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Conceptual framework to integrate food waste research and food systems research

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Abstract

It is estimated that a quarter to one-third of food intended for humans does not fulfil its original purpose. Yet, and despite its universally acknowledged importance for sustainability, mechanisms behind food waste generation are often studied unconnectedly from other challenges surrounding food systems. Here, we examine how concepts, assumptions and frameworks adopted in the food waste literature and the food systems literature overlap, contradict and complement one another. We discuss the current evidence on why and how food waste occurs and discuss modifications required for a conceptual framework to improve the integration between the two groups of studies. The resulting framework makes an explicit distinction between context-specific direct causes and context-independent indirect drivers of food waste, with practice theory interlinking them by portraying human behaviour and associated agency that translate the latter into the former. Central to our conceptualisation is an enhanced recognition that the ultimate cause of food waste is almost always natural decay, which cannot be prevented but can be managed through a systems approach with clear definitions of temporal boundaries.

1. Introduction

With ~1.9 Gt of global food originally produced for humans not consumed by humans each year[1], reducing food waste is often portrayed as one of the most effective strategies to improve the sustainability of the global food system[2]. Direct prevention of food waste is believed to contribute to greater food security and nutritional adequacy[3,4], while indirect mitigation through repurposing for an alternative use delivers a range of other benefits such as efficient nutrient cycling, energy independence and long-term economic development[5,6]. The importance of food waste reduction is also recognised in the UN Sustainable Development Goals, both as an explicit target (SDG 12.3) and implicitly through associated targets for nutritional (SDG 2), environmental (SDG 13, 14, 15) and economic (SDG 1, 9, 10) sustainability.

As food waste affects and is affected by all stages that collectively comprise a food value chain, system-wide knowledge on the structure of the problem is crucial for designing effective interventions[7,8]. If broader determinants of waste are not understood well, the dynamics in the relevant food system may interfere with the progress made in one part of the value chain (or for one commodity), potentially inviting unintended consequences and trade-offs that result in suboptimal outcomes[5,9,10].

Nevertheless, the existing literature on food waste has often been criticised for its lack of theoretical underpinnings[11,12], with no clear conceptual framework for investigation of its determinants that is suitable across all value chain stages[8]. This has resulted in unclarity as to what forms of interventions are most appropriate at any given circumstance for any given commodity, hindering the development of practical policy guidelines to inform policymakers and private stakeholders alike[13]. Furthermore, food waste is often studied separately from other food system challenges and system dynamics[6,14], creating a lack of cohesion and missed opportunities for integrated interventions to achieve broader sustainability aims.

The objective of the present Perspective, therefore, is to examine how concepts, assumptions and frameworks adopted in the food waste literature and the food systems literature overlap, contradict and complement one another. We discuss the current evidence on why and how food waste is generated and outline modifications required for a conceptual framework to improve the integration between the two groups of studies.

2. Treatment of food systems in the food waste literature

Definition of the food waste literature. Food waste studies around the world consider food systems at varying levels of depth and breadth. Consequently, there is no universal borderline to separate the food waste literature from the food systems literature, and indeed some studies may be best categorised into both groups. Notwithstanding, it is often possible to identify (from the study's stated objectives, title, abstract, keywords and wider content) whether the study's ultimate aim is reduction of food waste at one or more locations along an agri-food supply chain. In this article, studies meeting this criterion are collectively defined as the food waste literature and distinguished from the rest of the food systems literature. Further information on the approach employed at the literature search is provided in **Supplementary Material**.

Definition of food waste. The most common definition of food waste, by the Food and Agriculture Organization (FAO), comprises two distinct terms depending on the relative location along the value chain where the wastage occurs and would occur. Under this definition, food loss refers to "the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retailers, food service providers and consumers", whereas food waste refers to "the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food service providers and consumers" further down the supply chain[15]. The World Resources Institute (WRI), on the other hand, makes no distinction between upstream and downstream stages and instead defines food waste more universally as "food and associated inedible parts that are removed from the food supply chain"[16]. Both definitions count diversion of crops to animal feed or energy generation as a loss/waste when these crops are originally grown for human consumption. Further, neither definition includes pre-harvest reduction in yield or, perhaps more controversially, losses/wastage associated with crops purposefully grown for animal feed — even when these animals are reared to ultimately produce food. This inconsistency makes it difficult for food waste researchers to evaluate resource allocation and competition between food, feed and fuel as a systems-level problem[17].

Under the FAO definition, the volume of food loss/waste to be quantified is necessarily influenced by what constitute food, or edible parts of plants and animals. The terms such as unavoidable waste[18,19], processing waste and by-product[20] also rely on the overarching definition of edibility. Yet, from an environmental perspective, this definition is seldom informative; what matters more is the proportion of unconsumed parts that are meaningfully repurposed (thus replacing a value chain elsewhere)[12,14,21]. Furthermore, edibility is a fluid notion that is specific to individuals, cultures, situations and contexts[22,23]. When accompanied by appropriate knowledge and interventions, many so-called inedible parts offer great potential to improve food security[24,25] — as exemplified by the increasing consumption of insects in Europe and North America[26]. At the systems level, therefore, a narrow definition of food waste needlessly pre-defines and restricts the set of solutions that can be considered[14,27]. A similar argument can also be made for the case of overconsumption, whether measured by overpurchasing[28,29] or by intake beyond nutritional needs[21,30,31], as the relevant action results in system-wide inefficiency regardless of the physical fate of the food[29].

For the remainder of this article, the term "food waste" is used regardless of the stage of the value chain where the wastage occurs and ignores further distinctions of avoidability or edibility.

Upstream/downstream interactions. The FAO classifies factors contributing to food waste into two broad groups. Between them, direct causes are defined as actions or inactions immediately resulting in a greater volume of food waste. Indirect drivers, on the other hand, are defined as "the economic, cultural and political environment of the food system" that results in food waste generation[15]. The latter can further be separated into two forms of causal relationships, namely "two-way" upstream/downstream interactions within a value chain and "top-down" exogenous influences of the higher-level market environment that originate from outside the value chain.

In search of systems-level indirect drivers, interactions between upstream and downstream stages of the value chain have only been considered in a limited manner[32–34]. Instead, a large proportion of the discussion to date have exclusively focussed on a single stage predominantly towards the tail end of the system, for example at retail[33], hospitality[35] and households[32,36,37]. A notable exception is the consideration of system dynamics in the form of power imbalances amongst value chain actors, which has frequently been identified as an important indirect driver of food waste[38]. For example, the relationship between farmers and retailers has been shown to invite an excessive level of waste at the production stage due to fears for commodity rejection, even when products are perfectly adequate for human consumption[39,40]. Surplus inventories at the retail level are often passed on to consumers through multi-buy and discount offers that encourage excess purchase, creating a potential cause of wastage at home[36,41,42].

Higher-level indirect drivers. A small number of reviews have discussed factors contributing to food waste with a clear distinction between causes and drivers[37,43]. Some of them further acknowledge the multilevel structure amongst indirect drivers[33,38], with the identified levels ranging from stage-specific ("micro drivers"), value chain-specific ("meso drivers") to value chain-independent ("macro drivers")[44]. It has been observed that drivers from various levels are mutually influencing each other to collectively shape direct causes of waste[32,34]. Some of these examples are further discussed below.

Systems thinking has also facilitated comparative studies of causes and drivers across multiple value chains. Amongst them, identification of hotspots by region, commodity group and value chain stage is a recurring theme, highlighting the structural differences behind waste generation between contrasting food systems[1]. The differences in food supply chains between high-income countries (HICs) and low-and-middle-income countries (LMICs) have often been emphasised[7,45,46], particularly in the context of cold chain facilities to prevent spoilage[47]. It should be noted, however, that there is increasing evidence pointing to a repetition of the pre-conceived notion that waste generation patterns differ substantially between HICs and LMICs when, in fact, the apparent difference primarily stems from data availability and quality[27,48]. Counterintuitively, the latter does not always improve with income growth; for example, on-farm food waste in HICs is notoriously under-researched, with most countries lacking adequate reporting standards[40,49]. In this regard, the common narrative that food waste in LMICs is often caused by the absence of a method, material or technology that is widely available in HICs, is often unjustified. In addition, how food waste and associated interventions in one region would affect food waste elsewhere has not been sufficiently considered in the literature, particularly in the context of the roles of HIC food systems in LMIC food waste[50].

3. Treatment of food waste in the food systems literature

Definition of food systems. A food system encompasses "the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption, and disposal of food products that originate from agriculture, forestry or fisheries, and food industries, and the broader economic, societal, and natural environments in which they are embedded"[51]. Since the word "disposal" appears as part of the definition, a holistic study of food systems interventions is ought to consider their impacts on food waste.

The latter part of the food system definition, or "the economic, societal, and natural environments", influence and shape the actors, activities and outcomes of the relevant food system as exogenous factors[52]. Within the food systems literature they are commonly referred to as food system drivers, to distinguish them from the actors and their activities that are intrinsic to the relevant system[9,53]. However, food waste — and more generally disposed resources — are considered as a system constituent in only 40% of food system frameworks, leading to the absence of a full life cycle perspective[54]. As such, the roles of food system drivers in food waste generation (or the effect of food waste on other parts of the system) have not been examined in a systematic manner. This leaves a gap in our understanding of the mechanism behind waste generation, as further discussed below. The relationship between food waste and the market landscape, and particularly consumer-level food availability, food prices and food safety, has rarely attracted interest either[55].

Waste as a performance metric. Under the traditional "linear" model of food value chains, waste disposal is generally defined as the final activity that takes place within the food system[56]. Under a paradigm to support a more circular economy[57], food waste has been considered to be an outcome of a food system that represents its inefficiency and lack of sustainability[58]. Here, waste is used as an indicator of the resource leakage that prevents the system from performing at its economic, environmental, and human nutrition potential[2,3,21,59]. As such, waste is seen as a suboptimal allocation of resources with no nuanced purposes, for example as a means to enhance resilience against shocks[58], and waste prevention and mitigation are presumed to be equally desirable[1,21,59]. It is also assumed that an alternative destination for food, such as feed, compost and energy, can be created with sufficient capacity to absorb all waste and doing so is optimal and sustainable both short-term and long-term[60,61]. Thus, with this approach, the food waste problem effectively becomes a logistical question of how to match the demand and "supply" of wasted food to achieve positive outcomes arising from circularity[13]. Somewhat tautologically, the presence of food waste has been used as a basis to argue for increased circularity as well[5].

4. Direct causes of food waste

A prerequisite to apply systems thinking to food waste research is a shared and explicit recognition of natural phenomena, human actions and human decisions that immediately engender waste. Despite the common narrative in the literature that the reasons behind food waste generation are complex and multifaceted, few can be considered as truly direct causes. Here, these causes are classified into three groups: natural decay, accelerated decay, and human decisions resulting in wastage **(Figure 1, orange boxes)**.

Natural decay. All food items eventually become inedible as a result of natural decay, or spoilage facilitated by microbial, chemical and physical processes[62]. The speed at which this point is reached depends on intrinsic characteristics of food[63], the preservation techniques it receives[64], and the condition under which it is produced, handled and stored[65,66]. Fruits[67], vegetables[68,69] and animal products[70,71] generally display a greater degree of shelf-life variability than other food groups.

As already discussed, most food waste studies presume, either explicitly (e.g. by setting zero waste as the goal) or implicitly (e.g. by considering no diversion options for repurposing), that optimally designed agri-food value chains waste little or no food. An important corollary here is that unavoidable natural decay is seldom a cause of food waste, although the validity of this statement has not been thoroughly evaluated to date. Indeed, in a modern industrialised food system "natural" decay is never entirely uncontrolled; rather, its temporality is indirectly influenced by the environment in which food is produced, stored, packaged and transported[72,73]. In other words, this process cannot be prevented but can be managed and manipulated.

Accelerated decay. Where food waste is deemed avoidable, its causes are necessarily traced down to some form of human actions or inactions. Amongst them, the majority concern ill-guided design, choice or use of materials and equipment, which results in a shorter shelf-life of the relevant food[6]. These can arise across all parts of value chains, including harvest[74], processing[75], transport[76], storage[77] and retail[76] stages. Harvesting tools, for example, can exert excessive pressure on food items to damage them, accelerating the decay process via additional microorganisms. Transport containers can fail to protect the produce against external stressors, such as bumpy road conditions, extreme temperatures, humidity and pests[78]. Unsanitary, reckless and negligent handling practices often exacerbate the damage caused and thus result in further decay[74,79]. It is worthwhile noting that an introduction of material-based interventions has only meaningfully reduced waste in a quarter of experiments reported in scientific literature[6]. While these failures have been explained by the presence of indirect drivers, for example the lack of knowledge to make the intervention effective, the inadequacy of interventions and associated economic incentives in the context of local stressors are rarely reviewed post-investigation[80].

Human decisions. In addition to inadvertently accelerating decay through mismanagement and misjudgements, humans sometimes choose to waste food. Some of these decisions are made by value chain stakeholders to reduce their own economic risks. For example, fruits and vegetables that do not meet quality standards set by retailers, typically entailing the consistency of size and shape, can be left in the field and ploughed under even if they are nutritious and safe to eat[40]. Commodities that have been exposed to a stress, and are therefore more likely to deteriorate faster later on, can be discarded pre-emptively even before any sign of the actual decay is observed[65]. Retailers and hospitality service providers often oversupply to ensure that food is available when it is desired by customers, although some of these "strategies" may arise more from the lack of prediction and planning capability rather than by rational decision making[35,41,81]. Independent of these economic risks, consumers overpurchase as well. A large proportion of food consumers have a tendency to build up a surplus inventory at home, yet at the same time to prefer fresh produce over food in storage[82]. Plate waste during the meal is also frequently observed and has been attributed to inaccurate expectation of quantity, quality and taste[35,41]. At the cultural level, the notion of expectations further extends to the more fundamental question regarding the edibility of food as already seen above. Combined together, a common trigger behind human decisions to discard food seems to be a mismatch between human expectations on what food should be available, and what food can be available in a minimal/zero-waste world.

5. Indirect drivers of food waste

Roles of food systems in waste generation. By definition, all food wastage occurs within the boundary of a food system. Thus, in theory, not only commonly recognised food waste drivers but all food system drivers[9,53] must influence the causal mechanism regulating the generation, prevention and mitigation of food waste at varied levels of impact. This point is not universally acknowledged across either food waste or food systems literature[54].

As a case in point, it is widely accepted that the notion of a food system incorporates both socioeconomic and natural environments in which stakeholders operate and interact[51]. Notwithstanding, the aforementioned FAO definition of food waste drivers is solely composed of "economic, cultural and political" factors that contribute to waste generation, leaving the biophysical properties and constraints of the value chain outside the analytical framework. This thinking, in turn, is likely to have contributed to a research landscape where only biophysical interventions are used to reduce direct causes and only socioeconomic interventions are used to reduce indirect drivers, even when the opposite approach could in fact provide effective complementary solutions[6].

In this regard, the UN HLPE Sustainable Food Systems Framework proposes six groups of drivers[83] — natural environment, technology, economic environment, policy, demography and sociocultural factors — and may offer a useful building block for filling this gap in the literature **(Figure 1, blue boxes)**. In particular, its inclusion of both natural environment and technology as indirect systems drivers aligns well with the fact that the immediate cause of food waste is almost always physical decay (as observed above) and that, for the majority of value chain stakeholders, these factors are largely beyond their control just as most socioeconomic constraints are. These two groups of indirect drivers are briefly reviewed now.

Natural environment. Natural environmental factors are well-established drivers of food waste although, depending on the terminology adopted by the authors, some of them are referred to as "direct causes". For example, occurrences of pests and plant/animal diseases have been shown to have significant impacts on the quantity of food subsequently supplied downstream of the value chain, with the level of impact amplified under high rainfall and high temperature conditions[84]. Excess rain and floods[85] as well as droughts and irregular rain patterns[86] have also been associated with greater wastage both pre-harvest and post-harvest.

Because these factors contribute to waste primarily by expediating the decay process, most interventions take the form of altering the microenvironment under which food is produced, stored and transported[87]. Due to interactions between multiple natural environmental factors, however, interventions that have been shown to be effective at one location do not necessarily work elsewhere[71,74,88]. Similarly, interventions that only cover part of the value chain could potentially quicken the decay process due to a greater level of fluctuations in temperature and humidity[69].

For robust understanding of natural environmental factors, the material flow along agri-food supply chains should not be seen as a smooth movement at a constant speed; the dimension of time should also be considered **(Figure 1, dark green box)**. Different actors within food systems operate at different time scales, from yearly/seasonally in agriculture to weekly in transportation, daily in processing and momentary in cooking[89]. A mismatch of these temporalities often creates a system-level cause of waste, for example between a retailer's choice on pack-size availability and consumer's shopping frequency[90]. Upstream, pressures resulting from conflicted time scales reinforce existing power imbalances, such as at the market negotiation between farmers and commodity traders[39].

Technology. Alongside natural environmental factors, the absence of appropriate technologies — otherwise referred to as technology, infrastructure and innovation (TII) in the food systems literature — has also been frequently identified as a system-level driver of food waste[45]. The "absence" here can be either due to locally insufficient access to TIIs[15] or because TII solutions are non-existent and thus innovation and development are required[91].

For example, the absence of functional cold chains with an artificially controlled microenvironment to slow down the decay process is thought to be one of the most important drivers of food waste[76]. The lack of adequate post-harvest processing infrastructure and storage technologies is also frequently mentioned in both HIC and LMIC contexts[40,45]. Road network and road quality, which collectively determine the transportation time[70,74] as well as the likelihood of bruising for delicate commodities such as vegetables[92] and fruits[93], further affect the degree of spoilage particularly under warm and humid conditions.

It is worthwhile noting that effective TIIs often combine physical, chemical and biological solutions to lower the impact of indirect drivers while making waste prevention/mitigation an economically more attractive option. New varieties developed through targeted plant breeding have prolonged the shelf-life[68], and chemically enhanced packaging are continuously being developed for different food groups[87].

6. Linking indirect drivers and direct causes of food waste

The discussion thus far has identified a discrepancy between the food waste literature and the food systems literature, which can hinder the development of theoretical frameworks to more systematically investigate the causes, drivers and mediators of wastage. To address this shortcoming, explicit recognition that any food system driver could affect the generation and prevention of food waste (by food waste studies), and explicit inclusion of food disposal as part of the system boundary (by food systems studies), would both offer a positive first step. At the same time, it is also important to recognise that between indirect drivers and direct causes are humans, who “convert” the former into the latter through their actions and inactions. In other words, a robust analytical framework also requires a means to explain the pathway through which drivers create causes and, ideally, assess the relative importance of each pathway as well.

Thus emerges the need to explicitly define a third group of determinants of food waste. For example, beliefs, attitudes, intentions and perceptions held by value chain actors[94,95] are not generally considered as either direct causes or indirect drivers (in the sense defined above). The same also goes to actors’ abilities, knowledge and competences[93,96] as well as actors’ physical operating space that enables and inhibits certain actions from their feasible options[79].

We contend that these largely ”human intermediacy” factors, which have been shown to affect generation and prevention of food waste, find a strong alignment with practice theory. Practice theory, or theory (sometimes referred to using plural as “theories”) of social practices, has a long history in social sciences and humanities and is rooted in philosophy[97]. The theory attempts to explain and support the analysis of how human behaviour is constrained by physical and social structures and how through human agency these structures are maintained and overcome[98,99]. In the present example of food waste, practice theory would acknowledge the interrelated nature of external factors (drivers, e.g. packaging TII) and internal factors (direct causes, e.g. decay) through human agency (e.g. personal beliefs or abilities), which regulates the utilisation and implementation of the former to prevent the latter[100]. Indeed, the concept has been applied to an analysis of food waste generation across farm[40], retail[101], catering[102] and household[82] stages of the value chain, with an explicit aim to show the relevance of practice theory.

7. Towards better integration

Practice theory can be readily implemented into our proposed conceptual framework using its three basic elements: materials, meaning and competence **(Figure 1, yellow circle)**. Amongst them, material is a notion that encompasses the space in which human activities take place as well as the physical constraints faced by the system in question (e.g. a supermarket or a fruit stand)[100]. Meaning refers to norms, attitudes and beliefs possessed by food system actors which, according to the theory of planned behaviour, collectively guide their actions[41,103,104]. Competence describes an individual’s experience, expertise, knowledge and skills that shape their ability to respond to exogenous factors outside their control and manipulate direct causes appropriately[70,71,76]. An important common feature across all three elements is that they all have the power to affect the efficacy of interventions, i.e. as barriers and enablers.

Figure 1 graphically summarises the key elements of the resultant framework and their interrelationships. As conceptualised by the HLPE, indirect drivers are external to the food system and affect all actors, stages and processes therein (while also being informed by the food system’s performance, not represented in this figure). The influence exerted by these indirect drivers on direct causes of food waste, or more widely the diversion of food and associated parts away from the traditional linear progression in the supply chain, are mediated by the practice theory elements. Wastage (or diversion) can therefore take place at any stage of the food supply chain, as a result of an interplay between practice theory elements and direct causes triggered in response to indirect drivers. Longer-term, occurrence and non-occurrence (successful prevention/ mitigation) of food waste also affect observations and experiences by value chain actors, leading to gradual revisions of materials, meaning and competence (represented in the figure by the two-way arrow between practice theory elements and direct causes).

As already outlined, the primary value of the proposed conceptual framework lies in the explicit distinction between human behaviour (and agency) and the wider context (drivers) that induces that behaviour. Under this framework an indirect driver can no longer be deemed to have a constant effect on food waste, as practice theory elements act as its enablers/disablers and determine its context-specific importance in light of direct causes. This means, for example, that the presence or absence of a TII solution in a study region or setting alone is unable to explain the success or failure of specific waste reduction, necessitating (and thereby facilitating) more inclusive systems thinking upon us. Importantly, the above distinction remains in place regardless of the location along the value chain where wastage occurs, encouraging "human-centric" framing also in the upstream where physical interventions traditionally dominate (unlike the food consumption stage)[6]. Our experience to date indicates that the proposed framework can be used as a greatly enhanced version of an intra-team checklist to ensure the consistency and robustness of assumptions regarding human agency across the whole supply chain at various stages of a study workflow, from hypothesis development to intervention design, data collection, causality testing and collation of policy implications and recommendations.

Styled frameworks and conceptualisation of the problem do matter, because they encapsulate our view of the world, shape what information is gathered and investigated and how resources are allocated[105,106]. It is hoped that more studies in the future will adopt them at the conception stage, to better inform the development of research questions and methodologies and, ultimately, to make the proposed solution closer to the global optimum.

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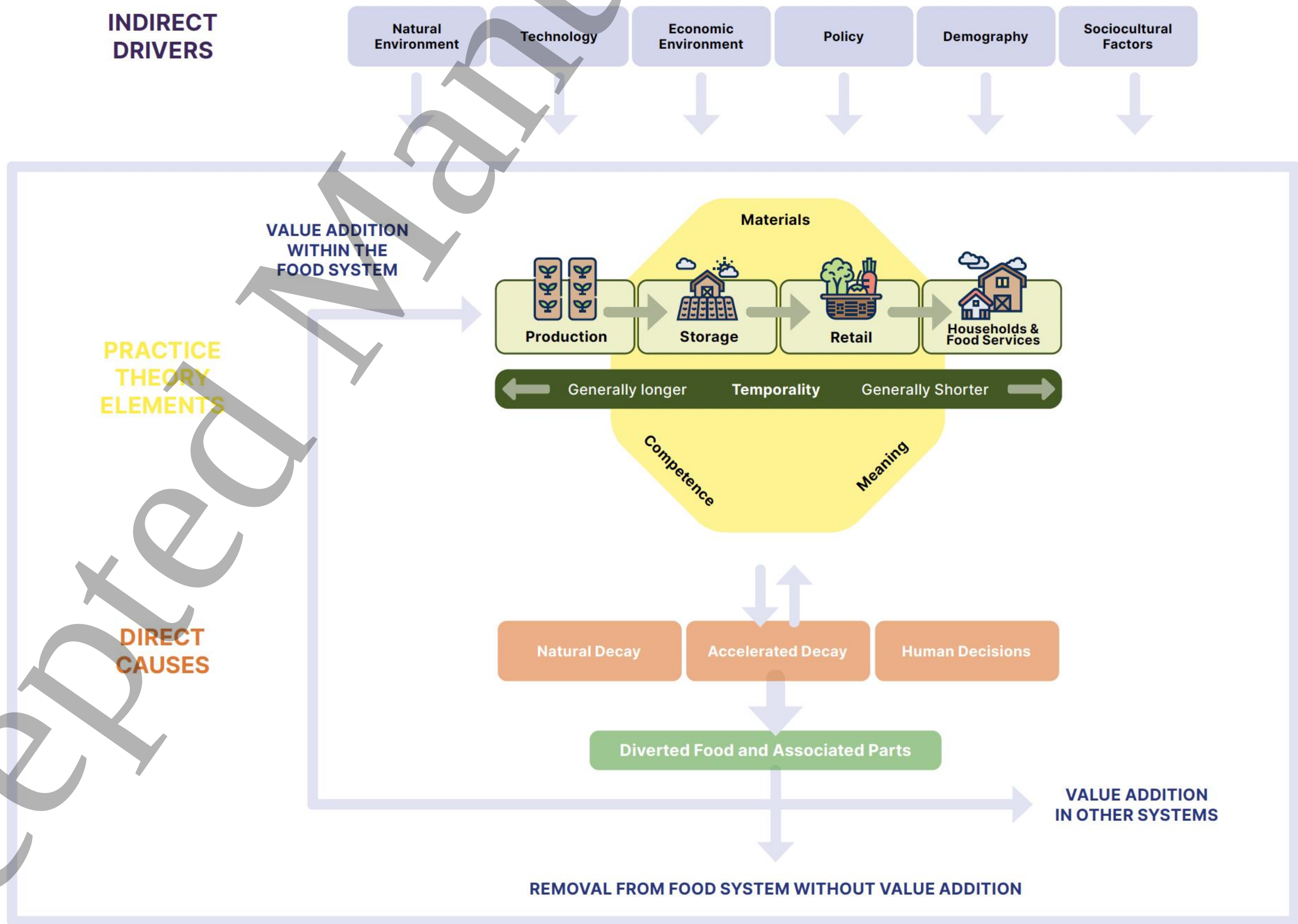

Figure 1. Modified conceptual framework to facilitate integration between food waste research and food system research

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