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# A new lens to the understanding and reduction of household food waste: A fuzzy cognitive map approach

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ABSTRACT

Food waste generated at the household level is known to be the main contributor to total food waste, particularly in developed regions. Reducing household food waste (HFW), however, is an extremely compelling task as there are many complex and interacting factors behind the HFW behavior. This study aims to address the factors behind the complexity by applying the Fuzzy Cognitive Map (FCM) method. FCM represents a new approach that enables the use of multiple resources, consideration of outnumbered factors, handling of linguistic ambiguities, and scenario analysis. Through FCM, this study aims to develop a more complete model of the complex HFW drivers' system and identify the most influential HFW drivers addressing which is key while designing HFW-reducing interventions. The current study employs a three-stage methodology that utilizes content analysis of scholarly published academic articles and exploits expert opinion to construct an FCM. In the final stage, through scenario analysis, the study tests and reports the effects of each HFW driver and evaluates them based on their potential to reduce HFW. The findings of this research reveal that system concepts *A12* (fail to consume what is in the fridge), *A2* (excessive purchasing), and *A9* (cooking and serving too much) are the most influential practices concerning HFW. While the study suggests innovative approaches that would enable people not to give up their normality to cope with *A12*, tackling *A9* requires challenging the normality, and addressing *A2* requires changing food store-related infrastructural elements. Moreover, the study draws attention to the concept *C2* (food safety and health concerns) due to its potential to be a disincentive to FW reduction efforts as well as to the concept *G1* (lack of knowledge/skill/awareness) which requires special attention to maximize its potential. Finally, the paper offers specific recommendations to practitioners and policymakers and provides future research directions.



## 1. Introduction

The issue of food waste (FW)[1] has recently received considerable attention. On the one hand, more food must be produced to feed the growing world population which is expected to reach 9 billion people by 2050 (Gobel et al., 2015: p.46), yet at the same time, 17 % of all food produced in the world is wasted (UNEP, 2021).[2] The inequity between food poverty and wasteful behaviors (Evans, 2012) creates both a moral dilemma (Papargyropoulou et al., 2014) and a burden on the environment as global food loss[3] and waste account for 8–10 % of total GHG emissions (Mbow et al., 2019). Therefore, FW reduction is essential to ensure sustainable food security and fight against the climate crisis (Foley et al., 2011; Jeswani et al., 2021). In this respect, the UN Sustainable Development Goal (SDG) Target 12.3 aims to halve per capita global food waste at retail and consumption levels (UN, n.d.).

Among the players involved in the food journey, households, particularly in developed regions, are the main contributor to the total amount of FW (Bravi et al., 2020; Jeswani et al., 2021). In Europe, households are responsible for more than half of the total FW (Stenmarck et al., 2016). In some countries, this ratio is even more drastic (e.g., 70 % in the UK (WRAP, 2020)). In addition, consumers can influence the whole food supply chain backward and cause food loss even in the initial stages

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[1] Food waste is '*food which was originally produced for human consumption but then was discarded or was not consumed by humans*' (Thyberg & Tonjes, 2016: p.112) and generated in the following sectors: retail, food service, households (UNEP, 2021: p.9).

[2] The most frequently used estimation of FAO (2011) stating that one-third of all food produced in the world is wasted constitutes both global food loss and food waste.

[3] Food loss is 'decrease in edible food mass throughout the part of the food supply chain (production, post-harvest, and processing) that would produce edible food for human consumption' (Thyberg & Tonjes, 2016: p.112).

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(Gobel et al., 2015). Therefore, reducing household food waste (HFW) is extremely crucial in reducing the total FW. However, as experts have noted, reducing FW at homes (i.e., at the consumption level), compared to the other stages of the food chain, is a more compelling task to accomplish (Woolley et al., 2022) as there are multifarious and interacting drivers behind the HFW behaviors (Schanes et al., 2018). Therefore, insights into ways of addressing those drivers to change HFW behaviors have become extremely critical for the HFW reduction efforts.

By applying the social practice theory (Schatzki, 1996; Warde, 2005), researchers have identified a substantial number of HFW drivers (Roodhuyzen et al., 2017). These drivers mainly constitute intertwined food-related routines (Reckwitz, 2002) (e.g., poor shopping planning, excessive purchasing, and stockpiling) that are persistent to change (Sahakian and Wilhite, 2014) and the essential elements (e.g., attitudes, preferences, concerns, materials, food/package/retail properties, socio-temporal factors, knowledge, and skills) whose grift structure form the nexus of these practices (Schatzki, 1996; Shove and Pantzar, 2005). The interaction of these wide-ranging drivers forms a multifaceted causal web generating different pathways that lead to HFW behavior (Roodhuyzen et al., 2017). To change the resultant wasteful behavior, intervention attempts/policies should be designed by i) identifying and targeting the most influential HFW driver(s), ii) addressing multiple drivers at the same time, and iii) accounting for the rebound effects (Evans et al., 2012; Sahakian and Wilhite, 2014).

To address these three points, we propose that the system formed by the HFW drivers should be demonstrated thoroughly with its entire complexity. Previous studies have failed to account for the complexities of the HFW system due to primarily methodological limitations. While some studies (e.g. Dobernig and Schanes, 2019; Farr-Wharton et al., 2014) have adopted qualitative methods (e.g., interview, participant observation, focus group, ethnography) and provided an in-depth understanding of interconnected relationships of multifaceted drivers, they have not quantified and prioritized their impact on HFW. Studies using quantitative methods (e.g., questionnaire, survey, experiment) have the potential to complement this gap by examining the relationships between drivers and HFW amount through statistical analysis (e.g., Giordano et al., 2019a; Van Dooren et al., 2019). However, by concentrating on a subset of factors, they have revealed the phenomenon partially (Roodhuyzen et al., 2017). Incompleteness might also stem from the abstract nature of factors that creates challenges in measurement or raises concerns regarding being parsimonious. In addition, the existing quantitative studies have revealed the influence of individual factors rather than their combined effect, and therefore, they have been unable to grab the rebound effects. Finally, the longitudinal approaches through which HFW amounts can be tracked regularly would be a highly reliable way to test the impact of an intervention. Nevertheless, they require building partner collaboration, and they are highly costly (Reynolds et al., 2019).

In that vein, Reynolds et al. (2019) have called for the need for greater integration of theory and previous research findings into the investigation by adopting different methodological techniques. The authors postulate "*would it, for instance, be possible to combine a qualitative account of social practices that generate food waste with quantitative tools that model the effects of different interventions*" (Reynolds et al., 2019: p.15). In addition, Roodhuyzen et al. (2017) argue that understanding the multifactorial and complex nature of HFW drivers is a prerequisite to observing the impact of an intervention. Similarly, Hebrok and Boks (2017) and Stockli et al. (2018) have called for finding new ways to test interventions. Responding to these calls would require utilizing tools that allow researchers to model a more complete representation of the complex HFW drivers' system and to test the effect of an intervention on this model. Fuzzy Cognitive Mapping (FCM) has several attractive features that enable us to address this need. With FCM, it is possible to use multiple resources, include outnumbering factors into the resultant model, deal with linguistic ambiguities, and consider all possible pathways to the outcome. Additionally, through the scenario analysis tool, it is possible to test the effect of each HFW driver and sort them by their impact to reduce HFW, therefore, identifying the most influential ones. Even though this paper particularly focuses on the identification of the most influential drivers, the proposed FCM will allow practitioners and researchers to conduct more nuanced scenario analysis by addressing multiple drivers as well as their rebound effects.

In summary, adopting the FCM approach, this paper aims to identify the most influential drivers of the HFW acknowledged in the literature. To this end, a three-stage methodology was designed. In the first stage, a content analysis of academic research papers focusing on the exploration of HFW drivers was conducted to identify the prevalent HFW drivers as system concepts and their causal relationships. Expert opinion was utilized for concept list consolidation and tuning. Through this stage, we were able to extract and integrate the HFW drivers-related information that was scattered and contextual and provide a well-refined framework. In the second stage, causal relationships between system concepts identified in the first stage were augmented and assessed to construct an FCM. This stage enabled us to resolve the disputes about the causal relationships. In the third stage, the FCM was utilized to test the effect of each concept on the system. Consequently, we obtained a prioritization among HFW drivers by their power of changing the HFW behavior, therefore, could uncover the most influential ones.

The paper is structured as follows. Section 2, the literature review, first discusses the complexities of the HFW drivers' system. Then, we briefly explain the social practice theory proposed to handle the complexity and how its key concepts were integrated into the research design. After a brief explanation of the FCM approach, we discuss how FCM can address the inherent complexities which justify the choice of the FCM method. Section 3, the methods, describes how the data was generated and analyzed through a three-stage methodology. Section 4 presents and discusses the findings of each stage as well as limitations and future research potentials. Finally, Section 5 concludes with the summary of findings and the theoretical and practical implications of the research.

## 2. Literature review

### 2.1. Complex nature of HFW drivers

We identified three basic complexity issues that inhibit the identification of the most influential HFW drivers.

i) HFW drivers are wide-ranging and high in number many of which are abstract
ii) Within a multifaceted causal web forming different pathways, the drivers may have multiple/interacting relationships with HFW behavior.
iii) Some of the drivers are distant from the disposing decision or action point which complicates the identification of their links to HFW behavior.

Complexity fundamentally emanates from a great number of wide-ranging and interacting drivers that are directly or indirectly affiliated with HFW. Through a systemic literature review, researchers have gathered previous research findings and came up with a long list constituting 116 drivers (Roodhuyzen et al., 2017). In addition, the abstract nature of many HFW drivers scales up the complexity. As identified by many scholars (e.g. Aschemann-Witzel et al., 2015; Evans, 2011; Porpino et al., 2015; Sosna et al., 2019; Urrutia et al., 2019), those drivers principally are HFW-generating intertwined food-related practices that are habitual (Reckwitz, 2002), and therefore, stubborn to change (Sahakian and Wilhite, 2014). To be more specific, poor shopping and meal planning (Janssens et al., 2019; Stefan et al., 2013), excessive purchasing (Bravi et al., 2020; Falasconi et al., 2019), stockpiling (Porpino et al., 2015; Setti et al., 2016), cooking too much (Baig et al., 2019;

Mattila et al., 2019), shopping less frequently (Giordano et al., 2019b; Lee, 2018) and so on, have been discussed as HFW generating practices. As suggested by practice theory, the nexus of these food-related practices is formed by the grift structure of essential elements (Reckwitz, 2002; Schatzki, 1996; Shove and Pantzar, 2005) such as attitudes, materials, food/package/retail properties, socio-temporal factors, and skills. More specifically, preference for fresh or variety (Hebrok and Heidenstrom, 2019; Porpino et al., 2016), food safety and health concerns (Farr-Wharton et al., 2014; Graham-Rowe et al., 2015), unavailability of smaller packages (Wansink, 2018; Wikstrom et al., 2019), past bad experiences (Aschemann-Witzel et al., 2015), lack of knowledge/skills regarding how to cook with leftovers (Stancu et al., 2016) or how to assess edibility (Mattila et al., 2019), and so on were reported as antecedents of HFW-generating practices.

The multifaceted nature of the causal web formed between those practices and elements is the second dimension of complexity. Roodhuyzen et al. (2017) conceptualized consumer food waste as a "*cumulative result of different causal sequences (pathways) of interacting factors*" (p.48) which means that a factor following different pathways might lead to different consequences. This manifests itself in literature with contradictory arguments regarding the relationship between some drivers and HFW. For instance, scholars (Farr-Wharton et al., 2014; Janssens et al., 2019; Mattila et al., 2019; Porpino et al., 2015; Stefan et al., 2013) depicted poor shopping planning mostly as a driver of HFW. However, others (Hebrok and Heidenstrom, 2019; Urrutia et al., 2019) revealed that strict or long-term planning (opposite of poor planning) may increase the HFW due to the inability to respond to unforeseen events. In addition, many others (Bravi et al., 2020; Elimelech et al., 2019; Giordano et al., 2019b; Stancu et al., 2016) found no relation between poor planning and the amount of food wasted.

Another reason for controversial accounts on a driver's impact on HFW might be its distance from the main action or decision point through which food is wasted (Hebrok and Boks, 2017). For instance, in-between shopping planning and disposing of food, consumers perform many practices through which they can compensate for the negative consequences of poor planning or through which they cannot remunerate advantages of strict planning. Between two decisions, many other drivers that can change pathways and naturally the outcome, are in action. Being distant from the moment of wasting does not make an HFW driver less effective in changing the resultant behavior. On the contrary, the existence of countless pathways with different effects on the result requires the investigation of the interplay of all drivers, including the distant ones. This way, the cumulative outcome of interacting drivers can be observed.

### 2.2. Handling complexity through social practice theory

As a "bundle" of activities and an organized nexus of actions (Schatzki, 2002: p. 71), practices (e.g., way of consuming, cooking, etc.) engrave social life. They are formed while doings and sayings are coordinated through essential elements (Schatzki, 1996, p. 89). Apart from the grift structure formed by many prerequisite elements, the presence of practices needs performance (Schatzki, 1996), in other words, routine reproduction (Shove and Pantzar, 2005). Habitual nature (Reckwitz, 2002) does not necessarily mean regularity or stability, on the contrary, practices incorporate both regular and constantly changing doings and sayings (Schatzki, 2002), and therefore, are temporally evolving (Schatzki, 1996). Thus, another significant feature of practices is their dynamism in the way individuals engage in their daily lives (Sahakian and Wilhite, 2014). The inherent dynamism of practice stems from its dependence on who does it (Shove and Pantzar, 2005). Individuals are the practice performers, however, rather than their individual properties, their routinized way of understanding is the necessary element (Reckwitz, 2002).

In practice theory, "*Social is a field of embodied, materially interwoven practices centrally organized around shared practical understandings*" (Schatzki, 2001: p. 12). Thus, instead of putting individuals into the center while defining social (Schatzki, 2001), practice theory takes practices as the smallest unit of analysis (Reckwitz, 2002). In addition, Sahakian and Wilhite (2014) criticize the dominant perspective that holds individuals responsible and labels them as either 'barrier or catalyst to change' (Sahakian and Wilhite, 2014: p. 26). Similarly, Evans et al. (2012) express that when the point of departure is individual choices, a desirable solution would be to persuade individuals to behave oppositely. That is why regarding individual decisions or choices as the source of the problem and changing them as the unique solution is an overly simplistic approach (Evans, 2011). Therewith, Warde (2005) finds the examination of how key elements of practices are seized and accommodated more productive for research on consumer behavior. More importantly, practice theory is found to be promotive for research on behavior changes towards more sustainable forms (Evans et al., 2012; Sahakian and Wilhite, 2014) because it allows untangling the complex nature of social life (Watson et al., 2020). As such, "*efforts to develop more environmentally sustainable eating practices require interventions that address the inter-connected activities that together form the practice*" (Evans et al., 2012: p. 121).

Drawing on practice theories, scholars (Evans et al., 2012; Sahakian and Wilhite, 2014) have reached some key points to consider while designing practice change policies. To this end, the identification of the most influential elements is the first critical point. The main corollary is the inequality between the impact of practice elements. If the impact of some elements is more remarkable than others, their capacity to change practice would also be more significant. The second one is that intervention should target multiple activities or elements that structure a practice since practices as a coordinated entity are "bundles" of activities. Sahakian and Wilhite (2014) also highlight the need for addressing multiple elements to alter the inflexible nature of habits. Habits such as how we shop for food and how we clean our homes are "recurrently and consistently reproduced by suitably committed practitioners" (Shove, 2012: p. 103), and deeply embedded in habitus and therefore stubborn to change (Sahakian and Wilhite, 2014: p. 28). Thus, to transform a habitual practice into a more sustainable way, fighting against more than one aspect is a prerequisite. Moreover, the "rebound effect" is a hidden danger that should be acknowledged (Sahakian and Wilhite, 2014: p. 39). This term is used for the unanticipated perverse effect of a change in one practice. Through an intervention, a significant reduction in one consumption domain could be achieved but the same intervention might lead to an increase in another. Therefore, since practices are entangled, they must be regarded as a system, and concentration on a specific practice should be avoided.

Social practice theory is not the only framework held in the inquiry of HFW behavior but offers the most rewarding framework compared to others. For instance, climate change policies built upon the ABC (attitude, behavior, choice) framework have been criticized due to their dependence on individualistic perspectives (Shove, 2010). In the discussion of FW, Evans (2011) shares the same account and remarks that the ABC framework supposes FW as a consequence of careless consumers and relies on the need for attitudinal change. In addition, the theory of planned behavior (TPB) (Ajzen, 1991) is among the most widely used framework (Barone et al., 2019; Russell et al., 2017; Schmidt, 2019; Soorani and Ahmadvand, 2019; Stancu et al., 2016; Stefan et al., 2013). In this model, the intention is the main determinant of behavior while attitudes, subjective norms, and perceived behavioral control are its antecedents. In this domain as well, scholars acknowledge the crucial role of food-related household practices and extend their model with related constructs to gain more explanatory power. Stefan et al. (2013) reveal that while intention does not significantly affect consumers' food waste, planning and shopping routines do. Similarly, Stancu et al. (2016) find that shopping and leftovers reuse routines are more predictive than intentions not to waste. These findings support the argument that food waste is a consequence of everyday routines performed by consumers rather than a consequence of conscious intentions of wasting.

### 2.3. Fuzzy cognitive mapping

Kosko (1986) developed Fuzzy Cognitive Mapping as a tool to apprehend and model complex causal-effect systems (Alizadeh et al., 2017). It is a method that represents a causal network between system concepts (Groumpos, 2010) that can be both quantitative (definitive) and qualitative (abstract) (Nair et al., 2019). System concepts, important variables that affect the system, are derived from the accumulated knowledge and experience of system experts (Groumpos, 2010; Papageorgiou et al., 2006). Through the utilization of natural language created by human experts (Nair et al., 2019), FCM is advantageous especially when the information is scarce, uncertain, and vague (Morone et al., 2019). It can establish a link between qualitative narratives and quantitative analysis. For that reason, fuzzy cognitive mapping has been incorporated into the toolbox for future studies (Jetter and Kok, 2014).

Fuzzy cognitive maps are graphical configurations that consist of nodes expressing concepts and directed arrows with weights connecting those concepts. An arrow, departing from a causing concept, shows the affected concept, while the weight indicates the strength of this relationship. Kosko (1986) developed fuzzy cognitive maps by adding fuzzy logic to cognitive maps. Until then, cognitive maps did not consider the relationship's strength. All relationships identified within a system were regarded to have equal impacts, and weights of directed arrows could be attained with values 0, 1, and − 1. In fuzzy cognitive maps, weights, besides the concepts, can have a value in between those numbers and are therefore fuzzy (Alizadeh et al., 2017; Papageorgiou and Salmeron, 2013). Weights can have three different meanings (Yaman and Polat, 2009).

- If weight has a value between [0,1], then there is a positive causal relationship between the two concepts. An increase (decrease) in causing concept leads to an increase (decrease) in the affected concept.
- If weight has a value between [−1,0], then there is a negative causal relationship between the two concepts. An increase (decrease) in causing concept leads to a decrease (increase) in the affected concept.
- If the weight is 0, then the causal relationship between the two concepts does not exist.

Kosko considered fuzzy cognitive maps as a '*simple form of recursive neural network*' (Jetter and Kok, 2014: p.46). When a fuzzy concept changes its state, a non-linear activation permeates through the map. Altered concepts transmit weighted activation directed at them to other concepts that are causally dependent on them. As fuzzy cognitive maps enable feedback loops, activation between concepts continues until the system reaches an equilibrium state, a point in which all the concepts are fixed. It may take several iterations to reach that fixed point which means that a concept may be activated and change more than once (Jetter and Kok, 2014).

Fig. 1 demonstrates a simple FCM sample consisting of five concepts. A concept is denoted with $C_i$ with a state value $A_i$ which can be a fuzzy value within [0,1]. The strength of the influence of the causing concept $C_i$ on effected concept $C_j$ is denoted with $W_{ij}$ that can take any value within [−1,1].

The adjacency matrix corresponding to the FCM (Fig. 1) is shown as follows.

$$W = \begin{bmatrix} 0 & -0.2 & 0.8 & 0 & 0.5 \\ 0 & 0 & 0 & 0.7 & 0.9 \\ 0 & 0 & 0 & 0 & -0.4 \\ 0 & -0.3 & 0 & 0 & 0.6 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (1)$$

In this FCM, the value of each concept indicated by $C_i$ ($i = 1, \ldots, n$) is calculated with the following iterative equation. Iterative computation

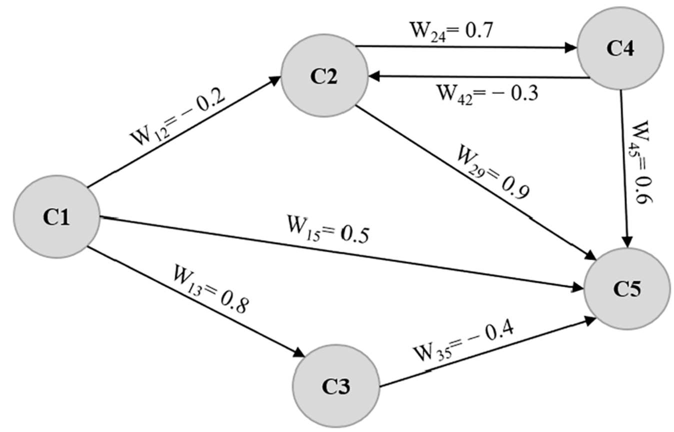


**Fig. 1.** An FCM.

of concepts' values with eq. (2) is the fundamental procedure of the method called the running cycle of FCMs (Groumpos, 2010).

$$A_i^t = f\left(A_i^{t-1} + \sum_{(j=1, j\neq i)}^{n} A_j^{t-1} W_{ji}\right) \quad (2)$$

$A_i^t$ represents the value of $C_i$ at iteration t, $A_i^{t-1}$ the value of $C_i$ at iteration *t-1*, $A_j^{t-1}$ the value of $C_j$ at iteration *t-1* and $W_{ji}$ the weight of interconnection from concept $C_j$ to concept $C_i$. *f* is a threshold function used to squash the results into a normalized range. In our approach, Eq. (3) with the value $\lambda = 1$ was used. In Eq. (3), concept values are restricted to be continuous and within [0,1] (Mei et al., 2014). λ is a parameter that determines its steepness.

$$f(x) = \frac{1}{1 + e^{-\lambda x}}, (\lambda > 0) \quad (3)$$

Having constructed an adjacency matrix, we can conduct scenario analysis. First, we attained an initial state of 1 for all concepts and did a steady-state calculation. Table 1 shows the result of the steady-state calculation of the FCM in Fig. 1. After the 8th iteration, we did not observe any changes in the concepts' value. So, a steady-state reached in the 8th iteration.

Having obtained the steady-state values of concepts, then we repeated the iterative calculation for a hypothetical scenario and compared the new values with the initial steady-state values. That is how we can interpret the scenario analysis outputs. Suppose a hypothetical scenario proposes an increase in the 2nd concept. Then, to simulate the impact of this scenario on the system, only *C2* should be activated. Table 2 represents the results of the scenario analysis.

**Table 1**
Calculation of steady-state for the sample FCM.

| Iteration | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| 0 | 1 | 1 | 1 | 1 | 1 |
| 1 | 0.7311 | 0.6225 | 0.8581 | 0.8455 | 0.9309 |
| 2 | 0.6750 | 0.5554 | 0.8089 | 0.7827 | 0.8829 |
| 3 | 0.6626 | 0.5463 | 0.7940 | 0.7634 | 0.8660 |
| 4 | 0.6599 | 0.5460 | 0.7899 | 0.7587 | 0.8617 |
| 5 | 0.6592 | 0.5465 | 0.7888 | 0.7579 | 0.8609 |
| 6 | 0.6591 | 0.5467 | 0.7885 | 0.7578 | 0.8607 |
| 7 | 0.6591 | 0.5467 | 0.7885 | 0.7578 | 0.8608 |
| 8 | 0.6590 | 0.5468 | 0.7885 | 0.7578 | 0.8608 |
| 9 | 0.6590 | 0.5468 | 0.7885 | 0.7578 | 0.8608 |
| 10 | 0.6590 | 0.5468 | 0.7885 | 0.7578 | 0.8608 |

**Table 2**
Results of Hypothetical Scenario Analysis for the FCM.

| Iteration | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| 0 | | 1.0000 | | | |
| 1 | 0.7311 | 1.0000 | 0.8581 | 0.8455 | 0.9309 |
| 2 | 0.6750 | 1.0000 | 0.8089 | 0.8243 | 0.9138 |
| 3 | 0.6626 | 1.0000 | 0.7940 | 0.8212 | 0.9107 |
| 4 | 0.6599 | 1.0000 | 0.7899 | 0.8207 | 0.9103 |
| 5 | 0.6592 | 1.0000 | 0.7888 | 0.8206 | 0.9103 |
| 6 | 0.6591 | 1.0000 | 0.7885 | 0.8206 | 0.9103 |
| 7 | 0.6591 | 1.0000 | 0.7885 | 0.8206 | 0.9103 |
| 8 | 0.6590 | 1.0000 | 0.7885 | 0.8206 | 0.9103 |
| 9 | 0.6590 | 1.0000 | 0.7885 | 0.8206 | 0.9103 |
| 10 | 0.6590 | 1.0000 | 0.7885 | 0.8206 | 0.9103 |

When we compared the hypothetical scenario values with the initial steady-state values, we can conclude that:

- an increase in *C2* will increase the state of *C4* by 0.0628 (from 0.7578 to 0.8206) and the state of *C5* by 0.0495 (from 0.8608 to 0.9103).
- an increase in *C2* does not affect *C1* and *C3*.

FCM has been used to promote the transition towards a clean and renewable energy sector (Zare et al., 2022; Zanjirchi et al., 2020; Falcone et al., 2018) and a circular bioeconomy (Morone et al., 2021; Kokkinos et al., 2020), to contribute to the diagnosis of health issues (Buyukavcu et al., 2016; Giabbanelli et al.,2012) and the prevention of unsafe behaviors (Malakoutikhah et al., 2022), and to support urban planning and resilience (Olazabal and Pascual, 2016; Pluchinotta et al., 2019) through the construction of supportive models and the identification of effective policy strategies. Although researchers have investigated FW using FCM (e.g., Irani et al., 2018; Morone et al., 2019), our study differs from them as it focuses on household food-related practices and integrates social practice theory and previous research findings.

### *2.4. Justification for the choice of FCM method selection*

As we have discussed before, the complexity of the HFW drivers' system originates from various factors. To summarize, HFW drivers are wide-ranging and high in number; many of them are abstract (hard to measure); forming different pathways, they may have diverse impacts on HFW; and it is difficult to clarify the relationship between a distant driver and HFW. In this section, we explained how the advances of FCM reported in literature could address these complexity factors.

First, FCMs can be made for almost any problem, and the number of variables is dependent only on the problem investigated. Ozesmi and Ozesmi (2004) developed a fuzzy cognitive map composed of 253 variables and 1173 relations for the case of an ecological problem. Ulengin et al. (2018) investigated the dimensions of the transportation sector related to climate change and identified 74 variables and 1214 relations. On the other hand, Giabbanelli et al. (2012) constructed an FCM for the obesity problem with only 15 psychosocial determinants. We highlighted these numbers to show the extent of concepts number that can construct an FCM. In short, FCMs allow a problem to be considered as a whole, even if a great number of contributing factors underlie it. In addition, the initial representation of the system can be continuously consummated with the addition of new factors and relationships (Jetter and Kok, 2014; Mei et al., 2014). In this respect, the flexibility of the approach manifests itself. Using FCM, we were able to model the complex network constituting a high number of HFW drivers.

Second, it is a tool that enables the researcher to deal with linguistic ambiguities (Alizadeh et al., 2017). Rather than concepts, the relationship strength is quantified which enables the verbal description of concepts whose quantification is hard (Jetter and Kok, 2014). As it utilizes experts' knowledge, FCMs allow a flexible description of system design (Mei et al., 2014). They allow using natural language that reflects perceptions or beliefs characterized by uncertain and ambiguous information. Natural language is utilized as it is formulated by experts or stakeholders (Nair et al., 2019). On this account, we were able to include all prevalent drivers in the resultant map regardless of their measurability.

Third, the pairwise evaluation of causal relations enables researchers to cope with a complex network including loops and feedback (Alizadeh et al., 2017). Pairwise assessment of relationships between system concepts allows for the consideration of all possible routes to the dependent variable rather than focusing on individual causal relations. Consequently, we could represent the diverse effect of a single concept following diverse pathways. Moreover, we could consider the potential impacts of distant concepts as the gaps within the series of relationships were eliminated with pairwise evaluation. Therefore, by utilizing FCM, we could make a more thorough cause and effect analysis.

Forth, it is possible to build collective fuzzy cognitive maps based on data drawn from multiple sources. By doing so, views of different experts or stakeholders can be incorporated under one map which subsequently presents a rich body of knowledge. Augmentation can be done both by mathematically mixing individual maps, or by encouraging experts to work in groups and reach a consensus on the elements, relationships, and weights of the system (Alizadeh et al., 2017; Papageorgiou and Salmeron, 2013). Employing collective mapping, we could resolute the problem of contradictory views regarding the impact of the HFW drivers.

Fifth, through simulation analysis, FCMs become an advantageous tool to compare the system response to different scenarios (Ulengin et al., 2018). They can be used for several purposes, prediction being one of them (Papageorgiou and Salmeron, 2013). Uncertain future states that cannot be eliminated through information gathering can be simulated through FCMs by building internally consistent scenarios. Jetter and Kok (2014) indicate FCM as a specific future study method that can improve scenario planning. In this paper, by utilizing the scenario analysis ability, we test the impact of each HFW driver and identify the most influential ones.

Lastly, both the application and comprehensibility of FCMs are simple and straightforward (Mei et al., 2014). They have been credited as being easy to use, requiring relatively low computational time, and producing understandable results for even non-technical audiences (Van Vliet et al., 2010).

## 3. Methods

This paper integrates the theory, previous research findings, and expert opinion to construct an FCM that models the complex system of HFW drivers. A three-stage methodology was designed for data collection and analysis (see Fig. 2). In the first stage, the most prevalent HFW drivers as system concepts and their causal relationships were identified. In the second stage, an FCM was constructed by augmenting and assessing causal relationships between system concepts identified in the first stage. In the third stage, the FCM was utilized as a unit of analysis for scenario analysis that revealed the individual impact of each concept on the system.

### *3.1. Identifications of system concepts and causal relationships*

FCM is a graphical demonstration of how a system is perceived by human beings. Therefore, system concepts should be derived from the accumulated knowledge of human experts who know the system's operation and behavior in different circumstances (Groumpos, 2010). Human experts can be technical people, academics, people working for NGOs, or people from policy advisory groups, supposed to be knowledgeable in a domain. For the system of HFW drivers, however, in their everyday life performing food-related household practices, consumers should be the main source of knowledge from which all possible causal

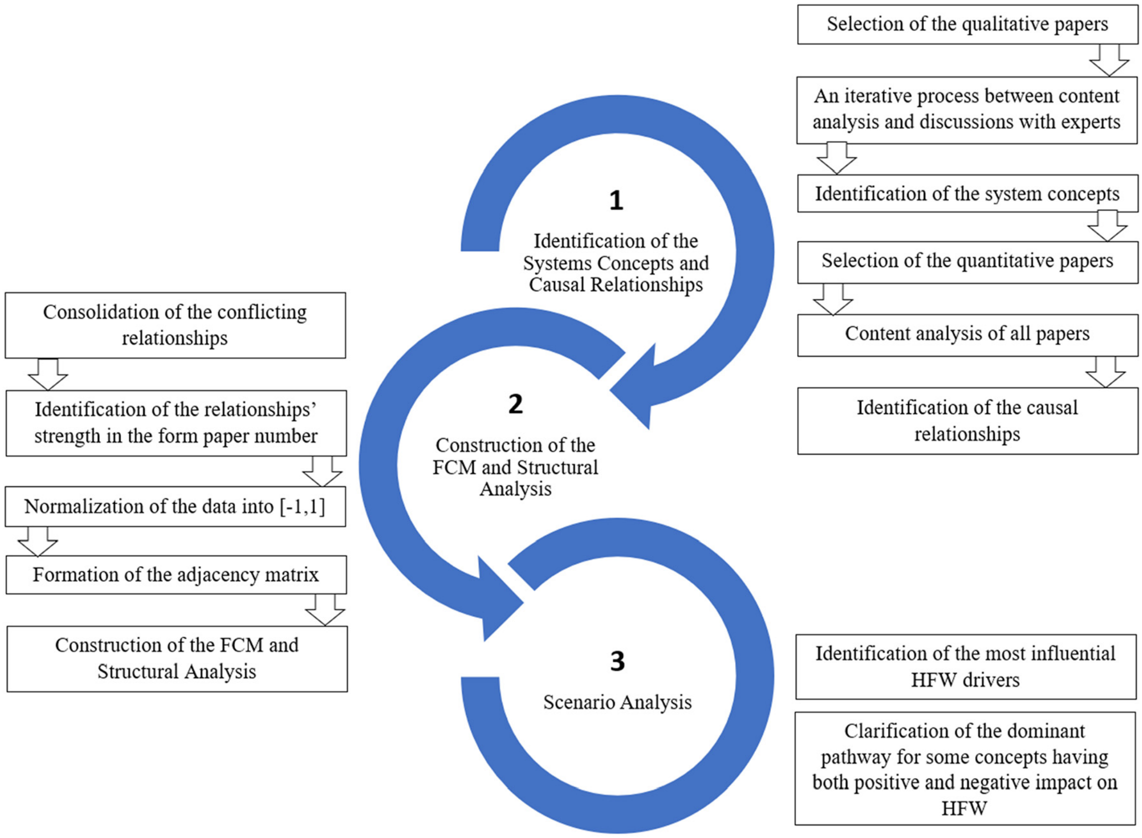


**Fig. 2.** Three-stage Methodology.

relationships can be disclosed. Researchers (Pearson and Perera, 2018) support this argument while conducting a focus group study with packaging experts. They realized that during FW discussions participants tend to mention their own household experiences as consumers instead of professional opinions. Papageorgiou and Salmeron (2013) remarked on this issue as a challenge for the use of FCM: '*…studies with stakeholders are likely to overrepresent people with strong personal interests in the subject matter under study, thus possibly distorting the insights gained*' (p.55). In addition, Kim et al. (2019) assert that campaigns aiming at behavior change should take the consumer perspective into the center of their strategy.

To be able to capture the consumers' perspective, we adopted a combined method which was previously adopted by Ulengin et al. (2018). Primarily, the content analysis of published academic articles as secondary resources was used (Alizadeh et al., 2017) to capture both system concepts and their relationships since an ample number of empirical studies in the literature provided a rich in-depth analysis of consumer HFW behavior. However, this abundance brought heterogeneity that made the formation of a valid and reliable concept list challenging. At this point, the opinion of three professional experts was sought (see Table 3 for expert profiles) only to identify the system concepts. Having an odd number of experts was considered to facilitate the resolution of possible disputes.

**Table 3**
Professional experts' background.

| Expert # | Affiliation | Experience |
|---|---|---|
| 1 | Professor of supply chain analytics at a well-known university in the UK | More than 10 years<br>Has publications regarding drivers of food waste including aspects related to consumer behavior and food waste minimization. |
| 2 | Department head at a governmental organization in Turkey | More than 10 years<br>Coordinates the national campaign to reduce food losses and waste |
| 3 | Consultant at one of the United Nations Specialized Agencies in Italy | More than 3 years<br>Works on planning initiatives to create awareness around food loss and waste. |

The Software package QSR NVivo 10 was utilized for the content analysis, as it enables performing qualitative assessment by coding relevant keywords as well as specifying underlying patterns in textual data (Leech and Onwuegbuzie, 2011). The coding manual composed by Wrightson (1976) was referred to determine the rules for building cognitive maps from documentary materials. The main principle of the coding protocol was to code each sentence, phrase, or paragraph stating a causal relation between two concepts. Causing concepts, linkage, and effected concepts were the elements that structure the content as a causal relation (Wrightson, 1976).

First, an initial list of concepts (codebook) was prepared through an unsystematic literature review. This preliminary review was also useful while determining the criteria applied for article sampling. This initial codebook was revised continuously while continuing the content analysis and discussions with experts. The codebook (see Appendix A) went through 4 revisions until it was finalized. Each time a revision was made, we reviewed all contents coded under the revised concept and its relationships and re-coded them following the new formation. In this respect, the formation of the codebook was a highly iterative as well as a fulfilling process.

We abided by the original language used in documents (Wrightson, 1976). Moreover, concepts were qualified as variables that can decrease and increase to be able to define causality between them. For validity and reliability, in collaboration with the experts, identical concepts were consolidated, consistent terminologies for similar concepts were adopted, and the granularity for concepts and sub-concepts was tuned (steps proposed by Alizadeh et al., 2017). Coding was performed by one of the researchers who paid strict attention to preventing spurious implications. The rule of thumb proposed by Wrightson to cope with

**Table 4**
Sampling criteria.

| Inclusion criteria | Exclusion criteria |
|---|---|
| Studies aiming at the exploration of HFW drivers. Studies focusing on food-related household practices. | Studies focusing on the FW reduction options that are placed at the bottom of the FW hierarchy such as separate waste collection and biological recovery |
| Qualitative studies (providing the richest content and representing better the perception of consumers) | Quantitative studies (limited in terms of variable and interaction diversity) |
| Literature review studies to compensate for the possible data loss from sampling. | Studies focusing on the measurement of FW amount as well as its equivalent in terms of environmental impact |
| Studies conducted in diverse contexts to capture cultural differences. | |

this danger is "*denotation rather than interpretation*" (1976: p. 293, 295). Correspondingly, assertions driven by connecting two paragraphs or combining more than a few sentences were avoided (Wrightson, 1976).

Purposive sampling was performed to specify the articles that were coded. We used the keyword "Household Food Waste" to search scholarly reviewed papers in the portal of Web of Science. From the major list composing 178 papers published between the years 2011 and 2020, the main articles according to the sampling criteria shown in Table 4 were selected.

Appendix B shows the list of articles selected following these criteria. Even though the saturation point had been reached in the eighth article, to obtain context diversity and to capture more relationships, we continued coding until we reached 17 papers. Fig. 3 demonstrates the accumulation of concepts by the increase in articles.

At this stage, one further step was followed as proposed by Alizadeh et al. (2017), who highlight the peril of referring to the same body of literature as it can result in possible gaps in the resulting model. Therefore, having determined the list of system concepts, the quantitative studies were also investigated to explore new relationships that could fulfill the potential gaps within the system. From the initial list of articles derived from the Web of Science, we examined 34 quantitative studies (see Appendix C) and coded for causal relationships between predetermined concepts.

In a summary, this study comprises the list of the most prevalent system concepts by gathering data through the content analysis of 17 qualitative articles and expert opinions. The data gathered from 51 articles (both qualitative and quantitative) was used to identify causal relationships between these concepts. As it can be seen in Fig. 4, the investigation was continued with 18 papers even after reaching the saturation point for the number of relationships in the 34th article.

In this stage, the elements of the FCM as system concepts and their relationships were identified. For each causal relation, quantitative

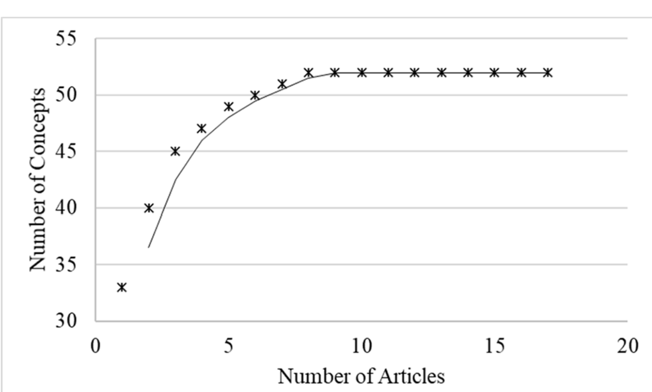


**Fig. 3.** Accumulation curve of system concept.

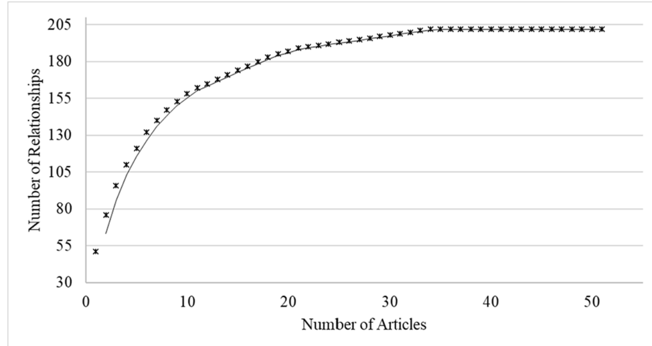


**Fig. 4.** Accumulation curve of causal relationships.

data in the form of an article number was obtained. This data was used in the second stage to compute relationship strengths (weights), the last element necessary to construct an FCM.

### 3.2. Construction of the FCM and structural analysis

Having paper numbers as an indicator of causal relationship strength, we worked on the normalization of this data within the range of [−1,1] to construct an FCM. However, conflicting relationships between some concepts made this transformation complicated. Inspired by the method proposed for adding individual maps together (Ozesmi and Ozesmi, 2004), we defined a rule for the computation of strengths. Ozesmi and Ozesmi (2004) emphasize that an augmented map gathered by adding many different maps represents the system better. While agreement about relationship direction (positive, negative, or neutral) tightens its strength, disagreement weakens it. So, to compute compound values for augmented maps, negative-positive-neutral calculus is suggested (Zhang and Chen, 1988).

Departing from this point of view, first, we supposed that each paper is an expert producing an individual map. Then, we carried out the following steps to form one single map from these individual maps.

- List all relationships with the number of papers they were coded.
- Consolidate conflicting relationships by adjusting the number of papers. Extract the number of papers coded for the weakest relationship from the number of papers coded for the most powerful relationship.
- Then, normalize the number of papers to the range of [−1, 1].

In the first stage, we coded a positive (+) causal relationship between concept *A12* and concept *I* in 25 papers which is the highest frequency. Since this relationship is the most powerful one within the whole system, the highest value in the range, 1 was attained in this relationship. Therefore, the strength of a relationship coded in one paper corresponded to 0.04, and all adjusted article numbers are normalized accordingly.

To illustrate the rule, Table 5 shows relationships of concept *A1* only as a causing concept.

From this table, it can be interpreted, for example, that:

- The following relationships were coded in 1 article: *A1* positively affects *A10* and *D3*, and negatively affects *G1*. Since any counterarguments were not coded, adjustment of article number was not required. The strengths of these three relationships were computed by multiplying the article number by 0.04.
- It was coded in 8 articles that *A1* positively affects *A2*. One article, however, confirmed no relationship (NR) between them. Since the first account was more powerful than the second account, in the adjacency matrix positive relationship remained. Contradictory accounts, on the other hand, decreased the strength of this relationship. The number of articles was adjusted to 7 (8–1 = 7). Then, the resulting strength of the relationship becomes 0.28 (7 × 0.04).

**Table 5**
A part of the causal relationship list (see Appendix D for the complete list).

| Concept | Influence | # of articles coded | | Relationship strength |
|---|---|---|---|---|
| A1 → | A2 (+) | 8 | 7 | 0.28 |
| | A2 (NR) | 1 | | |
| | A10 (+) | 1 | – | 0.04 |
| | A12 (+) | 1 | 0 | 0 |
| | A12 (−) | 1 | | |
| | A12 (NR) | 1 | | |
| | D3 (+) | 1 | – | 0.04 |
| | G1 (−) | 1 | – | -0.04 |
| | I (+) | 12 | 2 | 0.08 |
| | I (NR) | 7 | | |
| | I (−) | 3 | | |

- Three different accounts regarding how *A1* affects *A2* were coded: positively, negatively, and does not affect. Each relationship was coded in 1 article. Positive and negative relationships neutralized each other, and we did not define any relationship for the corresponding cell in the adjacency matrix.
- Similarly, three different relationships between *A1* and *I* were coded. The most powerful one, with 12 articles, was that *A1* positively affects *I*. Second most powerful one, with 7 articles, was that *A1* does not affect *I*. The least powerful one, with 3 articles, was that *A1* negatively affects *I*. We acknowledged the most powerful relationship, a positive one, but with an adjusted article number, 2 (12–7-3 = 2). Then, the strength of the relationship becomes 0.08 ($2 \times 0.04$).

Computing the weights for all acknowledged relationships, an $n \times n$ adjacency matrix (see Appendix E) where *n* represents the number of concepts was prepared. By using this matrix, an FCM was constructed on FCMapper (Bachhofer and Wildenberg, 2009), a free FCM analysis tool based on MS Excel. This tool is preferred because it enables researchers to perform multiple tasks (the iterative calculation of concepts' values, structural analysis, scenario analysis, and comparison of results) automatically by using a single system. In addition, FCMapper generates a .net-file usable as an input for the cognitive mapping analysis software Pajek (Batagelj and Mrvar, 2004) that was used to figure the FCM. FCMapper was also used by impactful papers (e.g., Olazabal and Pascual, 2016; Christen et al., 2015; Büyükavcu et al., 2016) and the recent studies (e.g., Zare et al., 2022; Malakoutikhah et al., 2022). Once the FCM was constructed, several structural analyses were also conducted in the second stage to indicate the characteristic features of the system of HFW drivers.

### 3.3. Scenario analysis

In addition to being a method to map the interrelationships between fuzzy concepts, FCMs can also allow researchers to generate and run scenario analyses (Jetter and Kok, 2014). In literature, scenario analyses are used not to forecast future states but to gain insights into the long-term impact of various scenarios by comparing them within a consistent base (Ulengin et al., 2018). Similarly, in the second stage, the FCM was used as a consistent base for comparing the effect of each system concept on the output, HFW. Each scenario initiated a change in only one system concept that proliferates throughout the FCM to attain a value by their HFW decreasing power within the system.

Using the procedure explained in section 2.3., for each scenario analysis, we attained a system concept with 1 (0) if an increase (a decrease) in its value was expected to mitigate a decrease in HFW. Then, the iterative calculation was conducted on FCMapper (Bachhofer and Wildenberg, 2009) that gave the new values after all system concepts reached their steady-state after the trigger. New values are meaningful if they are compared with the initial ones. So, after each scenario activation, FCMapper subtracted the computed values from the initial steady-state values. Consequently, the scenario analysis was conducted as much as the number of system concepts constituting the FCM. After each activation, a value was obtained indicating how much reduction in HFW can be achieved by a change in the respective HFW driver. The relative degree of change determined by FCMapper was used as an indicator facilitating the interpretation of the results and was divided into four.

- Strong if the value of change, $\underline{x} \geq 0.0100$
- Medium if $0.0010 \leq \underline{x} < 0.0100$
- Weak if $0.0001 \leq \underline{x} < 0.0010$
- Very weak if $\underline{x} < 0.0001$

Finally, all system concepts were sorted by the value of change in HFW they caused to reveal the most influential HFW drivers. Another purpose of this stage was to figure out the dominant impact of the concepts that can both increase and decrease the value of HFW by following different pathways. Since it is not possible to estimate the direction of change necessary to reduce HFW before running the system, these concepts were attained with both 0 and 1, and only the one that leads to a decrease in HFW is presented in the findings section.

## 4. Findings and discussion

Informed by social practice theory, this study aims to identify the most influential HFW drivers as one of the keys to altering established HFW-generating practices. For this purpose, we employed a three-stage methodology explained in Section 3. The first stage identified the HFW drivers as system concepts and explored their causal relationship by exploiting secondary resources. In addition, expert opinion was used to consolidate and tune the concept list. The second stage converted and normalized the data in the form of coding frequency gathered through the first stage into relationship strength to construct an FCM. Finally, the third stage made use of the resulting FCM to carry out scenario analyses that yielded the HFW-reducing potential of each system concept. The following sections present and discuss the findings of each stage, and then elaborate on the limitations and future research trajectories.

### 4.1. HFW drivers as system concepts and their relationships

In the first stage, a content analysis of published articles was conducted to reveal key HFW drivers and to identify the most prevalent system concepts and their causal relationships. Moreover, we relied on experts' opinions to obtain a valid and reliable concept list. To this end, we used a codebook composed of 52 variables (see Appendix A). After the content analysis of qualitative articles (see Appendix B), we obtained data in the form of coding frequency (i.e., the number of articles) for each concept. Referring to this data as well as discussing it with experts, we excluded some of the least mentioned concepts and reduced the number of variables to 35 including the dependent variable, HFW. Table 6 shows the list of main concepts causing HFW. We classified them under 8 categories and labeled them accordingly. The list of the main concepts (Table 6) and the list of their relationships (see Appendix D) identified through an iterative process of consolidation and tuning provide a well-refined framework of HFW. Considering the factors discussed in Section 2.1., this framework reflects the complexity with a holistic perspective.

*A2* (Excessive purchasing) and *A12* (Fail to consume what is in the fridge) were the most coded practices with 16 articles out of 17. *A1* (Poor shopping and meal planning) and *A9* (Cooking and serving too much) followed them with 15 articles. Under the category of attitudes and preferences *B1* (Preference for fresh and variety) was the most coded one with 14 articles. *E1* (The rhythm of everyday life) was the

**Table 6**
List of system concepts.

| Category | Main concepts | # of papers coded[a] |
|---|---|---|
| A. Food-Related Household Practices | A1. Poor shopping and meal planning | 15 |
| | A2. Excessive purchasing | 16 |
| | A3. Shopping frequency | 9 |
| | A4. Stockpiling | 12 |
| | A5. Lost/forgotten/ignored food items | 8 |
| | A6. Poor storage practices | 7 |
| | A7. Failure to extend the lifetime of food | 6 |
| | A8. Using freezer | 9 |
| | A9. Cooking and serving too much | 15 |
| | A10. Leftover generation | 13 |
| | A11. Cooking style | 7 |
| | A12. Fail to consume what is in the fridge | 16 |
| | A13. Reluctance to use own senses | 10 |
| B. Attitudes and Preferences | B1. Preference for fresh and variety | 14 |
| | B2. Value/appreciation of food | 11 |
| | B3. Feeling of guilt | 10 |
| | B4. Suboptimality perception | 6 |
| C. Concerns | C1. Good provider identity | 13 |
| | C2. Food safety and health concerns | 13 |
| | C3. Economic concerns | 10 |
| | C4. Environmental concerns | 4 |
| D. Infrastructure of Provisioning | D1. Lack of smaller package sizes | 13 |
| | D2. Low food prices | 7 |
| | D3. The attraction of special offers | 6 |
| | D4. The magnitude of the food store | 5 |
| | D5. Accessibility/physical proximity of the store | 5 |
| E. Socio -Temporal Context | E1. The rhythm of everyday life | 14 |
| | E2. Past bad experiences | 7 |
| | E3. Efforts devoted to food practices | 6 |
| | E4. The detachment of food production and consumption | 4 |
| F. Package and Food Properties | F1. Temporality/perishability of food | 10 |
| | F2. Confusing date labels | 8 |
| G. Knowledge and Awareness | G1. Lack of knowledge/skill/awareness | 12 |
| H. Domestic Material Conditions | H1. Limited technological advancements | 5 |
| I. Household Food Waste | | 17 |

[a] Concepts and frequencies are derived from the content analysis of 17 articles (see Appendix B).

most coded socio-temporal factor prevalent in the HFW generation with 14 articles. *C1* (Good provider identity) and *C2* (Food safety and health concerns) turned out to be the most coded concerns with 13. These numbers demonstrate the extent to which these drivers have been discussed in the literature. However, a driver's being elaborated frequently does not necessarily mean that it is one of the most influential drivers of HFW. To extract the most influential drivers, the outcome of the interaction among all the drivers should be evaluated which can be understood by constructing an FCM.

### *4.2. FCM and structural indices*

After attaining data in the form of coding frequency (paper numbers) for all possible types of causal relationships between system concepts, we transformed this data into relationship strength to form an adjacency matrix. During the transformation process, conflicting relationships were resolved by the method explained in Section 3.2. This transformation is needed because in the adjacency matrix only one type of relationship can be defined in a cell. Appendix D shows all possible causal relationships and computed relationship strengths. By using relationship strength values in this list, we prepared an adjacency matrix (see Appendix E) constituting 35 elements. Utilizing this adjacency matrix, the FCM was constructed on FCMapper (Bachhofer and Wildenberg, 2009) and visualized via Pajek (Batagelj and Mrvar, 2004). Fig. 5 demonstrates the FCM of the HFW drivers' system where red dotted lines show negative relationships and black lines positive relationships.

Once the FCM was constructed, several structural analyses were performed to reveal the key indicators of the HFW drivers' system. The first indicator is the FCM's density ($D$) as a connectivity index calculated by dividing the number of relationships ($R$) by the number of all possible relationships ($n^2$).

$$D = \frac{R}{n^2} \tag{4}$$

As the number of connections in an FCM increase, density, indicating a higher level of complexity, increases as well. A highly dense structure is prompted to be able to offer sufficient recommendations. Otherwise, the resulting simple model would imply a limited representation (Ulengin et al., 2018). The density of the FCM derived within the scope of this study is 0.14 which is considered moderate compared to some of the studies in the literature (Cossette and Audet, 1992; Craiger et al., 1996; Morone et al., 2019; Ulengin et al., 2018).

Subsequent indices are related to concept types, evaluation of which allows understanding the system structure. A system concept has outdegree and indegree values whose summation yield centrality value ($C_i$). Outdegree ($od_i$), the row sum of absolute values of a concept, indicates the cumulative strength of the relationships existing from the concept. Indegree ($id_i$), the column sum of absolute values of a concept, indicates the cumulative strength of the relationships entering the concept (Ozesmi and Ozesmi, 2004).

$$od_i = \sum\nolimits_{j=1}^{n} \overline{W}_{ij} \tag{5}$$

$$id_i = \sum\nolimits_{i=1}^{n} \overline{W}_{ji} \tag{6}$$

$$C_i = od_i + id_i \tag{7}$$

Centrality indicates the cumulative strength of connections a concept has with other concepts in the systems (Ozesmi and Ozesmi, 2004). In other words, centrality embodies all the connections between a concept and the rest of the system, therefore, it indicates the concept's contribution to the system (Ulengin et al., 2018). We calculated the centrality values for all the system concepts (Table 7). As a result, HFW (*I*) as the only receiver is the most central concept of the system which is followed by three food-related household practices: *A12*, *A2*, and *A9*. After the most central practices, *C2* appeared to be the most central concern and *B2* (value/appreciation of food) the most central attitude of the system.

Concepts are categorized under three types: receiver, transmitter, and ordinary (Ozesmi and Ozesmi, 2004). Concepts having non-zero *id* and zero *od* are the receiver concepts of the system. Receiver concepts indicate the outcomes and implications of a system (Eden et al., 1992), therefore, should be monitored to evaluate the system's response to a change. In the resulted FCM, one receiver concept emerged which is HFW (*I*). So, *I* was the main performance indicator while comparing the impact of different scenarios on the system.

Concepts having non-zero *od* and zero *id* are the transmitter concepts of the system. Structural analysis showed that *C3* (economic concerns), *C4* (environmental concerns), *D5* (the accessibility / physical proximity of store), *E1* (the rhythms of everyday life), *E2* (past experiences), and *F2* (confusing date label) are the transmitter concepts of HFW drivers` system. These concepts control the system but are not affected by the system (Ozesmi and Ozesmi, 2004), therefore, they indicate the variables on which the success of an intervention depends. While conducting scenario analysis, they can be used to uncover how the outcome of system interaction differs under different contextual conditions or according to different consumer profiles. For instance, if it is anticipated or targeted that an intervention will appeal to a highly environmentally concerned segment, by activating *C4* along with the

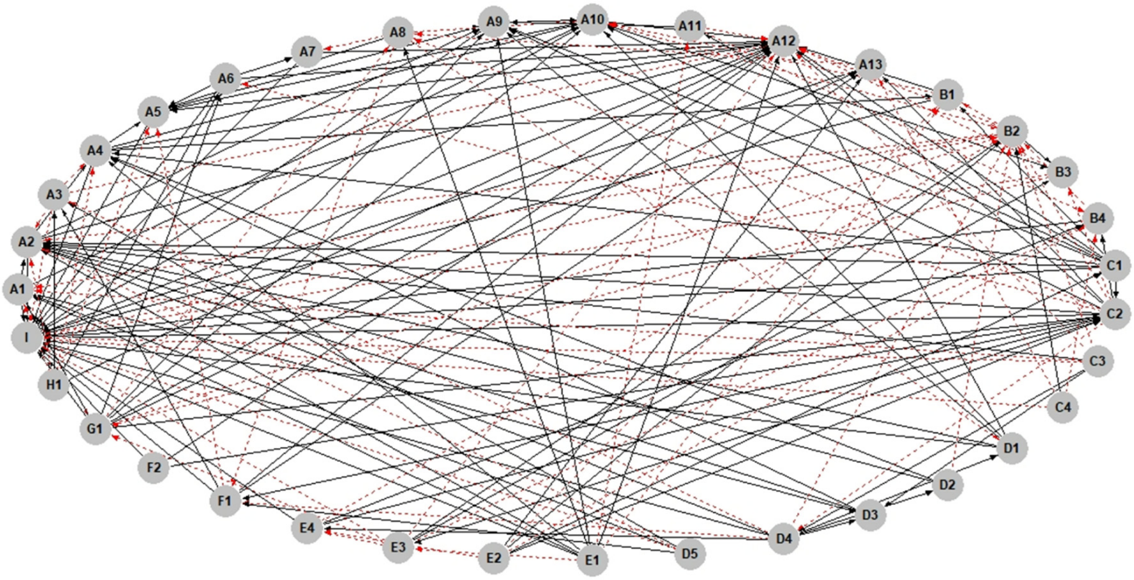


**Fig. 5.** FCM of HFW drivers' system.

ordinary variables, a more sophisticated scenario analysis can be achieved. Similarly, it will be possible to see how the effect of intervention changes according to the density of the stores in the region where it is applied by embodying *D5* in the scenario setup. Therefore, using transmitter concepts, the proposed FCM will allow assessing the impact of different interventions limited to some contextual factors or customized to specific groups. This is a remarkable capability of the proposed model since the growing body of literature has noted the importance of consumer profiling (Annunziata et al., 2020; Aschemann-Witzel, 2018; Aschemann-Witzel et al., 2018; Bilska et al., 2020; Delley and Brunner, 2017; Filipova et al., 2017; Gaiani et al., 2018; Pearson and Amarakoon, 2019).

**Table 7**
System Concept Indices and Categories.

| Concepts | $C_i$ | $Od_i$ | $Id_i$ | Type |
|---|---|---|---|---|
| I. Household food waste | 7.12 | 0.00 | 7.12 | Receiver |
| A12. Fail to consume what is in the fridge | 3.56 | 1.08 | 2.48 | Ordinary |
| A2. Excessive purchasing | 3.36 | 1.24 | 2.12 | Ordinary |
| A9. Cooking and serving too much | 1.72 | 0.68 | 1.04 | Ordinary |
| C2. Food safety and health concerns | 1.68 | 1.28 | 0.40 | Ordinary |
| B2. Value/appreciation of food | 1.48 | 0.60 | 0.88 | Ordinary |
| C1. Good provider identity | 1.24 | 1.16 | 0.08 | Ordinary |
| A10. Leftover generation | 1.20 | 0.56 | 0.64 | Ordinary |
| A5. Lost/forgotten/ignored food items | 1.12 | 0.60 | 0.52 | Ordinary |
| E1. The rhythm of everyday life | 1.12 | 1.12 | 0.00 | Transmitter |
| G1. Lack of knowledge/skill/awareness | 1.12 | 0.96 | 0.16 | Ordinary |
| A4. Stockpiling | 1.08 | 0.48 | 0.60 | Ordinary |
| A3. Shopping frequency | 1.00 | 0.64 | 0.36 | Ordinary |
| A13. Reluctance to use own senses | 0.96 | 0.36 | 0.60 | Ordinary |
| B1. Preference for fresh and variety | 0.92 | 0.68 | 0.24 | Ordinary |
| D1. Lack of smaller package sizes | 0.84 | 0.76 | 0.08 | Ordinary |
| A1. Poor shopping and meal planning | 0.80 | 0.48 | 0.32 | Ordinary |
| E3. Efforts devoted to food practices | 0.80 | 0.72 | 0.08 | Ordinary |
| A6. Poor storage practices | 0.72 | 0.48 | 0.24 | Ordinary |
| F1. Temporality/perishability of food | 0.64 | 0.44 | 0.20 | Ordinary |
| C3. Economic concerns | 0.64 | 0.64 | 0.00 | Transmitter |
| D4. The magnitude of the food store | 0.56 | 0.48 | 0.08 | Ordinary |
| D3. The attraction of special offers | 0.52 | 0.40 | 0.12 | Ordinary |
| E4. Detachment | 0.52 | 0.32 | 0.20 | Ordinary |
| E2. Past bad experiences | 0.48 | 0.48 | 0.00 | Transmitter |
| H1. Limited technological advancements | 0.48 | 0.44 | 0.04 | Ordinary |
| A8. Using freezer | 0.44 | 0.28 | 0.16 | Ordinary |
| F2. Confusing date labels | 0.44 | 0.44 | 0.00 | Transmitter |
| B3. Feeling of guilt | 0.44 | 0.24 | 0.20 | Ordinary |
| D5. Accessibility / physical proximity of the store | 0.44 | 0.44 | 0.00 | Transmitter |
| B4. Suboptimality perception | 0.40 | 0.12 | 0.28 | Ordinary |
| A7. Failure to extend the lifetime of food | 0.40 | 0.16 | 0.24 | Ordinary |
| D2. Low Food Prices | 0.36 | 0.32 | 0.04 | Ordinary |
| A11. Cooking style | 0.32 | 0.24 | 0.08 | Ordinary |
| C4. Environmental concerns | 0.28 | 0.28 | 0.00 | Transmitter |

**Note:** Concepts are ranked by their centrality values.

Concepts having both non-zero *id* and *od* are called ordinary concepts. In respective FCM, 28 concepts out of 35 concepts emerged as ordinary concepts which are both drivers of and affected by the system. The ratio of their id and od values determines their role (more receiver or transmitter) within the system. FCM concept indices and categories mentioned above were summarized in Table 7.

The final structural measure is the hierarchy index ($h$) which indicates the level of the hierarchy of a cognitive map. If $h$ equals 1, it means that the cognitive map is fully hierarchical. On the other hand, if $h$ of equals to 0, it means that the cognitive map is democratic. Democratic maps are more adaptable to local environmental changes (Ozesmi and Ozesmi, 2004). $h$ was calculated via the following equation.

$$h = \frac{12}{(n-1)n(n+1)} \sum_i \left[\frac{od_i - (\sum od_{i)}}{n}\right]^2 \tag{9}$$

For the respective FCM, $h$ is 0.001 which is the lowest value among the values of various studies gathered by Özesmi and Özesmi (2004). So, we confidently stated that the respective FCM is highly democratic. In summary, we aggregated all structural indices in Table 8.

Evident with the lower hierarchy index (0.001), we obtained a highly democratic map that positions concepts independently from the initial classification framed in Table 6. In other words, instead of regarding factors classified under the same category as tantamount, this study uncovers their unique contribution to the system that is evident in the structural analysis results. Table 7 shows that the system concepts are enmeshed categorically when sorted by their centrality values. The absence of categorical clustering is more prominent when we zoom in on food-related household practices. We identified A-category concepts as the minor activities of stages of food-related household practices – starting with planning and going on with shopping, storing, cooking, consuming, and disposal (see Appendix A Codebook). However, when they are sorted by their centrality, this temporal configuration gave way to a more disordered representation that reflects complexity as it

**Table 8**
Summary of structural indices.

| Indices | Values |
|---|---|
| Number of Concepts ($n$) | 35 |
| Number of Causal Relationships ($R$) | 173 |
| Number of Receiver Concepts | 1 |
| Number of Transmitter Concepts | 6 |
| Number of Ordinary Concepts | 28 |
| Density ($D$) | 0.14 |
| Hierarchy Index ($h$) | 0.001 |

is and reveals the agency power of each driver. This ascertains that not all practice-related drivers are necessarily central and require attention. In this sense, it would be more pertinent to classify system concepts as receiver, transmitter, and ordinary (Table 7) while the initial eight categories can serve as the mainframe to facilitate narrating the HFW drivers' system (Table 6).

We argue that a democratic map brings a clear advantage over the hierarchical models drawing paths towards waste by establishing relationships between main categories of practices, societal factors, or product factors (Aschemann-Witzel et al., 2015; Roodhuyzen et al., 2017). This approach seems to be well-grounded when it is aimed to provide an understanding by simplifying the complexity. However, it agglomerates subcategories into one category, therefore, cannot dissociate the individual contribution of each factor to the outcome. Distinctly, the FCM developed by this study provides a tool that will allow practitioners to canalize their efforts more precisely by distinguishing the key drivers. From this respect, our approach is consistent with the practice-oriented approach that pinpoints the moments within the series of practices (e.g., shopping, storing, cooking, assessing, etc.) addressing which would be more effective (Hebrok and Heidenstrom, 2019; Watson et al., 2020). The yields in this investigation, on the other hand, are higher due to the broader scope of the model including not just practices but also wide-ranging factors that shape those practices, as well as due to providing prioritization of the key action points alongside their identification.

In a summary, HFW is the only receiver, in other words, the outcome of the system. All other concepts are either ordinary (28 concepts) or transmitter (6 concepts) concepts of the system. What dissociates them from each other is their centrality (their impact) in the system. Expectedly, centrality values as well as the scenario analysis findings (discussed in the next section) confirm the indisputable role of household practices. However, not all of them carry equal importance as there is not a hierarchical order between concepts. While some A-category concepts (*A12*, *A2*, and *A9*) are the most central ones, the rest of them are spread throughout the list. In addition, non-A category concepts such as *C2*, *B2*, and *C1* are also significantly central to the phenomenon of HFW. Therefore, through this democratic map, the study successfully demonstrates the disordered structure of factors whose interaction drives HFW behavior.

### 4.3. Scenario analysis

We conducted a series of scenario analyses on the resulted FCM to resolve the ambiguities driven by the complex nature of HFW drivers. Each scenario corresponds to a case in which only one system concept was activated. As a result, we sorted all concepts by the value of change in HFW ($I$) they caused in the long run. Overall (see Fig. 6), the most influential first six elements were A-category food-related household practices. This result supports the argument that to achieve significant results in HFW reduction, actual food handling practices should be targeted (Hebrok and Heidenstrom, 2019). However, researchers and decision-makers should keep in mind that many other A-category elements were ranked at the bottom of the list, showing the democratic structure of the model as discussed in the previous section.

Among the food-related household practices, the scenario analyses suggest that *A12* (failure to consume what is in the fridge) and *A2* (excessive purchasing) stand out with their greatest potential for HFW reduction. As can be recalled from the previous stages, *A12* and *A2* were the most mentioned concepts (in 16 of 17 qualitative articles) as well as the most central concepts. This finding alone highlights the significance of *A12* and *A2*, therefore, interventions addressing those elements would have the highest potential for HFW reduction. In addition, this finding generally supports the work of other studies establishing a direct link between *A12* and *A2* and HFW (Bravi et al., 2020; Falasconi et al., 2019; Janssens et al., 2019; Parizeau et al., 2015; Van Dooren et al., 2019 and others). Even though both concepts have a strong effect on HFW, focusing particularly on one of them would be a strategic decision. In the food chain activities, consumption is the latest stage that the consequences of previous wasteful practices such as excessive purchasing or cooking too much, can be observed. For instance, if consumers can put the items purchased excessively to good use by adopting some strategies during consumption, they may avert wastage. Therefore, solutions targeting *A12* can be particularly rewarding as it has the potential to mitigate the negative impacts of previous practices. On the other hand, *A2* is the initial stage that triggers the subsequent wasteful practices such as stockpiling, failure to consume what is in the fridge, and cooking and serving too much. As can be deduced from Evans et al. (2012), *A2*-related behaviors generate a 'knock-on' effect (p.124) in subsequent steps. Therefore, designing interventions that target *A2* will be a strategic step to interrupting consecutive series of specific moments that grow the risk of food wastage.

The most intriguing outcome of the scenario analysis was that *A1* (poor shopping and meal planning), one of the most mentioned concepts as a prevalent driver of HFW, led to a weak change in HFW. Even though it was the third most mentioned practice (in 15 of 17 qualitative articles) after *A12* and *A2*, our study reveals its weak impact on HFW as the 23rd among 35 concepts. In other words, *A1* has received frequent attention in the literature as opposed to its low HFW-reducing potential. This implication supports our argument that even though household practices ambivalently are the most central and influential category as expected, not all the practices are equally powerful. Therefore, by dissecting the stages of the food journey (e.g., shopping, cooking, etc.) into their sub-elements, this study accomplished to shows that the six top-rated practice-related drivers (*A12, A2, A9, A10, A5, and A13*) merit more the focus of future efforts of HFW reduction.

In the rest of the section, we continue to discuss the major findings by giving some examples to clarify how the most influential drivers can inform practitioners designing interventions to reduce HFW.

#### 4.3.1. Fail to consume what is in the fridge (A12)

Representing the amount of food that remains uneaten in consumers' homes (Dobernig and Schanes, 2019), *A12* is the most influential driver of the system. We re-examined the scenario analysis results to figure out the antecedent that could create a strong decrease in *A12*. The strongest antecedent of *A12* is *B1* (preference for fresh and variety). Uneaten food mostly constitutes leftovers that are thrown away since household members simply do not like eating the same meal and want variety in their diet (Baig et al., 2019; Evans, 2012; Farr-Wharton et al., 2014; Urrutia et al., 2019; Wansink, 2018). Thus, overturning *B1* can be regarded as the starting point to disrupting the rigidness of the practice. On the other hand, *B1* reflects the self-other trade-off (White et al., 2019) that prevents consumers to adopt a more sustainable behavior. While preferring fresh and variety (Dobernig and Schanes, 2019; Evans, 2012), consumers opt for their benefit instead of sacrificing themselves (Aschemann-Witzel et al., 2015) and tolerating the cost of inferior quality (Schanes et al., 2018) by eating leftovers.

As Moloney and Strengers (2014) argue, practices such as the habit of avoiding leftover consumption are inherited from family and, have a long history through which they become normal, and therefore,

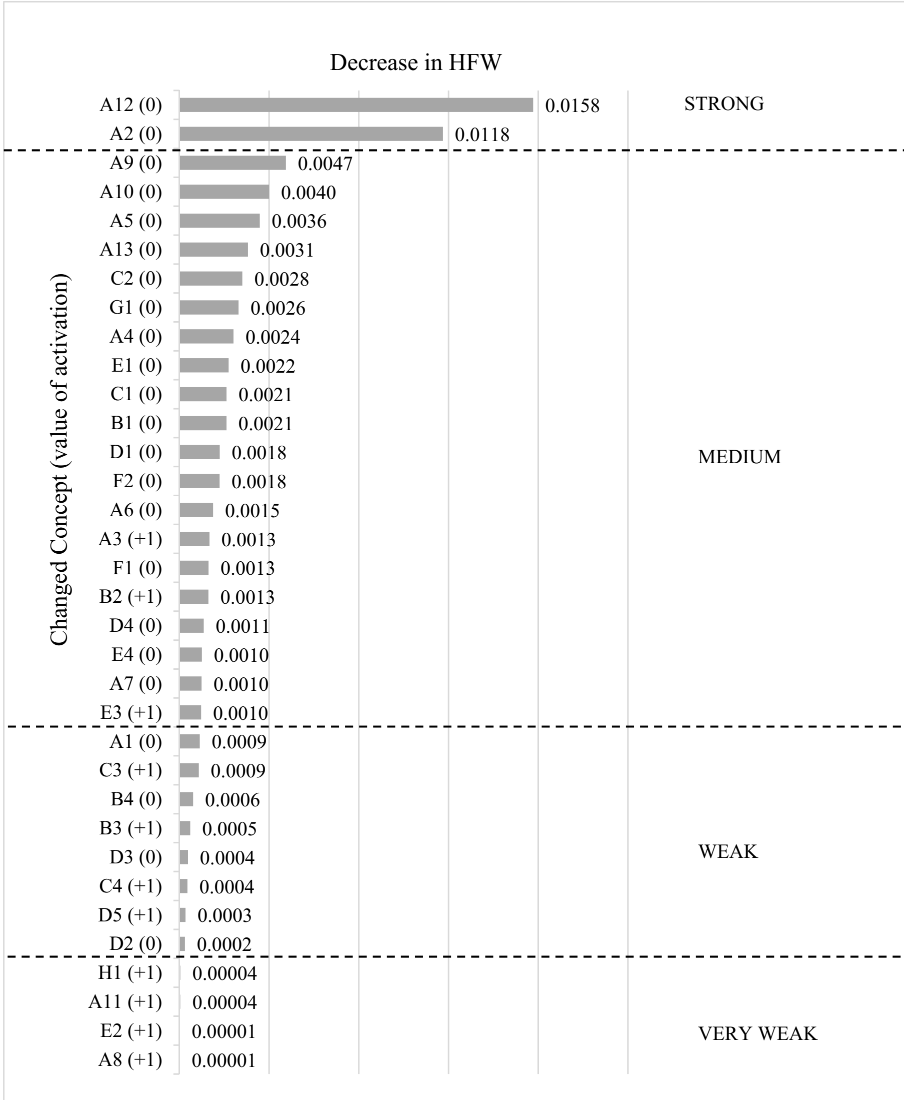


**Fig. 6.** Influence of each concept on HFW.

cannot be changed immediately by just telling people not to do it. From the practice-oriented stance, innovation of new approaches that would enable people not to give up their normality without generating waste is needed (Moloney and Strengers, 2014). One example of this is Hellmann's initiative, 'the restaurant with no food' in Brazil where people are asked to bring their thought to be useless leftovers which are then turned into five-star meals by professional chefs. The fact that meals cooked with leftovers can be transformed into tasty meals is demonstrated in practice to consumers. Therefore, our model suggests that by targeting *A12* through addressing B1, this intervention may have a significant impact on HFW.

#### *4.3.2. Excessive purchasing (A2)*

As the second most influential driver, *A2* includes various situations; impulse buying, purchasing both proper (healthy) and backup items, purchasing what already exists at home, and purchasing in bulk or big packs. According to scenario analysis results, the strongest antecedent of *A2* is *D3* (the attraction of special offers). Consumers overbuy food products due to promotional attractions in stores, such as buy-one-get-one-free and discounts (Graham-Rowe et al., 2015; Lee, 2018; Mattar et al., 2018; Wansink, 2018). Another infrastructure of provisioning-related concept, *D1* (the lack of smaller package sizes), has also a strong impact on *A2*. Scholars have reported larger package sizes as a factor that led consumers to purchase more than they needed (Aschemann-Witzel et al., 2015; Dobernig and Schanes, 2019; Urrutia et al., 2019; Wikstrom et al., 2019). These factors relate to the store structure provided the context in which the unsustainable habit of *A2* has been shaped (Dobernig and Schanes, 2019), and therefore, habit disruption requires contextual change (White et al., 2019).

Researchers (Dobernig and Schanes, 2019; Evans, 2012; Hebrok and Heidenstrom, 2019) argue that addressing food store structure as a material context that has a high impact on food-related practices could yield significant HFW reduction. With regards to the prominent antecedents, zero packaged groceries can be given as an example of contextual change that can alter *A2*. In this alternative food provisioning model, customers are expected to bring their reusable containers to eliminate the environmental burden of single-use packages. Concerning its HFW reduction potential, however, the most obvious target of the model is *D1*. In addition, these types of groceries, as compared to the conventional ones, do not rely on special offers (*D3*) to attract consumers. Therefore, our model suggests that zero packaged groceries can be a highly impactful alternative for targeting *A2* by changing the infrastructural elements *D1* and *D3*.

#### 4.3.3. Cooking and serving too much (A9)

*A12* and *A2* were followed by practice *A9* (cooking and serving too much) which caused a medium change in HFW. The strongest antecedent of the third most influential driver is *C1* (good provider identity). It is important to note that *C1* is the only concept that creates a strong change in *A12, A2*, and *A9*. As the only shared strong antecedent of the first three most influential drivers, *C1* is a key policy variable. *C1* as a system concept of the FCM constitutes hospitality (Baig et al., 2019), wishing to be a good provider (Aschemann-Witzel et al., 2015), or viewing food as an indication of wealth (Porpino et al., 2015). Addressing such socially constructed concepts requires calling the social norms or 'status quo' into question, which is perceived as politically threatening and avoided by the practitioners (Moloney and Strengers, 2014). In addition, consumers may not welcome that practitioners challenge their normal way of doing something.

In this respect, social influence created by 'aspirational role models' (White et al., 2019) or by peers (Moloney and Strengers, 2014) can motivate others to engage in the purpose of HFW reduction. To facilitate the notion of concertedness, what practitioners can do, on the other hand, is to provide a platform on which a community around HFW can originate and grow organically. Such settings may create a social force that is valued more by the people, especially when the outcome of wasting less is perceived as abstract and out of reach (White et al., 2019). The 'Love Food Hate Waste – Community' Facebook page can be one example where the meanings and images of their food-related practices are negotiated and challenged (Evans et al., 2012) not just by the social marketers but also by consumers as community members. According to Moloney and Strengers (2014), making and/or having conversations about what is normal is the first step of practice change. Therefore, by addressing cultural representations such as *C1*, communities that are formed around HFW can target most strongly *A9* together with *A12* and *A2* and thus induce a significant HFW reduction.

#### 4.3.4. Food safety and health concerns (C2)

After six top-rated A-category concepts, the most remarkable HFW-reducing impact was with the *C2* (food safety and health concerns) as it is the most interactive concept in the system: Among the 35 concepts, *C2* is the antecedent to 13 of them (see Appendix D). However, the implication of this finding (i.e., addressing *C2* through an intervention) might not be a straightforward task. The challenge of addressing *C2* emanates from its evolutionary nature through years of experiences, interactions, and exposures. Some antecedents of *C2* in our FCM such as *C1* (good provider identity), *E2* (past bad experiences), and *E4* (the detachment from food's origin) support this evolutionary nature. Similarly, Zhang et al. (2018) argued that food safety risk perception arises from a series of food safety crises experienced in the past. In addition, consumers are exposed to information regarding these cases in a heap from numerous sources such as media, governmental organizations, retailers, and consumer associations (Lobb et al., 2007).

On the other hand, caution on the rebound effect of a solution on *C2* is warranted as it can be the factor that hinders the behavior change. Food safety risk perception might accompany risk-reducing behaviors such as non-consumption (Yeung et al., 2010) or nonengagement in the case of an intervention that might obstruct its potential for behavior change. HFW literature supports this argument as well. Aschemann-Witzel et al. (2015) mention a trade-off between food safety and food wastage concerns and point out the priority given to eliminating risks of food safety hazards as opposed to waste prevention. Due to this trade-off, for instance, people prefer to dispose of leftovers they consider unhealthy (Baig et al., 2019). This implies that even if an intervention promises a substantial reduction in HFW, it could fail if it disquiets consumers. To this end, any possible rebound effect of an intervention on *C2* should not be overlooked, and practitioners should focus on the removal of the factors underpinning *C2* as potential barriers to their acceptance. This might require various measures taken by multiple actors from public, private, and non-profit sectors whose coordination becomes more of an issue to buffer against the backfire possibility of an intervention. The coordination of multiple actors must be catered to by the regulatory and incorporative efforts of the government (Moloney and Strengers, 2014) or a 'dedicated administrative body' (Evans et al., 2012).

#### 4.3.5. Lack of knowledge/skill/awareness (G1)

*C2* is followed by *G1* (lack of knowledge/skill/awareness) which similarly affects a great number of variables in the system (11 among 35). This finding indicates that raising knowledge and awareness has a higher HFW reduction potential. This finding is consistent with the literature suggesting informational interventions (Garrone et al., 2014; Stancu et al., 2016; Young et al., 2017). However, it must be interpreted with caution, as the current prolific attention on informational interventions and their effectiveness in behavior change has also been criticized (Evans, 2011; Hebrok and Heidenstrom, 2019; Osbaldiston and Schott, 2012). Criticism is grounded on the fact that informational interventions target individuals rather than their everyday food-related practices, and do not address factors such as socio-temporal factors and material conditions (Evans, 2011; Hebrok and Heidenstrom, 2019; Sutinen and Närvänen, 2021).

Considering both the unignorable potential of *C2* and the counterarguments, we argue that elaborating more on the aspects that can make an informational intervention more effective would be more constructive (Stockli et al., 2018). Therefore, burgeoning investigations into characteristics of an effective HFW knowledge and awareness campaign carry the utmost importance to be able to transform the potential of *C2* into reality. Up to date, several studies have investigated the necessary elements of a successful behavior change campaign. They propound that consumer participation (Kim et al., 2019), utilizing innovative delivery methods (Stockli et al., 2018; Zamri et al., 2020), focusing on positivity and easiness (Aschemann-Witzel et al., 2017), targeting a smaller segment and its context-dependent practices (Hebrok and Heidenstrom, 2019) and complementarity of other types of interventions (Stockli et al., 2018) are all key aspects of successful campaigns. The findings of this study will contribute to this literature by revealing the most influential practices that would enhance the effectiveness of an informational campaign. Among the first six top-rated practices, *A12* and *A13* are the most appropriate ones as *G1* changes only those two strongly.

#### 4.3.6. Resolution of the disputing relationships

Through scenario analysis, we could also clarify the dominant impact of some concepts following multiple pathways towards HFW and may have both decreasing and increasing impacts. For these concepts, we could not presume the direction of change (0 or 1) necessary to reduce HFW before observing the response of the system to both activations. For instance, consumers with economic concerns have a higher tendency towards eating leftovers with a sense of thriftiness, which in turn is an HFW reducing factor (Ellison and Lusk, 2018; Revilla and Salet, 2018). Meanwhile, consumers with economic concerns have been noted to be more vulnerable to special offers and gain a price advantage by purchasing larger packages, which leads to excessive purchasing, a practice causing HFW (Dobernig and Schanes, 2019; Farr-Wharton et al., 2014; Porpino et al., 2015). That is why *C3* (economic concerns) was activated twice by attaining '0' and '1' to figure out whether an increase or decrease in the concept would reduce HFW. As a result, when *C3* was (0), we observed a medium increase in HFW. When *C3* was (1), we observed a weak decrease in HFW (see Fig. 6). Therefore, our system supports the argument that consumers with higher economic concerns waste smaller amounts of food. In addition, with this ranking (see Fig. 6), we confirmed that an increase in economic concerns reduces HFW more than an increase in environmental concerns (Schanes et al., 2018).

Another concept that follows different pathways and may influence HFW both positively and negatively is *E2* (past bad experiences).

Consumers who have experienced scarcity in the past might attach a higher value to food and avoid wasting it (Aschemann-Witzel et al., 2015; Farr-Wharton et al., 2014; Porpino et al., 2016). On the other side, some might develop taste for abundance promoting wasteful practices such as stockpiling to leave behind bad memories (Porpino et al., 2016). Moreover, consumers who have lived bad experiences such as poisoning could be overly cautious about eating leftovers or could dispose of food early (Farr-Wharton et al., 2014). As a result of scenario analysis conducted twice by attaining '0' and '1' to *E2*, we revealed that an increase in *E2* reduces HFW. Even though the strength of change is very weak, based on this observation, we may say that facing difficulties in reaching food is an HFW reducing factor rather than a promoting factor.

Similarly, *H1* (limited technological advancement) has both a decreasing and increasing impact on HFW. Lack of proper storage conditions is shown as the cause of poor storage practices that leads to HFW (Farr-Wharton et al., 2014; Schanes et al., 2018). At the same time, Urrutia et al. (2019) propose that *H1* could promote HFW generation by promising large storage space that encourages less frequent shopping and excessive purchasing. To figure out whether an increase or a decrease in *H1* would reduce HFW, we carried out two simulations. While a decrease in *H1* led to an increase in *I*, an increase in *H1* reduces *I*. Thus, contrary to the first impression, *H1* may not be an issue that needs to be solved primarily in the fight against food waste. In other words, we may exclude renewing fridges to have larger space and optimal storage conditions from the list of suggested HFW-reducing solutions. However, looking at only the individual impacts can be misleading as we discuss in the next section.

### 4.4. Limitations and future research

A few potential limitations need to be recognized. Among the points proposed to alter the complex nature of HFW behavior, this study aims to address the identification of the most influential drivers. In line with this objective, we conducted scenario analyses by activating HFW drivers alone to be able to obtain a prioritization. This knowledge is valuable to initiate an effective intervention or to improve the effectiveness of an intervention. However, it can also be misleading if it shadows the alternative solutions. For instance, the weak individual impact of *D3* (the attraction of special offers) does not mean that addressing *D3* would be insignificant in the fight against HFW. Addressing *D3* by changing the promotion type can still create a significant impact if this change triggers one of the most influential practices alongside, namely *A2* (excessive purchasing) as we have discussed in Section 4.3.2. In addition, addressing multiple elements is another prerequisite to breaking the inflexible nature of practices. Therefore, when selecting among the alternatives, decision-makers should avoid reliance on drivers` prioritization so that the creative solutions will not be shunned. The focus should be on the system response to the activation of all possible concepts rather than their isolated impacts.

At this point, analysis of scenarios inspired by the real intervention cases would contribute greatly. Future studies can generate those scenarios by identifying the system concepts potentially triggered by each case. The basic examples given throughout the discussion of the study findings can guide interested researchers and practitioners on how to frame a scenario by the constructs of the proposed model. These scenarios should be extended to constitute all possible system concepts apart from the ones used by this study to demonstrate the utilization of the most influential drivers. Scenario analyses can also be enriched by considering the system concepts that may come out as rebound effects. Moreover, employing transmitter concepts as indicators of group characteristics, these analyses can be specialized to a particular group of people or a context. We also encourage future efforts to enlarge both the number and the type of interventions inspiring the scenario analyses to produce broader and comparative insights.

Furthermore, the resulting FCM might still be incomplete for certain contexts. This was observed during a meeting with one of the experts consulted. The expert stated that 'feeding the animals' is a common disposal practice that influences the HFW behaviors in the Turkish context where the protection of street animals is a contemporary issue. However, when we considered the objective and the scope of the study, we agreed with its exclusion due to its lower impact within the system representing a wider range of contexts. In addition, the resulting FCM represents a system of HFW drivers before COVID-19. Early research showcases how the pandemic might have transformed household food practices (Babbitt et al., 2021; Lahath et al., 2021). Therefore, the scope of FCM provided by this study should be critically examined for the possibility of a need for an extension. After all, the proposed FCM can be used as it is, customized to a specific context or a targeted group, or with changing temporal dynamics, as it is a flexible model that enables the inclusion of extra concepts and relationships. Furthermore, through the comparison of FCMs constructed for special contexts or periods, future research can generate new insights into factors accelerating behavior change.

Another contextual limitation stems from the scarcity of research studying HFW in the developing parts of the world. This research aimed to obtain an FCM unspecific to a context, therefore, seek for context diversity in sample selection. At the same time, we pursued ample evidence to fill the possible relationship gaps in the resulting FCM. However, as more articles were included in content analysis, the balance between developed and developing contexts could not be kept due to the shortcoming of studies conducted in developing ones. Therefore, future work in developing countries would help researchers to reach a model that represents both contexts equally. The unbalance in the literature is a natural consequence of the fact that in developed countries FW occurs in households whereas in underdeveloped countries it occurs in the primary stages of FSC. However, Lopez Barrera and Hertel (2021) have recently projected rapid growth of HFW in low and middle-income countries together with an increase in income levels and highlighted the precedence of interventions to change consumption behaviors. This again underlines the need for further work exploring the drivers of HFW and their complex interrelationships in developing regions.

A key strength of this research is its ability to take consumer perspective into the center of the inquiry, rather than primarily relying on the professional opinion that has been the common approach in FCM studies. Since this research aims to obtain a model unspecific to a context, academic articles as secondary resources that provide ample empirical evidence about consumer HFW behavior, are used. However, if the system concepts and their relationships could be identified through primary data collection methods such as interviews or focus groups with consumers, the utility of consumer centricity could be more explicit in the resultant FCM. When treated as experts, consumers might be more open and collaborative. Thus, future consumer behavior research could focus on exploring the applicability and the utility of FCM as a participatory method.

On the other hand, the procedures followed in this study to acquire knowledge can offer novel opportunities for FCM researchers. Contrary to the general opinion that FCM is useful when there is a lack of knowledge, it might be possible to refine big data (if it is available for the topic of interest as in the case of HFW) that is scattered, heterogeneous, inconsistent, or fragmented through FCM. This would be a promising approach for the development of FCM as it eliminates the problems of knowledge elicitation from experts. As noted by Jetter and Kok (2014) one major barrier to the widespread use of FCM is the difficulties in this process such as the inaccessibility of the respondents and their time limitations. In data-rich domains, adopting a hybrid approach can also be an alternative to knowledge acquisition from experts. For instance, Wee et al. (2015) integrated FCM with the Bayesian belief network to draw its powerful reasoning capability and develop a method for learning the causal network from the data. In this respect, future research combining FCM with other techniques would enlarge the scope of FCM applicability and contribute to its advancement. In addition to the Bayesian belief network (Azar and Dolatabad, 2019) agent-based modeling to represent interacting agents (Davis et al., 2019; Giabbanelli et al., 2017) or artificial neural network for time-series forecasting (Papageorgiou et al., 2019; Averkin and Yarushev, 2017) are the other techniques used by researchers interested in hybrid approaches to draw the strengths of both techniques.

Even though the use of FCM provided us with the advantage of tackling the complexities of HFW, the inherent characteristics of the methodology may limit the effectiveness of the data analyses. The conversion of rich qualitative data into quantitative representation might have led to the misrepresentation of some concepts or relationships. For this reason, the findings of this study should be regarded as indicative and should be adopted abiding by the broader context and understanding of the field. We suggest that future research should validate whether a scenario would induce presupposed changes through longitudinal case studies or experimental studies.

## 5. Conclusion

HFW reduction is critical in the fight against climate change and can be achieved by breaking the inflexible nature of unsustainable HFW-generating practices. To this end, this study set out to identify the most influential HFW drivers that are proposed as the first ladder to reach that goal. Utilizing a three-stage methodology that integrates theory, previous research findings, and expert opinion, this study has reached findings that have several theoretical and practical implications. First, we build an FCM that enabled us to address the complexity factors, therefore, presenting a more complete, democratic, and consumer-centric model of the HFW drivers` system. Second, through the analysis of scenarios aiming to change one driver at a time, this study prioritizes the HFW drivers by their HFW-reducing impacts. The order of drivers indicates starting points to canalize efforts of HFW reduction. The ranking shows that interventions that target the six top-rated household food-related practices (particularly *A12* and *A2* with strong impact followed by *A9, A10, A5*, and *A13* with medium impacts) can be very rewarding HFW-reducing efforts. In addition, *C2* and *G1* are the next most influential non-A-category concepts indicating the need for addressing food safety and health concerns as a potential rebound effect and to enhance the efficiency of informational campaigns to seize upon their potential. Finally, the present study uncovers the dominant impact of the concepts that are both positively and negatively affecting HFW. Ultimately, this study represents a tool that will enable testing wide-ranging scenarios inspired by real cases and intervention alternatives. Comparison of these scenarios within a consistent base can generate more nuanced insights for actors designing FW-reduction interventions.

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## 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.

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## Appendix A. Codebook

| # | Categories | Nodes | Example of Content Coded | Reference |
|---|---|---|---|---|
| 1 | Attitudes and Preferences | Desire to cook for specific purposes | *"As part of the culture, the Saudis love setting up lavish food tables during Eid festivals, weddings, parties, or informal get-togethers. They love to organize abundant banquets where wasting food is an indispensable feature."* | (Baig et al., 2019: p.1748) |
| 2 | Attitudes and Preferences | Feeling of guilt | *"The idea that good food cannot be thrown out was common to all of the households encountered in the study and they variously described themselves as 'worrying', 'feeling bad' or 'feeling guilty' about wasting food."* | (Evans, 2012: p.46) |
| 3 | Attitudes and Preferences | Preference for fresh and variety | *"Really, I don't like eating the same thing again, so I end up not eating it and throwing it out anyway."* | (Reynolds et al., 2019: p.51) |
| 4 | Attitudes and Preferences | Suboptimality perception | *"Regarding consumer food provisioning in terms of purchasing, a U.S. experiment found that consumers show little tolerance for visual imperfections"* | (Aschemann-Witzel et al., 2015: p.6462) |
| 5 | Attitudes and Preferences | Value / appreciation of food | *"A lack of knowledge about production processes makes it more difficult to appreciate the materiality of the produced good: for instance, the less you know and have experienced what it takes to produce a tomato, the harder it is to appreciate and ultimately value the growing process and the produce itself."* | (Dobernig and Schanes, 2019: p.8) |
| 6 | Concerns | Concern to decrease leftover ingredients | *"One of the things that I try to do is batch cook stuff, so I don't have like four or five half used ingredients kicking around."* | (Evans, 2012: p.51) |
| 7 | Concerns | Economic concerns | *"Economic constraints and price orientation traditionally, and to a renewed extent during the economic crisis, are drivers of food waste avoidance both in the store, as well as in the household."* | (Aschemann-Witzel et al., 2015: p.6469) |
| 8 | Concerns | Environmental concerns | *"Williams* et al. *(2012) indicate that respondents with greater environmental commitment waste less food that has passed its 'best before date'."* | (Schanes et al., 2018: p.985) |
| 9 | Concerns | Food safety and health concerns | *"People prefer to throw away the leftover food as they think it is unhealthy to eat or they do not want to eat the same food twice."* | (Baig et al., 2019: p.1748) |
| 10 | Concerns | Good provider identity | *"The so-called good mother identity (Stuart, 2009) is characterized by the desire to provide plenty of food, and it is related to the role of the matriarch. This can generate more waste and has been also reported to be a barrier to minimizing food waste in a study conducted in UK households (Graham-Howe* et al., *2014)."* | (Porpino et al., 2015: p.624) |
| 11 | Concerns | Social concerns | *"Ethical reasons related to fairness (*e.g., *in light of worldwide hunger)"* | (Aschemann-Witzel et al., 2015: p.6468) |
| 12 | Consumption Practices | Fail to consume what is in the fridge | *"When food is stored at home but not consumed are especially relevant"<br>* "Amounts of food that remain un-eaten in consumers' homes."* | (Dobernig and Schanes, 2019: p.2 & 7) |
| 13 | Consumption Practices | Reluctance to use own senses | *"We observed our study participants to experience difficulties in judging food's edibility. The findings showed consumers, particularly those who had negative experiences with food in the past, were prone to dispose of food prematurely."* | (Farr-Wharton et al., 2014: p.399) |
| 14 | Disposal Practices | Feeding the animals | *"Throwing away food that is fit for human consumption is 'unlawful'; it should be given to the poor or ultimately to animals."* | (Revilla and Salet, 2018: p.326) |
| 15 | Disposal Practices | Postponing the disposal | *"Procrastination, occasionally transforming valuable food (in particular leftovers) into waste by allowing the unpleasant disposal of food to be deferred."* | (Dobernig and Schanes, 2019: p.8) |

(continued on next page)

(*continued*)

| # | Categories | Nodes | Example of Content Coded | Reference |
|---|---|---|---|---|
| 16 | Domestic Material Conditions | Closeness of the fridge and the freezer to kitchen | *"In the households where the fridge and freezer were both located in the kitchen, the freezer was more actively used to prolong the lifespan of some food items by moving them from the fridge to the freezer."* | (Hebrok and Heidenstrom, 2019: p.1439) |
| 17 | Domestic Material Conditions | Limited technological advancements | *"This statement illustrates that having adequate storage possibilities, that is, both enough space and optimal storage conditions (temperature and lighting conditions) was crucial for our respondents to ensure that purchased food was kept fresh."* | (Dobernig and Schanes, 2019: p.6) |
| 18 | Food Preparation and Serving Practices | Cooking and serving too much | *"I bought too much food", "I cooked too much food", and "I do not use leftovers" showed a strong influence on the dependent variable, increasing the probability of the observations to declare a high household food waste.* | (Falasconi et al., 2019: p.6) |
| 19 | Food Preparation and Serving Practices | Cooking style | * Negative Side: Tried and tested recipes instead of using what is left in the fridge<br>* Positive Side: Cooking from scratch (not using readymade mixture of ingredients)<br>* *"We also observed that all these mothers have the habit of cooking from scratch, which can lead to over-preparation and therefore to more waste."* | (Porpino et al., 2015: p.625) |
| 20 | Food Preparation and Serving Practices | Leftover generation | *"Eight participants used time-saving strategies in meal-planning practices, including making leftovers on purpose to eat as future lunches and freezing meals in anticipation of future time scarcity."* | (Urrutia et al., 2019: p.4) |
| 21 | Food Preparation and Serving Practices | Overpreparation | *"The discarding of unconsumed food after cooking is also due to preparation problems such as burning the food."* | (Porpino et al., 2015: p.624) |
| 22 | Food Preparation and Serving Practices | Using self-service and smaller plates | *"Waste can also be increased by the overpreparation of these stockpiled foods or by the overserving that can occur because of large serving bowls or plates"* | (Porpino et al., 2015: p.621) |
| 23 | Infrastructure of Provision | Accessibility/ physical proximity of the food store | *"Access to grocery stores was linked to over-purchasing, in one of two ways: through the lack of a conveniently located store or having access to a vehicle".* | (Urrutia et al., 2019: p.4) |
| 24 | Infrastructure of Provision | The attraction of special offers | *"Additionally, the coefficient of 'Buy special offer' is significantly negative, suggesting that those who buy more special offers tend to waste more food. Our results suggest that those who buy more special offers tend to waste more food."* | (Mattar et al., 2018: p.1221) |
| 25 | Infrastructure of Provision | Huge food variety in a retailer | *"Some reported that the big offers tempted them to buy more food than planned because they did not want to make a decision that they would regret later on."* | (Dobernig and Schanes, 2019: p.5) |
| 26 | Infrastructure of Provision | Lack of smaller package sizes | *"Small, single-unit package sizes that are common in Japan made it easy to buy the amount that could be consumed at once while enabling to cook versatile meals and not-too-big an amount at a time"* | (Sirola et al., 2019: p.8) |
| 27 | Infrastructure of Provision | Low food prices | *"Economic affluence and welfare policies make food items available at subsidized rates, to the extent that most people can afford to waste"* | (Baig et al., 2019: p.1744) |
| 28 | Infrastructure of Provision | The magnitude of the food store | *"food waste is highest when people exclusively shop in large supermarkets, and decreases when purchasing takes place in different shopping facilities, in small shops and local markets"* | (Schanes et al., 2018: p.983) |
| 29 | Infrastructure of Provision | Visual appeal of food | *"In such cases, participants would buy 'whatever looks good', or what appealed to their senses, changing plans as they shopped"* | (Urrutia et al., 2019: p.4) |
| 30 | Knowledge and Awareness | Lack of knowledge/ skill/ awareness | *"Another prevalent trait in the sample studied is the lack of knowledge about adequate food storage"* | (Porpino et al., 2015: p.625) |
| 31 | Package and Food Properties | Confusing date labels | *"Using expiration dates, use by, or best purchased by labels psychologically extend the timing window that a person believes they would have before they would have to throw the product away"* | (Wansink, 2018: p.505) |
| 32 | Package and Food Properties | Familiarity/ reusability | *"Moreover, the participants who planned to use the same, familiar ingredients in several meals were generally more successful in putting all the food to use than those who tended to experiment more with unfamiliar ingredients and who planned very different dishes from day to day."* | (Hebrok and Heidenstrom, 2019: p.1444) |
| 33 | Package and Food Properties | Fresh/organic | *"Freshness* (e.g., *fresh food ingredients, meals cooked 'from scratch' and organic food) and taste are less frequently wasted than low-quality foods* (e.g., *processed food and less fresh food)"* | (Hebrok and Heidenstrom, 2019: p.1443) |
| 34 | Package and Food Properties | Lack of improved packaging | *"Cheese is seldom sold in packaging with a reclosing function. As the environmental impact of cheese is very high when compared to its packaging, it can be justifiable to invest in more packaging material, adding reclosing functions and/or lower amounts of cheese per package."* | (Wikstrom et al., 2019: p.7) |
| 35 | Package and Food Properties | Temporality/ perishability of food | *"The main reason for the wastage of fruits and vegetables is that they have degraded in quality"* | (Wikstrom et al., 2019: p.8) |
| 36 | Planning Practices | Poor shopping and meal planning | *"Our findings also indicate that mechanisms for domestic waste reduction such as shopping lists and planning meals may also reduce the occurrence of these incidents and help to encourage a shift in shopping routine"* | (Farr-Wharton et al., 2014: p.399) |
| 37 | Shopping Practices | Excessive purchasing | *"How the accumulation of food items that consumers never end up preparing or consuming—often referred to as 'overbuying' or 'overprovisioning'—comes about"* | (Dobernig and Schanes, 2019: p.2) |
| 38 | Shopping Practices | Shopping frequency | *"The frequency of shopping was also found to have an impact on food waste quantities, with food waste levels almost doubling for families who shopped once a month or every two weeks"* | (Giordano et al., 2019b: p.11) |
| 39 | Shopping Practices | Shopping with car | *"Four participants with limited (or no) access to a car noted that they usually could not buy large amounts of food because they were not able to carry it home."* | (Urrutia et al., 2019: p.4) |
| 40 | Social Relations | Eating together | *"The importance of rituals around the practice of eating, such as sitting at the table and eating together 'as a family', for transmitting food values to children."* | (Revilla and Salet, 2018: p.327) |
| 41 | Social Relations | Miscommunication between household members | *"Further, observations showed that households with more than one person purchasing food are subject to miscommunication between household members, which led to multiple same-day purchases of a product."* | (Farr-Wharton et al., 2014: p.397) |
| 42 | Social Relations | Sharing | *"Leftover food has different value for different actors, and it can be given to others to kill two birds with one stone: fulfilling the moral commitment to rescue value and sustain social relations."* | (Sosna et al., 2019: p.328) |
| 43 | Socio-Temporal Context | Detachment of food consumption and production | *"A lack of connection between consumers and the production of food and agricultural raw materials was suspected by one expert, with the effect that consumers have difficulty visualizing growth and production. Consumers thus might lack an understanding of variation in appearance or lack proper valuation of the food."* | (Aschemann-Witzel et al., 2015: p.6466) |
| 44 | Socio-Temporal Context | Effort devoted for food practices | *"Those households who spent more money eating out produced more organic waste than other households, leading to our hypothesis that these households are allowing groceries and/or leftovers to spoil in favour of meal options that are more spontaneous or convenient than cooking."* | (Parizeau et al., 2015: p.215) |
| 45 | Socio-Temporal Context | Increasing urbanization | *"First, we argue that rural environment might be special because of the opportunity to achieve long-term experience with plants and animals that shape human perception of value flows and reduces food wasting"* | (Sosna et al., 2019: p.326) |
| 46 | Socio-Temporal Context | Past bad experiences | *"Those consumers that have not experienced scarcity are often not overly concerned about ensuring the consumption of all the food they purchased before it expires. Therefore, they are more likely to throw out expired unconsumed goods"* | (Farr-Wharton et al., 2014: p.394) |
| 47 | Socio-Temporal Context | The rhythm of everyday life | * *"Waste, then, often occurs when food is bought but not eaten because of unplanned events occurring in consumers´ daily lives"* | * (Dobernig and Schanes, 2019: p.2) |

(*continued*)

| # | Categories | Nodes | Example of Content Coded | Reference |
|---|---|---|---|---|
| | | | * *"Where public debates intimate that food, waste arises when individuals do not have enough time to cook 'properly'"* * *"The problem of keeping on top of ingredients in various states of decay was not exclusive to persons living alone and managing an erratic work schedule"* | * (Evans, 2011: p.434) * (Evans, 2011: p.435) |
| 48 | Storing Practices | Failure to extend lifetime of food | *"The most important feature of the refrigerator today is its ability to maximize shelf life; however, there may still be untapped potential for using the refrigerator to reduce the uncertainty of shelf life and create more use-occasions."* | (Hebrok and Heidenstrom, 2019: p.1439) |
| 49 | Storing Practices | Lost/forgotten/Ignored food Items | *"Comments regarding the low visibility of food items within the refrigerator, particularly of items that were not located towards the front of shelves"* | (Farr-Wharton et al., 2014: p.396) |
| 50 | Storing Practices | Poor storage practices | *"The amount of food waste due to incorrect storage is only evaluated in the Norwegian studies, where consumers stated the incorrect storing during transport or in the home as a reason for waste"* | (Wikstrom et al., 2019: p.9) |
| 51 | Storing Practices | Stockpiling | *"These external influences point to underlying promoters of particular food purchasing behaviors that contribute to domestic food waste, such as the stockpiling of food."* | (Farr-Wharton et al., 2014: p.394) |
| 52 | Storing Practices | Using freezer | *"The second identified bundle of organising temporality is that of pausing. The sociomaterial practice of freezing food for future use was central in this bundle"* | (Mattila et al., 2019: p.1632) |

## Appendix B. List of qualitative articles

| # | Author (year) | Journal | Title | Methodology | Context |
|---|---|---|---|---|---|
| 1 | Aschemann-Witzel et al. (2015) | Sustainability | Consumer-Related Food Waste: Causes and Potential for Action | Literature Review + Expert Interviews | Europe |
| 2 | Baig et al. (2019) | Saudi Journal of Biological Sciences | Food waste posing a serious threat to sustainability in the Kingdom of Saudi Arabia – A systematic review | Literature Review | Kingdom of Saudi Arabia |
| 3 | Dobernig and Schanes (2019) | International Journal of Consumer Studies | Domestic spaces and beyond: Consumer food waste in the context of shopping and storing routines | In-depth, qualitative study | Austria |
| 4 | Evans (2011) | Critical Public Health | Blaming the consumer – once again: the social and material contexts of everyday food waste practices in some English households | Ethnographic study | UK |
| 5 | Evans (2012) | Sociology | Beyond the Throwaway Society: Ordinary Domestic Practice and a Sociological Approach to Household Food Waste | Ethnographic study | UK |
| 6 | Farr-Wharton et al. (2014) | Journal of Consumer Behavior | Identifying factors that promote consumer behaviors causing expired domestic food waste | Interviewing + Participant Observation | Australia |
| 7 | Hebrok and Heidenstrom (2019) | Journal of Cleaner Production | Contextualising food waste prevention - Decisive moments within everyday practices | Qualitative – Fridge Study | Norway |
| 8 | Mattila et al. (2019) | Time & Society | Dances with potential food waste: Organising temporality in food waste reduction practices | Qualitative analysis of blog spots and in-depth interview | Finland |
| 9 | Porpino et al. (2015) | International Journal of Consumer Studies | Food waste paradox: antecedents of food disposal in low income households | Observations, in-depth interviews, photographs | Lower-middle income Brazilian households |
| 10 | Porpino et al. (2016) | Journal of Food Products Marketing | Wasted Positive Intentions: The Role of Affection and Abundance on Household Food Waste | In-depth interviews, observations, and analysis of photos | Lower-middle income American families |
| 11 | Revilla and Salet (2018) | Journal of Cleaner Production | The social meaning and function of household food rituals in preventing food waste | Q-methodology and semi-structured interviews | Amsterdam |
| 12 | Schanes et al. (2018) | Journal of Cleaner Production | Food waste matters - A systematic review of household food waste practices and their policy implications | Systematic Literature Review | – |
| 13 | Sirola et al. (2019) | Sustainability | Mottainai! — A Practice Theoretical Analysis of Japanese Consumers' Food Waste Reduction | Mobile ethnography | Japan |
| 14 | Sosna et al. (2019) | Journal of Cleaner Production | Rescuing things: Food waste in the rural environment in the Czech Republic | Waste composition analysis of household waste and ethnographic research | Rural region in Czech Republic |
| 15 | Urrutia et al. (2019) | Resources, Conservation & Recycling | Material and visceral engagements with household food waste: Towards opportunities for policy interventions | Interviews, participant observation, and food waste measurements | Canada |
| 16 | Wansink (2018) | Journal of Food Products Marketing | Household Food Waste Solutions for Behavioral Economists and Marketers | Literature Review | – |
| 17 | Wikstrom et al. (2019) | Sustainability | The Importance of Packaging Functions for Food Waste of Different Products in Households | Literature Study + Expert Workshop | Sweden |

## Appendix C. List of quantitative articles

| # | Author (year) | Journal | Title | Methodology | Context |
|---|---|---|---|---|---|
| 1 | Abeliotis et al. (2016) | Waste Management & Research | Food waste prevention in Athens, Greece: The effect of family characteristics | Questionnaire study | Greece |
| 2 | Amirudin and Gim (2019) | Resources, Conservation & Recycling | Impact of perceived food accessibility on household food waste behaviors: A case of the Klang Valley, Malaysia | Literature review + Survey | Malaysia |
| 3 | Bravi et al. (2020) | Resources, Conservation & Recycling | Factors affecting household food waste among young consumers and actions to prevent it. A comparison among UK, Spain and Italy | Questionnaire study | UK, Spain and Italy |
| 4 | Diaz-Ruiz et al. (2018) | Journal of Cleaner Production | Moving ahead from food-related behaviors: an alternative approach to understand household food waste generation | Questionnaire study | Spain |
| 5 | Van Dooren et al. (2019) | Waste Management | Measuring food waste in Dutch households: A synthesis of three studies | Survey | Dutch Households |
| 6 | De Hooge et al. (2017) | Food Quality and Preference | This apple is too ugly for me! Consumer preferences for suboptimal food products in the supermarket and at home | An online choice experiment | Northern European |

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(*continued*)

| # | Author (year) | Journal | Title | Methodology | Context |
|---|---|---|---|---|---|
| 7 | Elimelech et al. (2019) | Sustainability | Exploring the Drivers behind Self-Reported and Measured Food Wastage | Physical waste, food purchases survey, questionnaire | Israel |
| 8 | Ellison and Lusk (2018) | Applied Economic Perspectives and Policy | Examining Household Food Waste Decisions: A Vignette Approach | Vignette methodology | U.S. |
| 9 | Falasconi et al. (2019) | Sustainability | Such a Shame! A Study on Self-Perception of Household Food Waste | Questionnaire study | Italy |
| 10 | Fanelli (2019) | Sustainability | Using Causal Maps to Analyse the Major Root Causes of Household Food Waste: Results of a Survey among People from Central and Southern Italy | Exploratory on-line survey | Italy |
| 11 | Giordano et al. (2019a) | International Journal of Consumer Studies | Do discounted food products end up in the bin? An investigation into the link between deal-prone shopping behavior and quantities of household food waste | Food waste diary experiment | Italy |
| 12 | Giordano et al. (2019b) | Sustainability | Quantities, Determinants, and Awareness of Households' Food Waste in Italy: A Comparison between Diary and Questionnaires Quantities | A diary and questionnaire study | Italy |
| 13 | Ilyuk (2018) | Journal of Retailing and Consumer Services | Like throwing a piece of me away: How online and in-store grocery purchase channels affect consumers' food waste | Experimental approach | – |
| 14 | Jaeger et al. (2018) | Food Quality and Preference | Buy, eat or discard? A case study with apples to explore fruit quality perception and food waste | Eye tracking | Uruguay |
| 15 | Janssens et al. (2019) | Foods | How Consumer Behavior in Daily Food Provisioning Affects Food Waste at Household Level in The Netherlands | An online survey | Netherlands |
| 16 | Jereme et al. (2016) | International Journal of Advanced and Applied Sciences | Addressing the problems of food waste generation in Malaysia | Questionnaire study | Malaysia |
| 17 | Mondejar-Jimenez et al. (2016) | Journal of Cleaner Production | From the table to waste: An exploratory study on behavior towards food waste of Spanish and Italian youths | Survey referring to PLS-SEM approach | Spain, Italy |
| 18 | Jörissen et al. (2015) | Sustainability | Food Waste Generation at Household Level: Results of a Survey among Employees of Two European Research Centers in Italy and Germany | Online survey | German, Italy |
| 19 | Lanfranchi et al. (2016) | British Food Journal | Household food waste and eating behavior: empirical survey | Survey | Italy |
| 20 | Lee (2018) | Journal of Cleaner Production | Grocery shopping, food waste, and the retail landscape of cities: The case of Seoul | Survey | South Korea |
| 21 | Mattar et al. (2018) | Journal of Cleaner Production | Attitudes and behaviors shaping household food waste generation: Lessons from Lebanon | Questionnaire study | Lebanon |
| 22 | Melbye et al. (2017) | Journal of Food Products Marketing | Throwing It All Away: Exploring Affluent Consumers' Attitudes Towards Wasting Edible Food | Survey | Norway |
| 23 | Parizeau et al. (2015) | Waste Management | Household-level dynamics of food waste production and related beliefs, attitudes, and behaviors in Guelph, Ontario | Waste weight + Survey | Canada, Ontario |
| 24 | Pellegrini et al. (2019) | British Food Journal | Household food waste reduction: Italian consumers' analysis for improving food management | Questionnaire study | Italy |
| 25 | Ponis et al. (2017) | Journal of Cleaner Production | Household food waste in Greece: A questionnaire survey | Questionnaire study | Greece |
| 26 | Ratinger et al. (2016) | Agric. Econ. – Czech | Sustainable consumption of bakery products; a challenge for Czech consumers and producers | Survey + focus group | Czech Republic |
| 27 | Russell et al. (2017) | Resources, Conservation & Recycling | Bringing habits and emotions into food waste behavior | Questionnaire study | UK |
| 28 | Qi and Roe (2016) | PLoS ONE, Research Article | Household Food Waste: Multivariate Regression and Principal Components Analyses of Awareness and Attitudes among U.S. Consumers | Model estimation by referring to a national survey of U.S. residents | U.S. |
| 29 | Schmidt (2016) | Resources, Conservation and Recycling | Explaining and promoting household food waste-prevention by an environmental psychological based intervention study | Intervention study | Germany |
| 30 | Schmidt and Matthies (2018) | Resources, Conservation & Recycling | Where to start fighting the food waste problem? Identifying most promising entry points for intervention programs to reduce household food waste and overconsumption of food | Online survey | Germany |
| 31 | Secondi et al. (2015) | Food Policy | Household food waste behavior in EU-27 countries: A multilevel analysis | The multilevel statistical perspective by referring to the 2013 Flash Eurobarometer survey | Europe |
| 32 | Setti et al. (2016) | British Food Journal | Italian consumers' income and food waste behavior | A questionnaire study | Italy |
| 33 | Stancu et al. (2016) | Appetite | Determinants of consumer food waste behavior: Two routes to food waste | Survey | Denmark |
| 34 | Visschers et al. (2016) | Journal of Environmental Psychology | Sorting out food waste behavior: A survey on the motivators and barriers of self-reported amounts of food waste in households | Mail Survey | Switzerland |

## Appendix D. List of causal relationships

| Concept | Influence[3] | # of articles coded[4] | | Relationship strength[5] | Concept | Influence | # of articles coded | | Relationship strength |
|---|---|---|---|---|---|---|---|---|---|
| A1 → | A2 (+) | 8 | 7 | 0.28 | A8 → | A5 (+) | 2 | – | 0.08 |
| | A2 (NR) | 1 | | | | A7 (−) | 2 | – | −0.08 |
| | A10 (+) | 1 | – | 0.04 | | A10 (−) | 1 | – | −0.04 |
| | A12 (+) | 1 | 0 | 0 | | D1 (−) | 1 | – | −0.04 |
| | A12 (−) | 1 | | | | F1 (−) | 1 | – | −0.04 |
| | A12 (NR) | 1 | | | | I (+) | 1 | 0 | 0 |
| | D3 (+) | 1 | – | 0.04 | | I (−) | 1 | | |
| | G1 (−) | 1 | – | - 0.04 | A9 → | A10 (+) | 7 | – | 0.28 |
| | I (+) | 12 | 2 | 0.08 | | I (+) | 10 | – | 0.40 |
| | I (NR) | 7 | | | A10 → | A5 (+) | 1 | – | 0.04 |
| | I (−) | 3 | | | | A12 (+) | 1 | – | 0.04 |

(*continued*)

| Concept | Influence[3] | # of articles coded[4] | | Relationship strength[5] | Concept | Influence | # of articles coded | | Relationship strength |
|---|---|---|---|---|---|---|---|---|---|
| A2 → | A4 | 6 | – | 0.24 | | B2 (−) | 1 | – | −0.04 |
| | A9 | 1 | – | 0.04 | | B3 (+) | 1 | – | 0.04 |
| | A12 | 3 | – | 0.12 | | I (+) | 10 | – | 0.40 |
| | H1 | 1 | – | 0.04 | A11 → | A9 (+) | 2 | – | 0.08 |
| | I (+) | 21 | 20 | 0.80 | | A12 (−) | 3 | – | −0.12 |
| | I (NR) | 1 | | | | B4 (−) | 1 | – | −0.04 |
| A3 → | A2 (−) | 3 | – | −0.12 | A12 → | A5 (+) | 2 | – | 0.08 |
| | A4 (−) | 2 | – | −0.08 | | I (+) | 25 | – | 1.00 |
| | A12 (−) | 2 | – | −0.08 | A13 → | A8 (−) | 1 | – | −0.04 |
| | I (−) | 10 | 9 | −0.36 | | I (+) | 8 | – | 0.32 |
| | I (+) | 1 | | | B1 → | A10 (−) | 1 | – | −0.04 |
| A4 → | A5 (+) | 2 | – | 0.08 | | A12 (+) | 11 | – | 0.44 |
| | A10 (+) | 1 | – | 0.04 | | I (+) | 5 | – | 0.20 |
| | A12 (+) | 2 | – | 0.08 | B2 → | A1 (−) | 1 | – | −0.04 |
| | B1 (+) | 1 | – | 0.04 | | A2 (−) | 1 | – | −0.04 |
| | I (+) | 6 | – | 0.24 | | A10 (−) | 1 | – | −0.04 |
| A5 → | A9 | 2 | – | 0.08 | | A12 (−) | 2 | – | −0.08 |
| | A12 (+) | 4 | – | 0.16 | | B1 (−) | 1 | – | −0.04 |
| | I (+) | 9 | – | 0.36 | | B3 (+) | 2 | – | 0.08 |
| A6 → | A5 | 3 | – | 0.12 | | I (−) | 7 | – | −0.28 |
| | A7 | 4 | – | 0.16 | B3 → | A12 (−) | 1 | – | −0.04 |
| | A12 | 1 | – | 0.04 | | G1 (−) | 2 | – | −0.08 |
| | I (+) | 5 | 4 | 0.16 | | I (−) | 5 | 3 | −0.12 |
| | I (NR) | 1 | | | | I (NR) | 1 | | |
| A7 → | A12 | 1 | – | 0.04 | | I (+) | 1 | | |
| | I (+) | 3 | – | 0.12 | | | | | |

[3](+) is denoted for a positive relationship, (NR) is denoted for no relationship, and (−) is denoted for a negative relationship between concepts and influenced concepts.
[4]Derived from the analysis of 51 qualitative and quantitative articles. Some concepts may have diverse influences on others. The second column under the # of articles column is for the adjusted # of articles coded for the most powerful relationship.
[5]Strength of influence was gathered through the normalization of article numbers between 0 and 1. The most powerful influence was referred by 25 articles between *A12* and *I*. So, its strength was assigned with 1 and others normalized accordingly.

| Concept | Influence | # of articles coded | | Relationship strength | Concept | Influence | # of articles coded | | Relationship strength |
|---|---|---|---|---|---|---|---|---|---|
| B4 → | B2 (−) | 1 | – | −0.04 | D1 → | A2 (+) | 7 | – | 0.28 |
| | I (+) | 2 | – | 0.08 | | A9 (+) | 4 | – | 0.16 |
| C1 → | A2 (+) | 6 | – | 0.24 | | A10 (+) | 2 | – | 0.08 |
| | A4 (+) | 2 | – | 0.08 | | A12 (+) | 2 | – | 0.08 |
| | A9 (+) | 7 | – | 0.28 | | I (+) | 4 | – | 0.16 |
| | A10 (+) | 1 | – | 0.04 | D2 → | A2 (+) | 4 | – | 0.16 |
| | A11 (+) | 1 | – | 0.04 | | A4 (+) | 1 | – | 0.04 |
| | A12 (+) | 4 | – | 0.16 | | B2 (−) | 3 | – | −0.12 |
| | B1 (+) | 2 | – | 0.08 | D3 → | A2 (+) | 9 | – | 0.36 |
| | C2 (+) | 2 | – | 0.08 | | A4 (+) | 1 | – | 0.04 |
| | I (+) | 4 | – | 0.16 | | I (+) | 2 | 0 | 0 |
| C2 → | A2 (+) | 3 | – | 0.12 | | I (−) | 1 | | |
| | A6 (−) | 1 | – | −0.04 | | I (NR) | 4 | | |
| | A8 (−) | 1 | – | −0.04 | D4 → | A2 (+) | 2 | – | 0.08 |
| | A9 (+) | 3 | – | 0.12 | | A3 (−) | 1 | – | −0.04 |
| | A12 (+) | 2 | – | 0.08 | | B2 (−) | 1 | – | −0.04 |
| | A13 (+) | 9 | – | 0.36 | | D1 (+) | 1 | – | 0.04 |
| | B2 (−) | 1 | – | −0.04 | | D2 (+) | 1 | – | 0.04 |
| | B3 (−) | 1 | – | −0.04 | | D3 (+) | 1 | – | 0.04 |
| | B4 (+) | 1 | – | 0.04 | | E4 (+) | 1 | – | 0.04 |
| | D4 (−) | 1 | – | −0.04 | | F1 (−) | 1 | – | −0.04 |
| | E3 (+) | 1 | – | 0.04 | | I (+) | 4 | 3 | 0.12 |
| | F1 (+) | 2 | – | 0.08 | | I (NR) | 1 | | |
| | I (+) | 7 | 6 | 0.24 | D5 → | A1 (+) | 1 | – | 0.04 |
| | I (NR) | 1 | | | | A2 (−) | 3 | – | −0.12 |
| C3 → | A1 (−) | 1 | – | −0.04 | | A3 (+) | 5 | – | 0.20 |
| | A2 (+) | 5 | – | 0.20 | | F1 (+) | 1 | – | 0.04 |
| | A12 (−) | 1 | – | −0.04 | | I (−) | 1 | – | −0.04 |
| | B2 (−) | 1 | – | −0.04 | E1 → | A1 (+) | 3 | – | 0.12 |
| | D3 (+) | 1 | – | 0.04 | | A2 (+) | 1 | – | 0.04 |
| | D4 (+) | 1 | – | 0.04 | | A4 (+) | 2 | – | 0.08 |
| | I (−) | 7 | 6 | −0.24 | | A8 (+) | 1 | – | 0.04 |
| | I (NR) | 1 | | | | A9 (+) | 6 | – | 0.24 |
| C4 → | A13 (−1) | 1 | – | −0.04 | | A11 (−) | 1 | – | −0.04 |
| | B2 (+) | 2 | – | 0.08 | | A12 (+) | 7 | – | 0.28 |
| | B4 (−) | 2 | – | −0.08 | | B1 (−) | 1 | – | −0.04 |
| | I (−) | 5 | 2 | −0.08 | | E3 (−) | 1 | – | −0.04 |
| | I (NR) | 3 | | | | I (+) | 5 | – | 0.20 |

(*continued on next page*)

(*continued*)

| Concept | Influence | # of articles coded | | Relationship strength | Concept | Influence | # of articles coded | | Relationship strength |
|---|---|---|---|---|---|---|---|---|---|
| E2 → | A13 (+) | 1 | – | 0.04 | F2 → | A12 (+) | 1 | – | 0.04 |
| | B1 (−) | 1 | – | −0.04 | | C2 (+) | 1 | – | 0.04 |
| | B2 (+) | 3 | – | 0.12 | | I (+) | 5 | – | 0.20 |
| | B4 (−) | 1 | – | −0.04 | G1 → | A1 (+) | 1 | – | 0.04 |
| | C1 (+) | 2 | – | 0.08 | | A6 (+) | 3 | – | 0.12 |
| | C2 (+) | 2 | – | 0.08 | | A8 (−) | 1 | – | −0.04 |
| | E4 (−) | 2 | – | −0.08 | | A9 (+) | 1 | – | 0.04 |
| E3 → | A12 (−) | 3 | – | −0.12 | | A10 (+) | 1 | – | 0.04 |
| | B2 (+) | 5 | – | 0.20 | | A12 (+) | 5 | – | 0.20 |
| | B3 (+) | 1 | – | 0.04 | | A13 (+) | 3 | – | 0.12 |
| | B4 (−) | 1 | – | −0.04 | | B2 (−) | 1 | – | −0.04 |
| | E4 (−) | 2 | – | −0.08 | | B4 (NR) | 1 | – | 0 |
| | G1 (−) | 1 | – | −0.04 | | C2 (+) | 1 | – | 0.04 |
| | I (−) | 6 | 5 | −0.20 | | I (+) | 8 | 7 | 0.28 |
| | I (NR) | 1 | | | | I (NR) | 1 | | |
| E4 → | B2 (−) | 3 | – | −0.12 | H1 → | A1 (−) | 1 | – | −0.04 |
| | B4 (+) | 1 | – | 0.04 | | A2 (−) | 2 | – | −0.08 |
| | C2 (+) | 1 | – | 0.04 | | A3 | 1 | – | 0.04 |
| | I (+) | 3 | – | 0.12 | | A4 (−) | 1 | – | −0.04 |
| F1 → | A3 (+) | 2 | – | 0.08 | | A5 (−) | 2 | – | −0.08 |
| | A5 (−) | 1 | – | −0.04 | | A6 (+) | 3 | 2 | 0.08 |
| | A12 (+) | 2 | – | 0.08 | | A6 (−) | 1 | | |
| | A13 (+) | 1 | – | 0.04 | | A12 (+) | 2 | – | 0.08 |
| | C2 (+) | 1 | – | 0.04 | | I (+) | 1 | 0 | 0 |
| | I (+) | 4 | – | 0.16 | | I (NR) | 1 | | |

## Appendix E. Adjacency matrix

| $n_i$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ | $A_8$ | $A_9$ | $A_{10}$ | $A_{11}$ | $A_{12}$ | $A_{13}$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $A_1$ | 0 | 0.28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $A_2$ | 0 | 0 | 0 | 0.24 | 0 | 0 | 0 | 0 | 0.0 | 0 | 0 | 0.12 | 0 | 0 | 0 | 0 | 0 |
| $A_3$ | 0 | - | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | 0 | 0 | 0 | 0 |
| $A_4$ | 0 | 0 | 0 | 0 | 0.08 | 0 | 0 | 0 | 0 | 0.04 | 0 | 0.08 | 0 | 0.04 | 0 | 0 | 0 |
| $A_5$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 | 0 | 0 | 0.16 | 0 | 0 | 0 | 0 | 0 |
| $A_6$ | 0 | 0 | 0 | 0 | 0.12 | 0 | 0.16 | 0 | 0 | 0 | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 |
| $A_7$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 |
| $A_8$ | 0 | 0 | 0 | 0 | 0.08 | 0 | - | 0 | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $A_9$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $A_1$ | 0 | 0 | 0 | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04 | 0 | 0 | - | 0.04 | 0 |
| $A_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0 | 0 | 0 | - | 0 | 0 | 0 | 0 | - |
| $A_1$ | 0 | 0 | 0 | 0 | 0.08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $A_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $B_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | 0.44 | 0 | 0 | 0 | 0 | 0 |
| $B_2$ | - | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | - | 0 | - | 0 | 0.08 | 0 |
| $B_3$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | 0 | 0 | 0 | 0 |
| $B_4$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | 0 |
| $C_1$ | 0 | 0.24 | 0 | 0.08 | 0 | 0 | 0 | 0 | 0.2 | 0.04 | 0.04 | 0.16 | 0 | 0.08 | 0 | 0 | 0 |
| $C_2$ | 0 | 0.12 | 0 | 0 | 0 | - | 0 | - | 0.1 | 0 | 0 | 0.08 | 0.36 | 0 | - | - | 0.04 |
| $C_3$ | - | 0.20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | 0 | - | 0 | 0 |
| $C_4$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | 0.08 | 0 | - |
| $D_1$ | 0 | 0.28 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.08 | 0 | 0.08 | 0 | 0 | 0 | 0 | 0 |
| $D_2$ | 0 | 0.16 | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | 0 |
| $D_3$ | 0 | 0.36 | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $D_4$ | 0 | 0.08 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | 0 |
| $D_5$ | 0.04 | - | 0.20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $E_1$ | 0.12 | 0.04 | 0 | 0.08 | 0 | 0 | 0 | 0.04 | 0.2 | 0 | - | 0.28 | 0 | - | 0 | 0 | 0 |
| $E_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04 | - | 0.12 | 0 | - |
| $E_3$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | 0 | 0.20 | 0.04 | - |
| $E_4$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 | 0.04 |
| $F_1$ | 0 | 0 | 0.08 | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0.08 | 0.04 | 0 | 0 | 0 | 0 |
| $F_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 |
| $G_1$ | 0.04 | 0 | 0 | 0 | 0 | 0.12 | 0 | - | 0.0 | 0.04 | 0 | 0.20 | 0.12 | 0 | - | 0 | 0 |
| $H_1$ | - | - | 0.04 | - | - | 0.08 | 0 | 0 | 0 | 0 | 0 | 0.08 | 0 | 0 | 0 | 0 | 0 |
| I | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| $n_i$ | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $D_1$ | $D_2$ | $D_3$ | $D_4$ | $D_5$ | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $F_1$ | $F_2$ | $G_1$ | $H_1$ | I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $A_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.04 | 0 | 0.08 |
| $A_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04 | 0.80 |
| $A_3$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.36 |
| $A_4$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.24 |
| $A_5$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.36 |
| $A_6$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.16 |
| $A_7$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.12 |
| $A_8$ | 0 | 0 | 0 | 0 | -0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.04 | 0 | 0 | 0 | 0 |
| $A_9$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.40 |
| $A_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.40 |
| $A_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $A_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.00 |
| $A_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.32 |
| $B_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.20 |
| $B_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.28 |
| $B_3$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.08 | 0 | -0.12 |
| $B_4$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.08 |
| $C_1$ | 0 | 0.08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.16 |
| $C_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.04 | 0 | 0 | 0 | 0.04 | 0 | 0.08 | 0 | 0 | 0 | 0.24 |
| $C_3$ | 0 | 0 | 0 | 0 | 0 | 0 | 0.04 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.24 |
| $C_4$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.08 |
| $D_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.16 |
| $D_2$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $D_3$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $D_4$ | 0 | 0 | 0 | 0 | 0.04 | 0.04 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0.04 | -0.04 | 0 | 0 | 0 | 0.12 |
| $D_5$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04 | 0 | 0 | 0 | -0.04 |
| $E_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.04 | 0 | 0 | 0 | 0 | 0 | 0.20 |
| $E_2$ | 0.0 | 0.08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.08 | 0 | 0 | 0 | 0 | 0 |
| $E_3$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.08 | 0 | 0 | -0.04 | 0 | -0.20 |
| $E_4$ | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.12 |
| $F_1$ | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.16 |
| $F_2$ | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.20 |
| $G_1$ | 0 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.28 |
| $H_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| I | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

(*continued*)

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