways embedded in the model structure. This approach allows structured interpretation of high-dimensional simulation outputs without implying statistical inference to real-world populations. Importantly, causal relationships between variables are defined by the behavioural rules embedded in the ABM. The regression models do not establish causality but provide a structured statistical summary of the simulated relationships generated by these underlying model mechanisms.

Each model links to a specific behavioural decision. The Portion model (Eq. (1)) tests how experimental manipulations affect standardized average portion size (mean_portion_size_s). We include main effects and the four two-way interactions that test whether the effect of plate size or message depends on sustainability awareness or clientele structure.

$$\begin{aligned} mean\_portion\_size\_s_i = {} & \beta 0 + \beta 1 Small\_plate_i + \beta 2 sustainability_i \\ & + \beta 3 Clientele\_structure_i + \beta 4 message_i \\ & + \beta 5 (Small\_plate_i \times sustainability_i) \\ & + \beta 6 (Small\_plate_i \times Clientele\_structure_i) \\ & + \beta 7 (message_i \times sustainability_i) + \beta 8 (message_i \\ & \times Clientele\_structure_i) + \epsilon_i \end{aligned} \tag{1}$$

The Refill model (Eq. (2)) predicts the average number of extra portions (Total_extra_mean_s), controlling for initial portion size:

$$\begin{aligned} Total\_extra\_mean\_s_i = {} & \beta 0 + \beta 1 Small\_plate_i + \beta 2 sustainability_i \\ & + \beta 3 Clientele\_structure_i + \beta 4 message_i \\ & + \beta 5 (Small\_plate_i \times sustainability_i) \\ & + \beta 6 (Small\_plate_i \times Clientele\_structure_i) \\ & + \beta 7 (message_i \times sustainability_i) + \beta 8 (message_i \\ & \times Clientele\_structure_i) + mean\_portion\_size\_s_i + \epsilon_i \end{aligned} \tag{2}$$

The Mediated Leftovers model (Eq. (3)) estimates standardized mean leftovers per guest (mean_leftovers_s) as a function of portioning, refilling, and scenario variables (including interactions). This model investigates how portioning and extra-ordering jointly determine PW, while also controlling for any remaining direct effects of the simulated scenario manipulations.

$$\begin{aligned} mean\_leftovers\_s_i = {} & \beta 0 + \beta 1 mean\_portion\_size\_s_i + \beta 2 Total\_extra\_mean\_s_i \\ & + \beta 3 (mean\_portion\_size\_s_i \times Total\_extra\_mean\_s_i) \\ & + \beta 4 Small\_plate_i + \beta 5 sustainability_i \\ & + \beta 6 Clientele\_structure_i + \beta 7 message_i + \beta 8 (Small\_plate_i \\ & \times sustainability_i) + \beta 9 (Small\_plate_i \times Clientele\_structure_i) \\ & + \beta 10 (message_i \times sustainability_i) + \beta 11 (message_i \\ & \times Clientele\_structure_i) + \epsilon_i \end{aligned} \tag{3}$$

After breaking down the behavioural pathways leading to PW, the Total-effect Leftovers model (Eq. (4)) captures the total effect of experimental manipulations on mean_leftovers_s, excluding mediators (portion size and refills) to estimate combined direct and indirect influences.

$$\begin{aligned} mean\_leftovers\_s_i = {} & \beta 0 + \beta 1 Small\_plate_i + \beta 2 sustainability_i \\ & + \beta 3 Clientele\_structure_i + \beta 4 message_i + \beta 5 (Small\_plate_i \\ & \times sustainability_i) + \beta 6 (Small\_plate_i \times Clientele\_structure_i) \\ & + \beta 7 (message_i \times sustainability_i) + \beta 8 (message_i \\ & \times Clientele\_structure_i) + \epsilon_i \end{aligned} \tag{4}$$

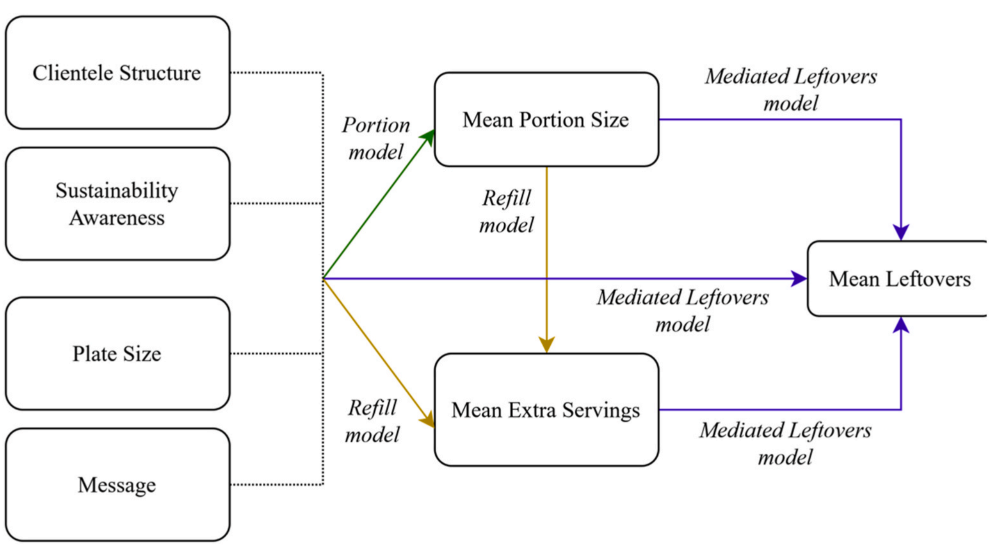

Fig. 3. Predictor structure of the regression models. Arrows colours refer to each model pathway: Green = Portion model; Yellow = Refill model; Purple = Mediated Leftover model.

Table 2
Parameter setting and average results for the 36 simulated scenarios.

Scenario ID	Plate size	Clientele structure	Sustainability awareness	Communication strategy	Average PW/guest/day and standard deviation (g)
1	small	high business	high	no communication	11.46 ± 5.67
2	small	high business	high	provocative message	17.41 ± 6.37
3	small	high business	high	positive message	9.73 ± 5.76
4	small	high business	low	no communication	109.95 ± 18.96
5	small	high business	low	provocative message	130.01 ± 18.46
6	small	high business	low	positive message	108.53 ± 19.75
7	small	balanced	high	no communication	12.26 ± 7.39
8	small	balanced	high	provocative message	29.7 ± 8.44
9	small	balanced	high	positive message	13.43 ± 7.25
10	small	balanced	low	no communication	182.8 ± 25.64
11	small	balanced	low	provocative message	184.01 ± 25.41
12	small	balanced	low	positive message	191 ± 23.01
13	small	low business	high	no communication	15.44 ± 8.39
14	small	low business	high	provocative message	20.73 ± 8.71
15	small	low business	high	positive message	16.97 ± 7.43
16	small	low business	low	no communication	256.89 ± 29.03
17	small	low business	low	provocative message	277.41 ± 28.41
18	small	low business	low	positive message	255.63 ± 27.85
19	large	high business	high	no communication	10.61 ± 5.92
20	large	high business	high	provocative message	17.56 ± 6.3
21	large	high business	high	positive message	11.91 ± 6.29
22	large	high business	low	no communication	107.49 ± 17.27
23	large	high business	low	provocative message	117.82 ± 19.1
22	large	high business	low	positive message	111.08 ± 17.49
25	large	balanced	high	no communication	13.48 ± 8.05
26	large	balanced	high	provocative message	15.2 ± 7.25
27	large	balanced	high	positive message	11.02 ± 5.58
28	large	balanced	low	no communication	174.89 ± 25.85
29	large	balanced	low	provocative message	185.73 ± 24.46
30	large	balanced	low	positive message	184.93 ± 29.2
31	large	low business	high	no communication	14.77 ± 8.74
32	large	low business	high	provocative message	24.61 ± 11.98
33	large	low business	high	positive message	14.85 ± 7.59
34	large	low business	low	no communication	248.8 ± 29.03
35	large	low business	low	provocative message	260.25 ± 29.98
36	large	low business	low	positive message	262.36 ± 29.69

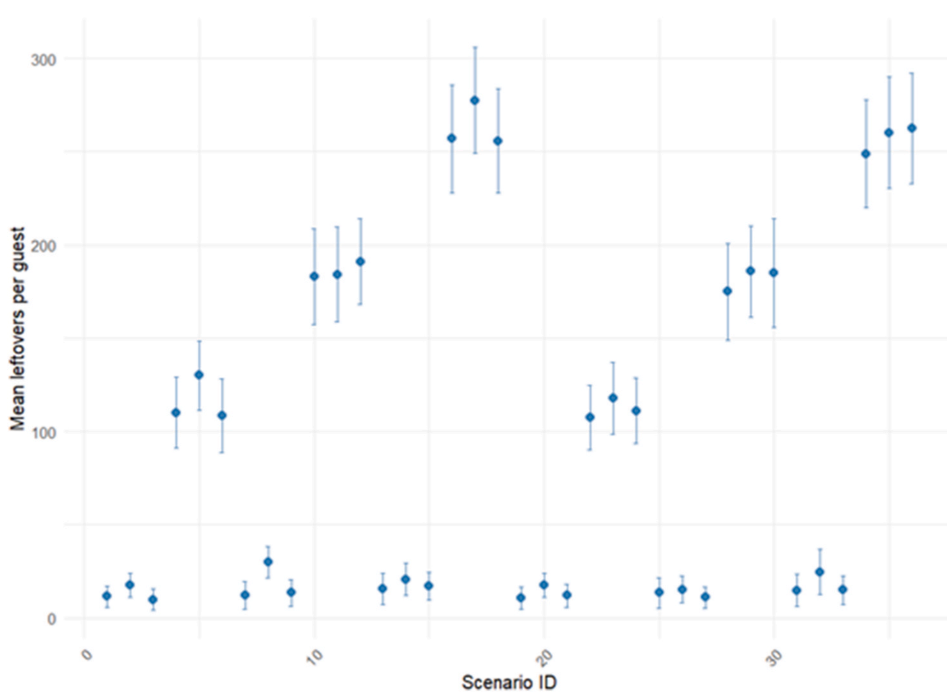

Fig. 4. 36 simulated scenarios and PW results.

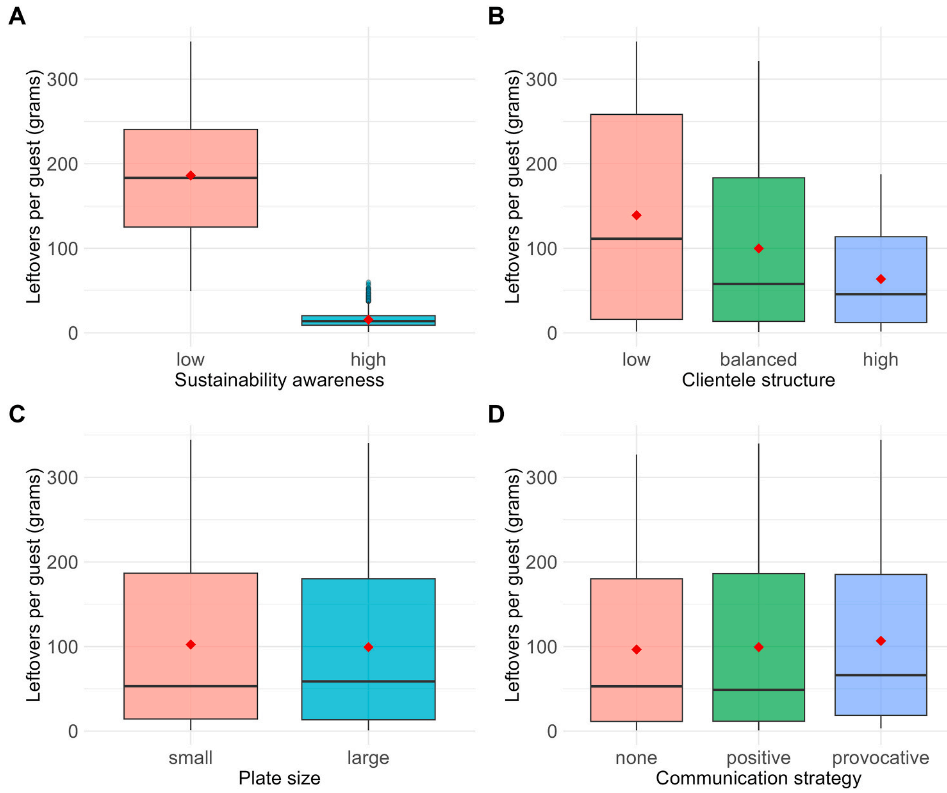

Fig. 5 A-D. Effects of key scenario parameters on simulated leftovers per guest. Panel (A) shows the influence of sustainability awareness, (B) the proportion of business guests, (C) plate size, and (D) communication strategy. Red dots indicate the mean value.

In all models, ϵ_i captures stochastic variability across simulation runs induced by the probabilistic structure of the ABM.

Robustness checks include re-estimations without interactions and regression diagnostics (Supplementary Material Sections 7-8). Fig. 3 shows the paths examined in Models 1-3.

Each model is accompanied by figures to visualize results. To facilitate interpretation, figures report results from models estimated with unstandardized variables, expressed in grams.

3. Results

3.1. Descriptive scenario results

Each scenario represents a specific configuration of key parameters, allowing assessment of their effects on guest behaviour and PW. Full parameter settings and mean PW per guest are reported in Table 2.

Across the 36 simulated scenarios, average PW ranged from 9.7 g to 277 g per guest per day.

Fig. 4 summarizes the simulation outcomes. Within the simulated ABM environment, scenarios with high sustainability awareness consistently fall among the lowest PW scenarios, suggesting that, within the ABM structure, awareness acts as a key driver of simulated outcomes.

To compare outcomes across scenarios, a Tukey HSD was applied to the simulated outputs to compare scenario-level differences. The resulting pairwise comparisons reflect variability across simulation runs rather than statistical inference on empirical data. The resulting heatmap is presented in *Supplementary Figure D*.

Fig. 5A–D presents boxplots grouping results by sustainability awareness, clientele structure, plate size, and communication strategy. Wider boxes reflect greater variability, indicating the factor's relative contribution to PW, while the red dots correspond to the mean value. Since the boxplots are based on 5400 simulations, the dispersion reflects both systematic variation due to other experimental factors and stochastic variation inherent in the ABM.

Scenarios with high sustainability awareness consistently produce lower simulated PW (Fig. 5A).

Scenarios with a low proportion of business show the highest mean PW and variability, whereas those with a high proportion have the lowest median PW (~50 g). Thus, within the simulated scenarios, a

Table 3
Portion model – Key standardized coefficients (with interactions).

Variable	Specification with interactions Estimate (SE)
Intercept	0.789 (0.047)***
Large plate	0.377 (0.045)***
High Sustainability Awareness	−0.178 (0.045)***
Clientele Structure Balanced	−0.407 (0.054)***
Clientele Structure High Business	−0.843 (0.056)***
Positive Message	−0.761 (0.056)***
Provocative Message	−1.832 (0.057)***
Large plate x High Sustainability Awareness	0.122 (0.043)**
Large plate x Clientele Structure Balanced	−0.358 (0.054)***
Large plate x Clientele Structure High Business	−0.919 (0.053)***
Clientele Structure Balanced x Positive Message	0.808 (0.066)***
Clientele Structure High Business x Positive Message	1.649 (0.069)***
Clientele Structure Balanced x Provocative Message	0.754 (0.069)***
Clientele Structure High Business x Provocative Message	1.747 (0.067)***
Adjusted R^2	0.38

Note: Only significant coefficients (p < 0.1) shown. Full specification in Supplementary Table D.
Significance codes: *'.' p < 1; '*'p < .05; '**'p < .01; '***'p < .001*
Standardized coefficients (mean = 0, SD = 1). SD (original scale): Mean portion size = 8.89 g. To convert effects to grams, multiply coefficients by the SD of the dependent variable.

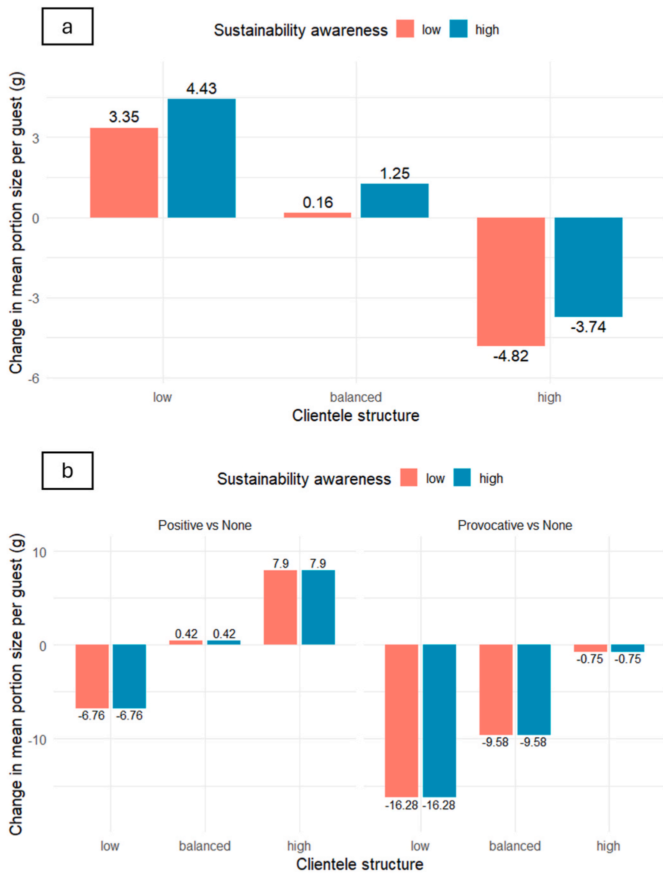

Fig. 6. Increment in mean portion size per guest changing a) small → large plate size; b) no message → positive/provocative message
Note: The figure display results from models estimated with unstandardized variables to allow interpretation in grams.

stronger business presence corresponds to lower simulated waste within the ABM, reflecting the behavioural rules encoded in the ABM (Fig. 5B).

Fig. 5C compares average PW per person across simulations featuring either small or large plate sizes. The boxplots for both sizes are almost identical, suggesting that, under the current model assumptions, plate size alone does not substantially alter simulated PW outcomes.

Provocative messages lead to slightly higher PW than either positive or no messages (Fig. 5D).

3.2. Regression analysis

The following regression analyses are applied exclusively to simulated outputs generated by the ABM and are used to structure and quantify model-internal relationships, thus they do not represent empirical inference.

3.2.1. Portion model - determinants of first portion decisions

Table 3 presents standardized coefficients for the Portion model, with small plates, low sustainability awareness, low business share, and no message as baseline.

In the specification without interaction terms (*Supplementary Table D*), plate size and sustainability awareness are not significantly associated with differences in initial portions. In contrast, a higher share of business guests and the presence of provocative messages are associated with smaller simulated portions.

Including interactions plate size, messages, and population variables improves model fit (Adjusted $R^2 = 0.38$). Fig. 6a illustrates how the same intervention (changing plate size) can produce opposite behavioural responses within the ABM depending on clientele structure,

Table 4
Refill model – Key standardized coefficients (with interactions).

Variable	Specification with interactions
	Estimate (SE)
Intercept	0.613 (0.019)***
Large plate	−0.920 (0.024)***
High Sustainability Awareness	−1.085 (0.018)***
Clientele Structure Balanced	−0.298 (0.024)***
Clientele Structure High Business	−0.814 (0.023)***
Positive Message	0.683 (0.025)***
Provocative Message	1.320 (0.032)***
Mean Portion Size	0.014 (0.008).
Large plate × Clientele Structure High Business	0.510 (0.030)***
Clientele Structure Balanced × Positive Message	−0.327 (0.032)***
Clientele Structure High Business × Positive Message	−0.476 (0.032)***
Clientele Structure Balanced × Provocative Message	−0.225 (0.041)***
Clientele Structure High Business × Provocative Message	−0.257 (0.038)***
High Sustainability Awareness x Positive Message	0.192 (0.024)***
High Sustainability Awareness x Provocative Message	0.612 (0.031)***
Adjusted R^2	0.79

Note: Only significant coefficients ($p < 0.1$) shown. Full specification in Supplementary Table E.
Significance codes: '.' $p < 1$; '*'$p < .05$; '**'$p < .01$; '***'$p < .001$
Standardized coefficients (mean = 0, SD = 1). SD (original scale): Mean extra servings = 0.45.

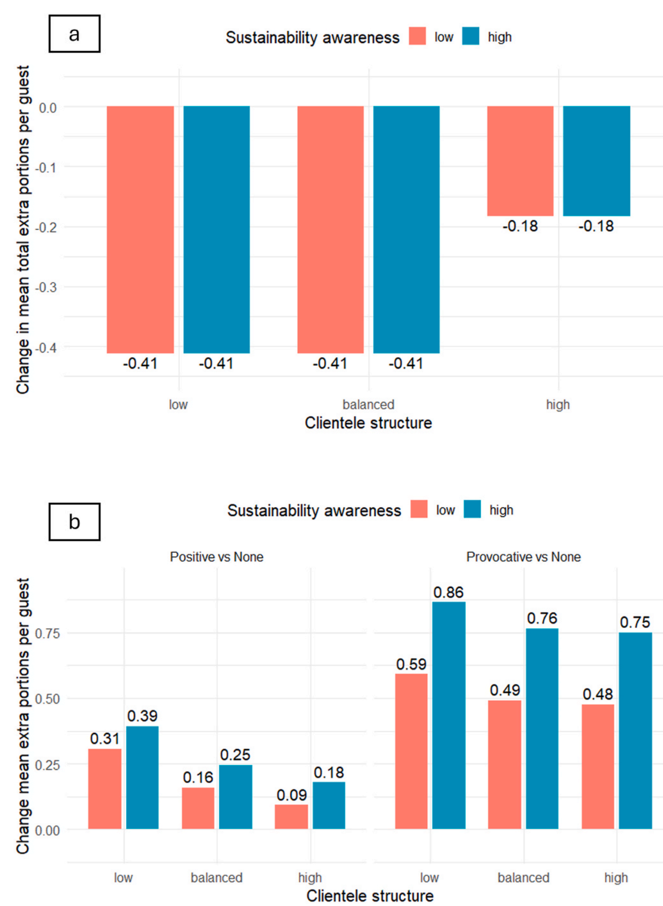

Fig. 7. Increment in mean extra portion per guest changing a) small → large plate size; b) no message → positive/provocative message
Note: The figure display results from models estimated with unstandardized variables to allow interpretation in grams.

highlighting the context-dependent nature of portioning decisions in the model. Both message types are associated with smaller portions among leisure guests. As shown in Fig. 6b, positive messages may produce a backfire effect in settings with a higher business clientele structure, where they are associated with larger portions rather than reductions in serving size. Sustainability awareness shows only a small direct negative effect. In summary, within the ABM simulations, business guests show more controlled portioning behaviour within the simulations, generating smaller initial servings across conditions. Provocative messages are associated with smaller portions, while positive messages and plate size interventions show effects that strongly depend on clientele structure.

3.2.2. Refill model – determinants of extra serving decisions

The Refill model examines the simulated mean number of extra portions taken (Table 4). The initial portion size was included in this model as a result of a correlation analysis (Supplementary material Section 6). In the specification without interactions (*Supplementary Table E*), larger initial portions are associated with a lower probability of refilling. Holding portion size fixed, large plates ($\beta = -0.718$, $p < 0.001$), high sustainability awareness ($\beta = -0.801$, $p < 0.001$), and business-dominant settings ($\beta = -0.812$, $p < 0.001$) correspond to fewer simulated extra servings. In contrast, both message types are associated with higher refill frequencies.

When interaction terms are added, the reducing main effect of large plates strengthens, but weakens in business-dominated contexts (Fig. 7a), suggesting that within the ABM business guests are less sensitive to plate size cues. Communication effects also vary by guest shares: both message types correspond to higher refilling among leisure guests, but less so among business ones (Fig. 7b). Fig. 7b highlights a compensatory behavioural pattern: messages, that are associated with smaller initial portions (as shown in Fig. 6b), are also associated with higher refilling, illustrating a compensatory behavioural mechanism across decision stages.

Without messages, high awareness guests tend to take fewer extra servings, but both message types are associated with higher levels of refilling, consistent with a messaging-related reactance mechanism embedded in the model.

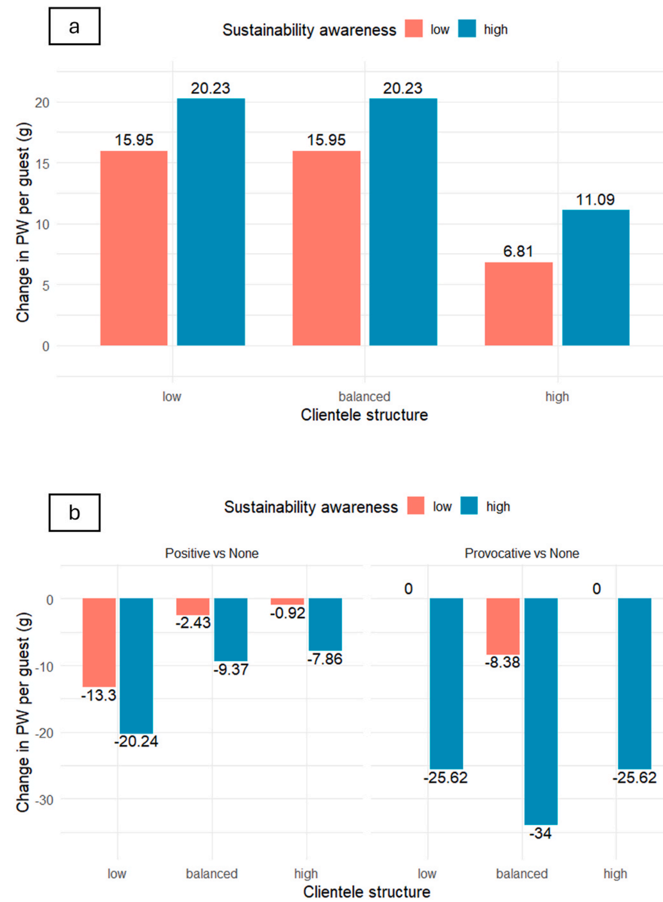

Fig. 8. Increment in mean PW per guest changing a) small → large plate size; b) no message → positive/provocative message

Note: The figure display results from models estimated with unstandardized variables to allow interpretation in grams.

In the simulated decision environment of the ABM, refilling behaviours decrease with large plates, higher awareness, and a higher business share, but increase under message interventions, particularly among leisure-oriented audiences.

Table 5
Mediated Leftovers model – Key standardized coefficients (with interactions).

Variable	Specification with interactions Estimate (SE)
Intercept	1.067 (0.022)***
Mean Portion Size	0.065 (0.006)***
Mean Extra Servings	0.230 (0.012)***
Large plate	0.164 (0.024)***
High Sustainability Awareness	−1.456 (0.020)***
Clientele Structure Balanced	−0.318 (0.020)***
Clientele Structure High Business	−0.610 (0.025)***
Positive Message	−0.137 (0.028)***
Mean Portion Size × Mean Extra Servings	0.105 (0.007)***
Large Plate × High Sustainability Awareness	0.044 (0.018)*
Large Plate × Clientele Structure High Business	−0.094 (0.027)***
Clientele Structure Balanced × Positive Message	0.112 (0.026)***
Clientele Structure High Business × Positive Message	0.128 (0.032)***
Clientele Structure Balanced × Provocative Message	−0.086 (0.026)***
Clientele Structure High Business × Provocative Message	−0.055 (0.033).
High Sustainability Awareness × Positive Message	−0.072 (0.021)***
High Sustainability Awareness × Provocative Message	−0.264 (0.024)***
Adjusted R^2	0.89

Note: Only significant coefficients ($p < 0.1$) shown. Full specification in Supplementary Table F.
Significance codes: '.' p < 1; '*'p < .05; '**'p < .01; '***'p < .001
Standardized coefficients (mean = 0, SD = 1). SD (original scale): Mean leftovers = 97.05 g.

3.2.3. Mediated Leftovers model – determinants of mean leftovers

The Mediated Leftovers model (Table 5) explores the drivers of simulated guests' wasting behaviour, including portioning and refilling variables. It shows the highest explanatory power among all models.

In the simulated outputs, larger first portions and extra servings correspond to higher levels of PW.

Within the ABM simulations, high sustainability awareness and business-oriented settings are associated with lower simulated PW, while large plates slightly increase it. Message effects are modest, but become more meaningful when interactions are considered. Fig. 8a illustrates how sustainability awareness moderates the relationship between plate size and PW, indicating that the same intervention may produce different outcomes depending on guests' sustainability profiles. As shown in Fig. 8b, sustainability awareness also conditions the effectiveness of communication messages, suggesting that behavioural interventions may be more effective among sustainability-aware guests. This highlights that intervention effects are not only direct, but also depend on how behavioural traits shape decisions across the portioning-refilling-leftovers pathway.

Taken together, Figs. 6–8 illustrate that plate waste emerges from interacting behavioural decisions rather than isolated effects, with compensatory dynamics across portioning and refilling stages shaping

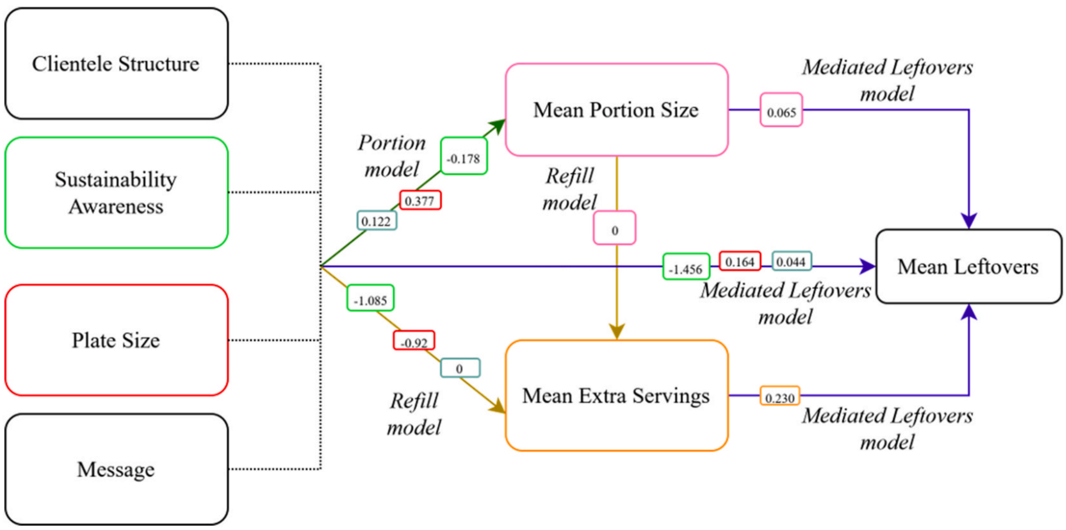

Fig. 9. Pathway of the three regression models and example coefficients for plate size (red), sustainability awareness (light green), their interaction (dark green), mean portion size (pink) and mean extra servings (orange) across models, illustrating their indirect and total effects on PW.

Table 6
Total-effect Leftovers model - Key standardized coefficients.

Variable	Estimate (SE)
Intercept	1.226 (0.022)***
Large Plate	−0.047 (0.026).
High Sustainability Awareness	−1.739 (0.020)***
Clientele Structure Balanced	−0.384 (0.020)***
Clientele Structure High Business	−0.769 (0.025)***
Provocative Message	0.161 (0.033)***
Large Plate × High Sustainability Awareness	0.034 (0.018).
High Sustainability Awareness × Positive Message	−0.056 (0.020)**
High Sustainability Awareness × Provocative Message	−0.047 (0.024).
Adjusted R^2	0.88

Note: Only significant coefficients ($p < 0.1$) shown. Full specification in Supplementary Table G.
Significance codes: '.' $p < 1$; '*'p < .05; '**'p < .01; '***'p < .001
Standardized coefficients (mean = 0, SD = 1). SD (original scale): Mean leftovers = 97.05 g.

final outcomes.

3.2.4. Total-effect leftovers model – combined direct and indirect effects

The previous models decompose the pathways through which the experimental manipulations influence PW in the ABM, identifying how portioning and extra servings mediate these effects. Fig. 9 exemplifies this by including the previous models' coefficients for plate size and sustainability awareness.

The Total-effect Leftovers model (Table 6) estimates total effects of all manipulations on PW, excluding mediating variables.

Within the simulation outputs, high sustainability awareness shows the largest overall association with lower PW across simulated scenarios, close to two standard deviations of the dependent variable, followed by clientele structure. In the ABM-generated data, provocative messages are associated with higher simulated PW, while positive messages are associated with lower PW only when guests have a high level of sustainability awareness. Plate size effects are small and only marginally significant.

4. Discussion

This study, within a simulation environment, examined how individual characteristics (sustainability awareness, social identity), external factors (plate size, message framing), and portioning behaviours interact to shape PW in hotel breakfast buffets using a validated ABM. By linking simulated behavioural data with regression analyses, the study advances a theoretical and simulation-based understanding of behavioural pathways in buffet systems, complementing but not substituting empirical research on FW interventions in hospitality. The contribution lies in identifying how micro-level behavioural rules generate macro-level patterns under controlled simulated conditions, rather than estimating real-world effects. Our findings highlight not only statistical associations but the behavioural mechanisms encoded in the ABM, showing how interventions act on specific steps of the portioning–refilling–leftovers pathway. Fig. 10 summarizes the results of the four behavioural-pathway regression model, exemplifying how the simulated interventions generate compensatory dynamics within the ABM.

Within the ABM framework, sustainability awareness and clientele structure emerge as the strongest simulated predictors. Guests with higher sustainability awareness and in more business-oriented settings tend to serve smaller portions, take fewer refills, and generate less PW. Conversely, leisure-oriented scenarios with low sustainability awareness show less restrained portioning and higher waste outcomes. In the ABM, waste emerges from a sequence of interconnected choices rather than a single conscious decision. This aligns with the MOA framework (van Geffen et al., 2020) which conceptualises FW as the unintended outcome of iterative decisions shaped by internal drivers and external conditions.

For plate size (RQ1), the simulations indicate a multistep effect. Consistent with previous findings (Wansink and van Ittersum, 2013), larger plates induce larger initial portions because they shift the visual norms of appropriate portion upwards. This happens especially for leisure guests. Conversely, business guests partially resist the visual cue, reflecting the ABM assumption of stronger self-regulation. Larger plates reduce refills, suggesting that guests perceive their initial portion as sufficient. However, the higher overall quantity taken leads to more PW when portion size and refills are considered. When direct and indirect effects are combined (Total-effect Leftovers model), the net impact becomes small. This highlights a compensatory behavioural mechanism: interventions that reduce one waste-related behaviour (e.g., refills) may simultaneously increase another (e.g., initial portion size), ultimately limiting the net effect on PW.

Compared with earlier ABM studies that primarily focused on plate size in isolation (Ravandi and Jovanovic, 2019), our results highlight the importance of modelling multiple interacting psychological, behavioural, and contextual drivers. Rather than directly reducing waste, plate size interventions in this ABM primarily shape how and when food

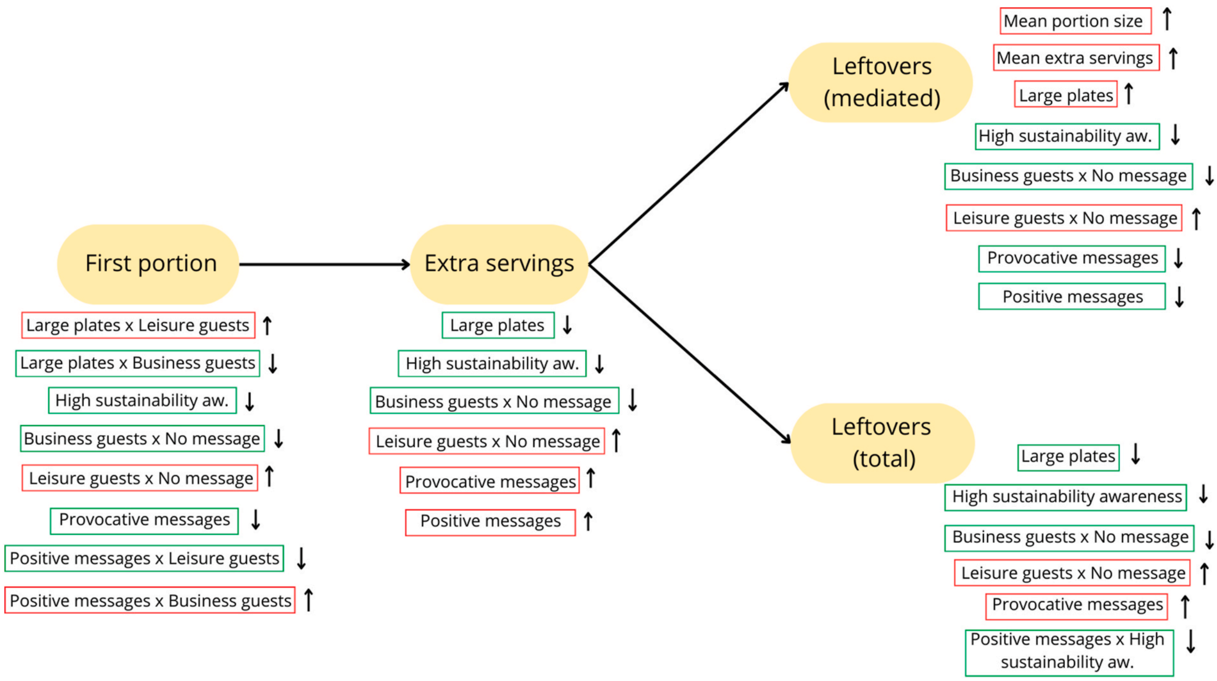

Fig. 10. Overview of how experimental variables influence portioning, refilling, and PW outcomes.

is taken, with downstream effects that depend on clientele structure and implemented interventions. This broader modelling perspective helps explain why apparently effective nudges may fail to produce substantial waste reductions once behavioural pathways and compensatory dynamics are taken into account.

Communication messages (RQ3) show context-dependent effects. In the simulations, provocative messages initially reduce first servings but later increase refilling and total waste. This pattern illustrates a form of psychological reactance embedded in the ABM and aligns with theoretical expectations (Brehm and Brehm, 1981). Positive messages, in contrast, show modest direct effects. Positive framing reduces PW primarily under conditions of high sustainability awareness and balanced guest mixes. This indicates that the effectiveness of communication interventions depends strongly on the sustainability profile of the guest population.

Sustainability awareness (RQ4) and clientele structure (RQ2) are the most robust predictors of responsible behaviour in the ABM. While the negative association between sustainability awareness and PW is theoretically expected (Visschers et al., 2016; Stancu et al., 2016), the simulations highlight how awareness interacts with other behavioural drivers. Higher sustainability awareness directly and indirectly reduces waste in the model, but more importantly it moderates how agents respond to behavioural interventions. In particular, sustainability-aware agents show greater compliance with positive messages and are less prone to compensatory behaviours along the portioning–refilling pathway. Business guests waste less, an outcome that follows from the ABM's assumptions regarding efficiency norms and time constraints (Puga-Gonzalez et al., 2025). Looking at the behavioural pathway, higher self-control and conformity lead them to choose smaller initial portions and take fewer refills. Limited time further discourages large servings, since time pressure forces more goal-directed decisions. Overall, the lower PW observed among business guests reflects not a single causal factor but the interaction of social norms (conformism), individual capacities (self-control), and contextual constraints (time pressure), all of which reduce portion sizes and increase the likelihood of finishing served food.

Portioning behaviour (RQ5) acts as a key mediator. The relationships observed in the ABM between portion size, refills, and leftovers mirror those reported in canteen and restaurant studies (Berkowitz et al., 2016; Lorenz-Walther et al., 2019) but our modelling approach shows how these behaviours are sequentially linked. Synthesizing results from the first three models allows tracing how interventions influence behaviour at different stages, while the Total-effect Leftovers model quantifies their overall impact. Comparing the models clarifies how direct and mediated effects differ: some interventions (e.g., provocative messaging) appear effective at early stages but increase final waste once downstream behaviours are considered.

These results can be interpreted through a micro–meso–macro perspective. At the micro level, the ABM represents individual behavioural decisions in the consumption pathway (i.e., how much guests serve themselves, whether they return for refills, and whether they leave PW). At the meso level, these behaviours unfold in contextual conditions such as clientele structure, plate size, and the messaging strategy, which influence how individuals interpret nudges and constraints. At the macro level, aggregate PW emerges from the interplay of these micro decisions under specific meso conditions. The ABM and the scenario analysis link these levels: micro choices drive portion size and refills; meso factors shape decision-making; macro PW emerges from their interaction across scenarios.

A key insight is the presence of behavioural compensation: interventions that reduce one PW-related behaviour (e.g., refills) simultaneously increase another (e.g., initial portions), leading to unimportant net effects. This mechanism explains why certain nudges appear promising in isolation but fail to reduce waste in aggregate. These compensatory patterns emerge from the interaction of multiple decision rules rather than from any single model assumption, suggesting that similar dynamics may arise in real-world settings.

The model suggests that effective nudges require an integrated view of how motives, opportunities, and abilities interact over time. Plate size adjustments alone are unlikely to achieve results if not paired with other cues that influence subsequent behaviour. Communication strategies should consider tone and audience: positive, value-consistent messages engage sustainability-oriented guests, while moralizing messages may backfire.

4.1. Limitations and future work

Some limitations must be acknowledged. First, results rely on simulation data calibrated through aggregated empirical observations. Many behavioural parameters (e.g., reactance thresholds, sensitivity to messages) are not empirically calibrated at the individual level. Outcomes partially depend on these assumptions, and future research should incorporate individual-level empirical data to calibrate the ABM. Second, the ABM focuses on PW and excludes hotel-level operational processes, such as overproduction or buffet management practices. Integrating these operational dynamics would provide a more comprehensive view of hospitality FW.

Third, while distinguishing between business and leisure guests captures important differences, empirical evidence on how these groups differ in food-related decision-making remains scarce. Field data capturing variations in motivation and time use could improve our modelling assumptions. Additionally, other sources of heterogeneity, such as age groups, dietary preferences, and cultural differences, were not included in the ABM to maintain parsimony. Their inclusion represents potential for future work.

Fourth, the 36 scenarios explored are a selection of combinations of factors, not covering, for example, the continuous variation of sustainability awareness or alternative message framings. More extensive scenario simulation could display additional results.

Finally, as presented by Puga-Gonzalez et al. (2025), calibration data were collected in a single country, potentially limiting the generalizability of results to other cultural or regional contexts.

This work addresses conceptual and methodological issues noted by Puga-Gonzalez et al. (2025). Nevertheless, future research should continue combining empirical observation, cross-cultural data, and advanced simulation techniques to enhance external validity and theoretical integration.

5. Conclusions

This study investigated, within a simulation framework, how individual characteristics, contextual factors, and portioning behaviours interact to shape PW in hotel breakfast buffets, based exclusively on outputs generated by an agent-based model. We analysed these simulated outputs through four interconnected regression analyses, used as metamodels to formally summarize and decompose behavioural pathways encoded in the model. Results show that, within the ABM, PW does not derive from a single decision, but emerges from a chain of interconnected behavioural steps. These conclusions reflect patterns generated within the ABM structure and are intended to inform theoretical reasoning about behavioural interactions and compensatory mechanisms, rather than provide empirical estimates.

The primary contribution of the study is to demonstrate how behavioural pathways and compensatory dynamics emerge from the interaction of multiple drivers within a simulation framework. Within the ABM simulations, sustainability awareness and clientele structure act as structural background conditions that shape how behavioural interventions unfold. In particular, awareness moderates the effectiveness of communication strategies and influences how guests respond across the portioning–refilling pathway. Communication strategies' effectiveness is context-dependent: positive messages support conscious behaviour under the simulated conditions, while provocative messages can backfire and lead to choices that increase waste. Plate size influences when and how guests serve food, but larger plates are connected to compensatory mechanisms that reduce their overall simulated impact.

The research extends the Establishment Diner agent-based framework (Puga-Gonzalez et al., 2025), by using it as a virtual experimentation platform to explore behavioural mechanisms that are difficult to isolate empirically. The scenario-based approach highlights interactions and compensatory pathways that may remain hidden in real-world field settings due to observational constraints. By connecting micro-level decision rules with macro-level aggregate outcomes, the ABM illustrates how interventions modify behavioural pathways within a controlled simulation environment. Practically, these simulation-based findings provide indications that plate size alone may be insufficient, that messaging should be aligned with guest profiles, and that increasing sustainability awareness emerges as a robust lever within the ABM structure.

Thanks to its structure, the Establishment Diner ABM can support future exploration of operational, behavioural, and communication strategies in different hospitality contexts. Future work should integrate individual empirical data and hotel operational dynamics to guide the design of more robust, evidence-based interventions for sustainable hospitality management.

Declaration of generative AI

During the preparation of this work, the authors used ChatGPT to improve the readability of the text. After using this tool, the authors carefully reviewed and edited the text generated and take full responsibility for the content of the manuscript.

Funding

This research was undertaken within the CHORIZO (Changing practices and Habits through Open, Responsible, and social Innovation towards ZerO food waste) project, funded by the European Union (EU)'s Horizon research and innovation programme under Grant Agreement No 101060014 (http://chorizoproject.eu). The content of this article does not reflect the official opinion of the European Union. Responsibility for the information and views expressed therein lies entirely with the authors.

CRediT authorship contribution statement

Caterina Rettore: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Larissa L. Lima:** Conceptualization, Data curation, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Ivan Puga-Gonzalez:** Conceptualization, Investigation, Methodology, Software, Writing – review & editing. **Filippo Pini:** Conceptualization, Investigation, Methodology, Visualization, Writing – review & editing. **Paulina Szwed:** Conceptualization, Investigation, Writing – review & editing. **Patrycja Antosz:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Writing – review & editing. **Matteo Vittuari:** Conceptualization, Funding acquisition, Methodology, Project administration, Writing – review & editing.

Declaration of competing interest

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

Acknowledgements

The authors also wish to thank Markus G. Rousseau at the Center for Modeling Social Systems – NORCE (Kristiansand, Norway) for his valuable contribution to the conceptual discussion.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clrc.2026.100435.

Data availability

Data will be made available on request.

References

Alonso Miquélez, I., Ávila, C., Alcat, G., Coopmans, I., Forbang Echo, C., Twarogowska, A., et al., 2024. D2.3 Empirical Evidence Sensemaking.

Berkowitz, S., Marquart, L., Mykerezi, E., Degeneffe, D., Reicks, M., 2016. Reduced-portion entrées in a worksite and restaurant setting: impact on food consumption and waste. Public Health Nutr. 19 (16), 3048–3054. https://doi.org/10.1017/S1368980016001348. PubMed PMID: 27256403.

Bonabeau, E., 2002. Agent-based modeling: methods and techniques for simulating human systems. Proc. Natl. Acad. Sci. 99 (Suppl. l_3), 7280–7287. https://doi.org/10.1073/PNAS.082080899. PubMed PMID: 12011407.

Boukamcha, F., 2016. Situational and personality effects on smokers' psychological reactance. Int. J. Pharmaceut. Healthc. Market. 10 (4), 432–448. https://doi.org/10.1108/IJPHM-10-2015-0052.

Boz, Z., Kiker, G.A., Haase, H., Orr, R., Vignesh, A., Campbell, C., et al., 2024. Modeling Waste: an Agent-based Model to Support the Measurement of Household Food Waste. https://doi.org/10.2139/SSRN.5017237.

Brehm, J.W., Brehm, S.S., 1981. Psychological Reactance – a Theory of Freedom and Control. Academic Press, New York.

Chawla, G., Lugosi, P., Hawkins, R., 2021. Food waste drivers in corporate luxury hotels: competing perceptions and priorities across the service cycle. Tour. Hospit. 2 (3), 302–318. https://doi.org/10.3390/TOURHOSP2030019.

Chen, H.S., Jai, T.M. (Catherine), 2018. Waste less, enjoy more: forming a messaging campaign and reducing food waste in restaurants. J. Qual. Assur. Hospit. Tourism 19 (4), 495–520. https://doi.org/10.1080/1528008X.2018.1483282.

Cialdini, R.B., Goldstein, N.J., 2004. Social influence: compliance and conformity. Annu. Rev. Psychol. 55 (1), 591–621. https://doi.org/10.1146/annurev.psych.55.090902.142015.

Cohen, J.F.W., Jahn, J.L., Richardson, S., Cluggish, S.A., Parker, E., Rimm, E.B., 2016. Amount of time to eat lunch is associated with children's selection and consumption of school meal entrée, fruits, vegetables, and milk. J. Acad. Nutr. Diet. 116 (1), 123–128. https://doi.org/10.1016/J.JAND.2015.07.019. PubMed PMID: 26372337.

Cozzio, C., Tokarchuk, O., Maurer, O., 2021. Minimising plate waste at hotel breakfast buffets: an experimental approach through persuasive messages. Br. Food J. 123 (9), 3208–3227. https://doi.org/10.1108/BFJ-02-2021-0114.

Dhir, A., Talwar, S., Kaur, P., Malibari, A., 2020. Food waste in hospitality and food services: a systematic literature review and framework development approach. J. Clean. Prod. 270, 122861.

Ellemers, N., De Gilder, D., Haslam, S.A., 2004. Motivating individuals and groups at work: a social identity perspective on leadership and group performance. Acad. Manag. Rev. 29 (3), 459. https://doi.org/10.2307/20159054.

EUROSTAT, 2025. Household consumption by purpose [cited 2025 Dec 1]. Available from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Household_consumption_by_purpose#Data_sources.

Filimonau, V., Todorova, E., Mzembe, A., Sauer, L., Yankholmes, A., 2020. A comparative study of food waste management in full service restaurants of the United Kingdom and the Netherlands. J. Clean. Prod. 258, 120775. https://doi.org/10.1016/J.JCLEPRO.2020.120775.

Freedman, M.R., Brochado, C., 2010. Reducing portion size reduces food intake and plate waste. Obesity 18 (9), 1864–1866. https://doi.org/10.1038/OBY.2009.480. PubMed PMID: 20035274.

Guimarães, N.S., Reis, M.G., Júnior, FE. de M., Fontes, L., de, A., Raposo, A., Saraiva, A., et al., 2024. From plate to planet: a systematic review and meta-analysis on strategies to reduce plate food waste at food services. Sustainability (Switzerland) 16 (20), 9099. https://doi.org/10.3390/SU16209099/S1.

Heikkilä, L., Reinikainen, A., Katajajuuri, J.M., Silvennoinen, K., Hartikainen, H., 2016. Elements affecting food waste in the food service sector. Waste Manag. 56, 446–453.

Jager, W., Antosz, P., Bouman, L., Li, T., Gareth Polhill, J., Szczepanska, T., et al., 2025. HUMAT: an integrated framework for modelling individual motivations. Soc. Exchange Network Dynam. 28 (1), 2025. https://doi.org/10.18564/JASSS.5611, 4.

Juvan, E., Grün, B., Dolnicar, S., 2018. Biting off more than they can chew: food waste at hotel breakfast buffets. J. Trav. Res. 57 (2), 232–242.

Juvan, E., Grün, B., Zabukovec Baruca, P., Dolnicar, S., 2021. Drivers of plate waste at buffets: a comprehensive conceptual model based on observational data and staff insights. Ann. Tour. Res. Empirical Insights 2 (1), 100010. https://doi.org/10.1016/J.ANNALE.2021.100010.

Kallbekken, S., Sælen, H., 2013. 'Nudging' hotel guests to reduce food waste as a win–win environmental measure. Econ. Lett. 119 (3), 325–327. https://doi.org/10.1016/J.ECONLET.2013.03.019.

Kandemir, C., Reynolds, C., Verma, M., Grainger, M., Stewart, G., Righi, S., et al., 2020. Modelling approaches to food waste : discrete event simulation; machine learning; Bayesian networks; agent-based modelling; and mass balance estimation. Routledge Handbk.Food Waste 326–344. https://doi.org/10.4324/9780429462795-25.

Kasavan, S., Mohamed, A.F., Abdul Halim, S., 2019. Drivers of food waste generation: case study of island-based hotels in Langkawi, Malaysia. Waste Manag. 91, 72–79. https://doi.org/10.1016/J.WASMAN.2019.04.055. PubMed PMID: 31203944.

Kavvouris, C., Chrysochou, P., Thøgersen, J., 2020. "Be careful what you say": the role of psychological reactance on the impact of pro-environmental normative appeals. J. Bus. Res. 113, 257–265. https://doi.org/10.1016/J.JBUSRES.2019.10.018.

Li, Z., Shi, J., 2025. Message effects on psychological reactance: meta-analyses. Hum. Commun. Res. https://doi.org/10.1093/HCR/HQAF016.

Liu, T., Juvan, E., Qiu, H., Dolnicar, S., 2022. Context-and culture-dependent behaviors for the greater good: a comparative analysis of plate waste generation. J. Sustain. Tourism 30 (6), 1200–1218.

Lorenz-Walther, B.A., Langen, N., Göbel, C., Engelmann, T., Bienge, K., Speck, M., et al., 2019. What makes people leave LESS food? Testing effects of smaller portions and information in a behavioral model. Appetite 139, 127–144. https://doi.org/10.1016/J.APPET.2019.03.026. PubMed PMID: 30959084.

Macal, C.M., North, M.J., 2010. Toward teaching agent-based simulation. Proceedings - Winter Simulation Conference, pp. 268–277. https://doi.org/10.1109/WSC.2010.5679158.

MacInnis, D.J., Moorman, C., Jaworski, B.J., 1991. Enhancing and measuring consumers' motivation, opportunity, and ability to process brand information from ads. J. Market. 55 (4), 32. https://doi.org/10.2307/1251955.

McAdams, B., von Massow, M., Gallant, M., Hayhoe, M.A., 2019. A cross industry evaluation of food waste in restaurants. J. Foodserv. Bus. Res. 22 (5), 449–466. https://doi.org/10.1080/15378020.2019.1637220.

Middleton, J., Buboltz, W., Sopon, B., 2015. The relationship between psychological reactance and emotional intelligence. Soc. Sci. J. 52 (4), 542–549. https://doi.org/10.1016/j.soscij.2015.08.002.

Muposhi, A., Musavengane, R., 2023. Influencing hotel guests' food waste reduction intentions through social marketing and corporate social responsibility stimuli. Afr. J. Hosp. Tour. Leis. 12 (2), 783–797. https://doi.org/10.46222/AJHTL.19770720.399.

Murre, J.M.J., Dros, J., 2015. Replication and analysis of ebbinghaus' forgetting curve. PLoS One 10 (7), e0120644. https://doi.org/10.1371/JOURNAL.PONE.0120644. PubMed PMID: 26148023.

Nisa, C.F., Bélanger, J.J., Scumpe, B.M., 2022. Assessing the effectiveness of food waste messaging. Environ. Sci. Pol. 132, 224–236. https://doi.org/10.1016/J.ENVSCI.2022.02.020.

Okumus, B., Taheri, B., Giritlioglu, I., Gannon, M.J., 2020. Tackling food waste in all-inclusive resort hotels. Int. J. Hospit. Manag. 88, 102543.

Oliveira, B., de Moura, A.P., Cunha, L.M., 2016. Reducing food waste in the food service sector as a way to promote public health and environmental sustainability. In: Climate Change and Health: Improving Resilience and Reducing Risks. Springer, pp. 117–132.

Papargyropoulou, E., Steinberger, J.K., Wright, N., Lozano, R., Padfield, R., Ujang, Z., 2019. Patterns and causes of food waste in the hospitality and food service sector: food waste prevention insights from Malaysia. Sustainability 11 (21), 6016. https://doi.org/10.3390/SU11216016.

Papargyropoulou, E., Wright, N., Lozano, R., Steinberger, J., Padfield, R., Ujang, Z., 2016. Conceptual framework for the study of food waste generation and prevention in the hospitality sector. Waste Manag. 49, 326–336.

Price, J., Just, D.R., 2015. Lunch, recess and nutrition: responding to time incentives in the cafeteria. Prev Med (Baltim) 71, 27–30. https://doi.org/10.1016/J.YPMED.2014.11.016. PubMed PMID: 25459372.

Puga-Gonzalez, I., Lima, L.L., Antosz, P., Carrella, E., Iori, E., Rettore, C., et al., 2025. To eat or not to eat: modeling food waste behavior at a hotel breakfast buffet. Clean. Responsib. Consum. 19, 100333. https://doi.org/10.1016/J.CLRC.2025.100333.

Ravandi, B., Jovanovic, N., 2019. Impact of plate size on food waste: agent-based simulation of food consumption. Resour. Conserv. Recycl. 149, 550–565. https://doi.org/10.1016/J.RESCONREC.2019.05.033.

Rimal, R.N., Real, K., 2005. How behaviors are influenced by perceived norms. Commun. Res. 32 (3), 389–414. https://doi.org/10.1177/0093650205275385.

Shen, L., 2015. Antecedents to psychological reactance: the impact of threat, message frame, and choice. Health Commun. 30 (10), 975–985. https://doi.org/10.1080/10410236.2014.910882.

Skeldon, A.C., Schiller, F., Yang, A., Balke-Visser, T., Penn, A., Gilbert, N., 2018. Agent-based modelling to predict policy outcomes: a food waste recycling example. Environ. Sci. Pol. 87, 85–91. https://doi.org/10.1016/J.ENVSCI.2018.05.011.

Sprengholz, P., Tannert, S., Betsch, C., 2023. Explaining boomerang effects in persuasive health communication: how psychological reactance to healthy eating messages elevates attention to unhealthy food. J. Health Commun. 28 (6), 384–390. https://doi.org/10.1080/10810730.2023.2217098. PubMed PMID: 37246897.

Stancu, V., Haugaard, P., Lähteenmäki, L., 2016. Determinants of consumer food waste behaviour: two routes to food waste. Appetite 96, 7–17. https://doi.org/10.1016/J.APPET.2015.08.025. PubMed PMID: 26299713.

Tajfel, H., Turner, J., 1979. An integrative theory of intergroup conflict. In: Austin, W.G., Worchel, S. (Eds.), The Social Psychology of Intergroup Relations. Brooks/Cole, Monterey, CA, pp. 33–47.

Tukey, J.W., 1949. Comparing individual means in the analysis of variance. Biometrics 5 (2), 99. https://doi.org/10.2307/3001913. PubMed PMID: 18151955.

UNEP, 2024. Think Eat save Tracking Progress to Halve Global Food Waste [Internet]. Nairobi. Report. Available from: https://www.unep.org/resources/publication/food-waste-index-report-2024.

Van, K., Wansink, I.B., Antic, B., Chang, L., He, S., Hsu, T., et al., 2011. Plate size and color suggestibility: the delboeuf illusion's bias on serving and eating behavior. J. Consum. Res. Inc • 39. https://doi.org/10.1086/662615.

van Geffen, L., van Herpen, E., Sijtsema, S., van Trijp, H., 2020. Food waste as the consequence of competing motivations, lack of opportunities, and insufficient abilities. Resour. Conserv. Recycl. 5, 100026. https://doi.org/10.1016/J.RCRX.2019.100026.

Visschers, V.H.M., Gundlach, D., Beretta, C., 2020. Smaller servings vs. information provision: results of two interventions to reduce plate waste in two university

canteens. Waste Manag. 103, 323–333. https://doi.org/10.1016/J.WASMAN.2019.12.046. PubMed PMID: 31918178.
Visschers, V.H.M., Wickli, N., Siegrist, M., 2016. Sorting out food waste behaviour: a survey on the motivators and barriers of self-reported amounts of food waste in households. J. Environ. Psychol. 45, 66–78. https://doi.org/10.1016/J.JENVP.2015.11.007.
von Massow, M., McAdams, B., 2015. Table scraps: an evaluation of plate waste in restaur ants. J. Foodserv. Bus. Res. 18 (5), 437–453.
Wansink, B., 2004. Environmental factors that increase the food intake and consumption volume of unknowing consumers. Annu. Rev. Nutr. 24, 455–479. https://doi.org/10.1146/ANNUREV.NUTR.24.012003.132140/CITE/REFWORKS. PubMed PMID: 15189128.
Wansink, B., van Ittersum, K., 2013. Portion size me: plate-size induced consumption norms and win-win solutions for reducing food intake and waste. J. Exp. Psychol. Appl. 19 (4), 320–332. https://doi.org/10.1037/a0035053.
Ward, N.J., Finley, K., Townsend, A., Scott, B.G., 2021. The effects of message threat on psychological reactance to traffic safety messaging. Transport. Res. F Traffic Psychol. Behav. 80, 250–259. https://doi.org/10.1016/J.TRF.2021.04.013.
Williams, H., Wikström, F., Otterbring, T., Löfgren, M., Gustafsson, A., 2012. Reasons for household food waste with special attention to packaging. J. Clean. Prod. 24, 141–148. https://doi.org/10.1016/J.JCLEPRO.2011.11.044.
Wu, C.M.E., Teng, C.C., 2022. Reducing food waste in buffet restaurants: a corporate management approach. Foods 12 (1), 162. https://doi.org/10.3390/FOODS12010162, 2023.
Yuan, S., Kuehl, C., 2023. Exploring the influence of aggressive and target-framing messages on proenvironmental behaviors. Sci. Commun. 45 (2), 225–251. https://doi.org/10.1177/10755470231153634.
Zeileis, A., Köll, S., Graham, N., 2020. Various versatile variances: an object-oriented implementation of clustered covariances in R. J. Stat. Software 95, 1–36. https://doi.org/10.18637/JSS.V095.I01.
Zhu, Q. (Jacqueline), Liu, P., 2025. Exploring factors influencing consumer behavior towards food waste reduction in buffet style restaurants. Br. Food J. 127 (3), 839–856. https://doi.org/10.1108/BFJ-06-2024-0592.