

## Review Paper

## The role of reducing food waste for resilient food systems

Bojana Bajželj<sup>a,b,\*</sup>, Thomas E. Quested<sup>b</sup>, Elin Rööös<sup>a</sup>, Richard P.J. Swannell<sup>b</sup><sup>a</sup> Swedish University of Agricultural Sciences, Department of Energy and Technology, Box 7032, 750 07 Uppsala, Sweden<sup>b</sup> WRAP, Blenheim Court, 19 George Street, Banbury OX16 5BH, UK

## ARTICLE INFO

## Keywords:

Food waste  
Resilience  
Food sustainability  
Interventions  
Food policy

## ABSTRACT

Food waste undermines long-term resilience of the global food system by aggravating ecosystem damage. The global community must therefore work to reduce the amount of food that gets wasted. However, we should be mindful of some potential conflicts between food waste reduction and food system resilience. Over-production and over-supply are a contributing cause of waste, yet they also provide resilience in the form of redundancy. In this paper, we examine individual interventions designed to minimise food waste by scoring their impact on different aspects of resilience. We find that there are strong synergistic elements and interventions that support short- and long-term resilience, such as improved storage, which reduces the need to provide a constant flow of 'surplus food' and replaces it with a stock of 'spare' food. Some interventions carry a risk of trade-offs due to possible losses of redundancy, and investment lock-in that may reduce the ability of farmers to adapt by changing what and where they farm. Trade-offs do not mean that those interventions should not be pursued, but they should be recognised so that can be adequately addressed with complimentary actions. This review underlines the necessity of food-systems thinking and joined-up policy.

## 1. Introduction

Food systems around the world face multiple challenges, and multiple objectives as response to those challenges. Two of such separate objectives are (i) to increase the resilience of food system -the ability of the food system to withstand and to recover from shocks, (Sustainable Development Goal 2.4), and (ii) to reduce food waste in the food system (Sustainable Development Goal 12.3). The underlying reason for improving resilience is to ensure disturbances do not reduce food security, and the underlying reason for reducing food waste is to improve the environmental sustainability of food production.

There are a few possible interpretations of the relationship between 'sustainability' and 'resilience' (Roostaie et al., 2019). The two concepts can be seen as one and the same, or largely overlapping (Maleksaeidi and Karami, 2013). Tendall et al. (2015) see food system resilience as a pre-requisite to its sustainability, as food systems cannot 'sustainably' continue provisioning food unless they are able to overcome disturbances. However, due to the magnitude of the impacts that food systems have on the environment and ecosystem services that support the food production itself (Foley et al., 2005; Costanza et al., 2014) we argue that food system sustainability (aimed at reducing those impacts) is also a prerequisite for long-term food system resilience. This paper therefore takes the view that sustainability and resilience are separate

concepts, but the achievement of one is largely required to achieve the other.

But herein lies a tension: while food sustainability and resilience are pre-requisites of each-other, some of their building blocks are opposing. The concept of redundancy for example, which is considered as one of key principles of resilience (Biggs et al., 2012; Tendall et al., 2015), can in some manifestations be in conflict with increasing efficiency, including reductions of waste, which are key strategies to achieve food sustainability (Godfray and Garnett, 2014; Bajželj et al., 2014).

How can we still achieve the goals of resilience and sustainability simultaneously? Are there food waste reduction interventions that are synergetic with resilience that we could prioritise, and others that are opposing and that we should therefore de-prioritise or re-consider? What trade-offs should we be mindful of? To answer these questions, this papers sets out to analyse linkages between food waste reductions and food system resilience.

## 1.1. Food system

Complex questions, such as those posed above, underline the need for systemic approaches to food sustainability (DG for Research and Innovation, 2019; Ingram, 2011; UNEP, 2016). For the purpose of this enquiry, we focused particularly on how action in one area, in this case

\* Corresponding author at: Swedish University of Agricultural Sciences, Department of Energy and Technology, Box 7032, 750 07 Uppsala, Sweden.

E-mail address: [bojana.bajzelj@slu.se](mailto:bojana.bajzelj@slu.se) (B. Bajželj).

<https://doi.org/10.1016/j.ecoser.2020.101140>

Received 9 April 2019; Received in revised form 14 May 2020; Accepted 11 June 2020

2212-0416/ © 2020 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

food waste reduction, impacts on other areas of concern – in this case the resilience of the overall food system.

With this paper, we aim to cover all major stages of the supply chain, and develop concepts broad and universal enough to cover different geographies, traditional and modern food systems, low income and high-income settings. Often, food systems span across different geographies and income settings and modes of production (for example, farmers in Kenya growing green beans for markets in the European union along with subsistence crops). While the need for more resilient food system is most acutely felt in the low-income setting, the opportunities to improve both food waste and resilience exist across all types of food system, its stages and geographies. While the challenges of some actors in the food supply chains, e.g. small-holder farmers, are unique, many concepts apply to several stages of supply chain. For example, both a farmer and a household provider may struggle with matching food 'supply and demand'. For a farmer this may mean planting just the right amount to meet his contract without wasting seeds, fertiliser, time and energy. For a provider this may mean buying just the right amount to feed the family for the next week.

### 1.2. Resilience

Food system resilience, the ability of the food system to withstand and to recover from shocks, is of increasing interest due to the increase in climatic and price variability, political instability. Adding to this the recent experience of the threats to the food system from pandemics, threatening to further increase the increasing number of undernourished people globally (FAO, IFAD, UNICEF, WFP and WHO, 2018).

Existing definitions of food system resilience (Schipanski et al., 2016; Tendall et al., 2015; Urruty et al., 2016; Biggs et al., 2012) refer to the ability to withstand shocks and external pressures while maintaining the system's basic structure, processes, and functions, through buffering capacity, adaptability and ability to recover from disturbances.

Food system resilience is closely related to ecosystem services, as the production related disturbances we worry about (crop failures due to e.g. floods, droughts and disease) are often related to the failure or insufficient provision of supporting and regulating ecosystem services. The stocks of natural capital that provide these services continue to shrink (Costanza et al., 2017, 2014), driven by anthropogenic climate and global environmental change. There are multiple causes of this, but one of the largest driver is actually food production and its expansion itself (Foley et al., 2005). Meaning that food production activities undermine their own resilience, which is exacerbated by over-production of food caused by much of the food being wasted. Threats to food system resilience are compounded by a number of other factors, including the increasing homogenization of crops and agricultural landscapes.

Food resilience is also related to food security (adequate access to safe and nutritious food by all people), but here we treat them as separate concepts. For the purpose of this paper, we consider the stability and recovery from disturbances as main attributes of resilience, which is one of the important conditions to achieving stable food supply and therefore food security. Other conditions, most notably sufficient social security and income levels, are additional factors needed to ensure food security.

### 1.3. Food waste

In this paper we use the term 'food waste' as a general term to refer to material which was produced with the intention to be consumed by people, but ultimately exited the food supply chain. We do not separate the terms 'food loss' (often used to describe losses earlier in the supply chain, or those related mostly to the lack of infrastructure and access to market), and the term 'food waste' (often used to describe losses later in the supply chain, or those related to the behaviour of different actors)

(Chaboud and Daviron, 2017), as often multiple factors - a combination of structural and behavioural ones - are at play regardless of where in the supply chain food is lost. The intervention to address food loss and food waste are often hard to distinguish as well; however, the consequences of the interventions may be different (see the Discussion).

The UN FAO estimated that roughly one-third, or about 1.3 billion tonnes per year, of the edible parts of food produced globally for human consumption is lost or wasted (Gustavsson et al., 2011). This global estimate is based on extrapolation and is in need of an update, but while it is possible that the wastage is somewhat higher or lower, it is undoubtedly significant. Food waste across supply chain has been more robustly measured by a small number of individual countries, roughly arriving at similar estimates (WRAP, 2019).

The causes of food waste are complex and varied. In this paper, we put forward the following framework on causes of food waste. As a simplification, each instance of food waste could be explained as a 'rational' economic decision based on comparing the cost of time and materials (infrastructure, appropriate storage etc.) needed to prevent wasting food, with the value of food at risk of waste. This decision-making process by actors in the supply chain is however further complicated by the following issues:

1. In low-income settings, access to capital and infrastructure present barriers, for example a farmer in Kenya may be aware that investing in a cooler would pay back quickly through all the milk saved from spoilage, but they may still not be able to afford to buy a cooler in the first place; see (Gromko and Abdurasulova, 2018).
2. Issues related to these decisions are being made on the basis of *perceived costs* (of both time and resources needed on one side and food on the other side), which are often different to *market costs* (value of food on the market), which themselves are different to *true costs* (costs also including externalities). People are often unaware of the cumulative financial value of the food that they waste (this is true for both consumers, as well as factory managers and even farmers (WRAP, 2017)). Furthermore, the financial cost of food is typically much below its true cost, i.e. one that would price in all externalities such as GHG emissions, the cost of pollution generated, the economic losses associated with biodiversity losses etc. (Chen et al., 2014; National Research Council, 2012). The market therefore tends to under-price and under-value food (Benton and Bailey, 2019). As a consequence, the decisions that lead to food waste may be rational for that individual and the market, but are not rational at all from a societal or whole-system perspective.
3. Many decisions leading to food waste may not be rational at all, as we are not very good at rationally considering everyday decisions, which are often done habitually on a subconscious level (Kahneman, 2012).

### 1.4. Food waste and resilience – what do we know so far?

It has been suggested that an oversupply of 30% over the nutritional need is desired to ensure adequate food supply (Papargyropoulou et al., 2014; Smil, 2004). It has therefore been suggested, that only waste over 30% (as is likely the case in most high income countries, but not low income countries) is excessive – the rest is a natural result of the over-production needed for food security, in other words, short-term resilience.

On the other hand, a significant food waste reduction has been suggested as one of several key systemic changes that could significantly reduce the unsustainable use of ecosystem services and natural capital, including a significant reduction in GHG emission from the food system, which are key for long-term resilience. Kummu et al. (2012) show the total land, water and fertiliser footprint of global food loss and waste are significant. Bajželj et al. (2014), Rööös et al. (2017) and Springmann et al. (2018) have all shown, on the basis of modelling approaches, that low-waste food systems (food systems where current

wastage rates are halved) would require significantly less land, water and reduce GHG emissions associated with the food system in the future in scenarios for 2050. According to these studies, food sustainability goals seem out of reach without a significant reduction of food waste; such findings has also led to the formulation of SDG 12.3 of halving food loss and waste.

Stopping the unsustainable use of natural capital is important for food system resilience in the long term, as food system resilience is already at risk from climate change and increasing scarcity of suitable agricultural land and water reserves and decline in many ecosystem services crucial for food production. However, as the concept of the 30% safety margin exemplifies, food waste reduction may run contrary to some aspects of resilience. The complex direct and indirect, short-term and long-term relationships between resilience and food waste reduction have not yet been explored.

### 1.5. Contributions of this paper

In this paper we examine the main linkages, positive and negative, between low waste and high resilience food systems. A significant reduction of food waste seems essential to establish long-term resilience, but could lead to short-term trade-offs. We therefore also examine individual interventions aimed at food waste reduction through the lens of food system resilience. We discuss in more detail the interventions that appeared most synergistic for both food system objectives, and suggest how policy could benefit.

## 2. Material and methods

### 2.1. Conceptual framework

We studied the literature that describe the principles, policies, strategies and characteristics to achieve either food waste reduction or increased resilience, and mapped reinforcing and opposing linkages between these two food system objectives.

The literature describes different ‘characteristics’ or ‘principles’ of a resilient food system. For food waste, the literature mostly discusses ‘policies’ (e.g. food waste measurements and reporting), and environmental and social ‘costs’ of the current food waste levels. In this paper, we suggest a novel approach to group and differentiate these concepts in a way that facilitates identifying linkages between the two objectives. We propose a separation between:

1. **Interventions**, which are defined as concrete, practical mechanisms to achieve fostering conditions. For example, putting irrigation in place is a resilience intervention that provides stability. Provision of dryers improves overall storage capacity and is an example of a food waste reduction intervention.
2. **Fostering conditions** are conditions that will make reaching desired food system objectives more likely (some of which we can directly influence by policy or interventions);
3. **Objectives** are key characteristics that describe the status of the food system that were the overall goal of the interventions; and
4. **Other outcomes** are those that are also likely to occur as a consequence of the reaching the objective that are of concern for sustainability or resilience (desired or undesired).

#### 2.1.1. Characterising food waste reduction

We reviewed a wide range of academic and grey literature to characterise food waste reduction interventions, fostering conditions, objectives and outcomes, all described below.

**Food waste reduction interventions** were defined as specific activities and changes to the food system that lead to less food being lost or wasted across the supply chain. These include changes to infrastructure and operations alongside changes that target human behaviour (e.g. through training or campaigns) along the supply chain.

These need to be specific enough to have a clear mechanism through which they work. To ensure we were comprehensive, we searched in Scopus using the following combinations of terms: either “food waste” or “food loss” and either “intervention” or “behaviour change” for any year. A range of articles related to food waste policy were also reviewed. The majority of articles related to the household consumption stage. We augmented the academic literature review with case studies from grey literature and media.

**Fostering conditions** were one of the following: broader system characteristics that multiple interventions aimed to achieve; broader policy context; or a reversal of the key drivers for waste, drawn from the same literature as above, most importantly from the following papers and reports: Parfitt et al., (2010), Queded et al. (2013), Papargyropoulou et al. (2014), HLPE (2014), Schanes et al. (2018), WRAP (2017) and Flanagan et al. (2019). These agree that **higher awareness** of food waste as an issue and widespread **measurement** and reporting are the basic condition to reduce the levels of food waste across all stages of the supply chain. Some of these authors and organisation however also emphasise that this in itself is not enough. **Better storage capacity/infrastructure** as well as **reduced rate of spoilage** (either through improved conditions or skills) of food when it is either in storage and transit, are commonly mentioned. **Matching of supply (production) and demand**, both in quantity, quality and time is another broad condition that would prevent waste in most stages of supply chain (either through planning, forecasting or communication). Increasing the **value of food** (e.g. with priced-in externalities) or **cost of wasting** is highlighted by FAO (2018) and Benton and Bailey (2019).

**The objectives** of a low waste food system were defined as a significant reduction in the flow of food material leaving the food system, and a significant increase in the ratio between food consumed and food grown.

**Other outcomes.** According to economic theory (Rutten, 2013), reducing food waste may lead to two outcomes (providing we avoid shifting waste from one stage of supply chain to another): (i) **increase food consumption** or (ii) **reduced food production**. In the absence of other changes in the food system, the occurrence of one over the other depends on the elasticity of supply and demand, through a downward pressure on food prices. A combination of both may also occur. Policy can be used to encourage one of these outcomes over the other. Both of these outcomes have consequences for resilience, through different mechanisms. Where food security is an issue, increased consumption of (nutritious) foods can be a positive development and directly improve resilience. Elsewhere, and when it comes to less nutritious foods, it would be more beneficial from a sustainability perspective to steer the system towards reducing over-production (rather than increasing consumption) and therefore reducing the use of resources including land, water, fertiliser, pesticides and seeds, reducing GHG emissions and pollution and maximising ecosystem services. An additional reduction in GHG emissions and pollutions comes from reduced waste management requirements (e.g. less waste in landfill). However, reduced over-production also means that there is a reduced surplus flow of food in the system.

#### 2.1.2. Characterising food system resilience

We characterised food system resilience based on the following literature: Biggs et al., 2012; Ingram, 2011; Schipanski et al., 2016; Tendall et al., 2015; Urruty et al., 2016; and Vermeulen et al., 2018. From these papers, we pooled together what authors described as characteristics, principles or mechanisms of food system resilience, and categorised them according to the conceptual framework designed here.

**Resilience interventions** – concrete and specific activities implemented to improve food production that recovers quickly from disruptions – were taken as examples from the literature listed above. Unlike for food waste we did not attempt to provide an exhaustive list of the interventions, as the main focus of this paper is to examine the

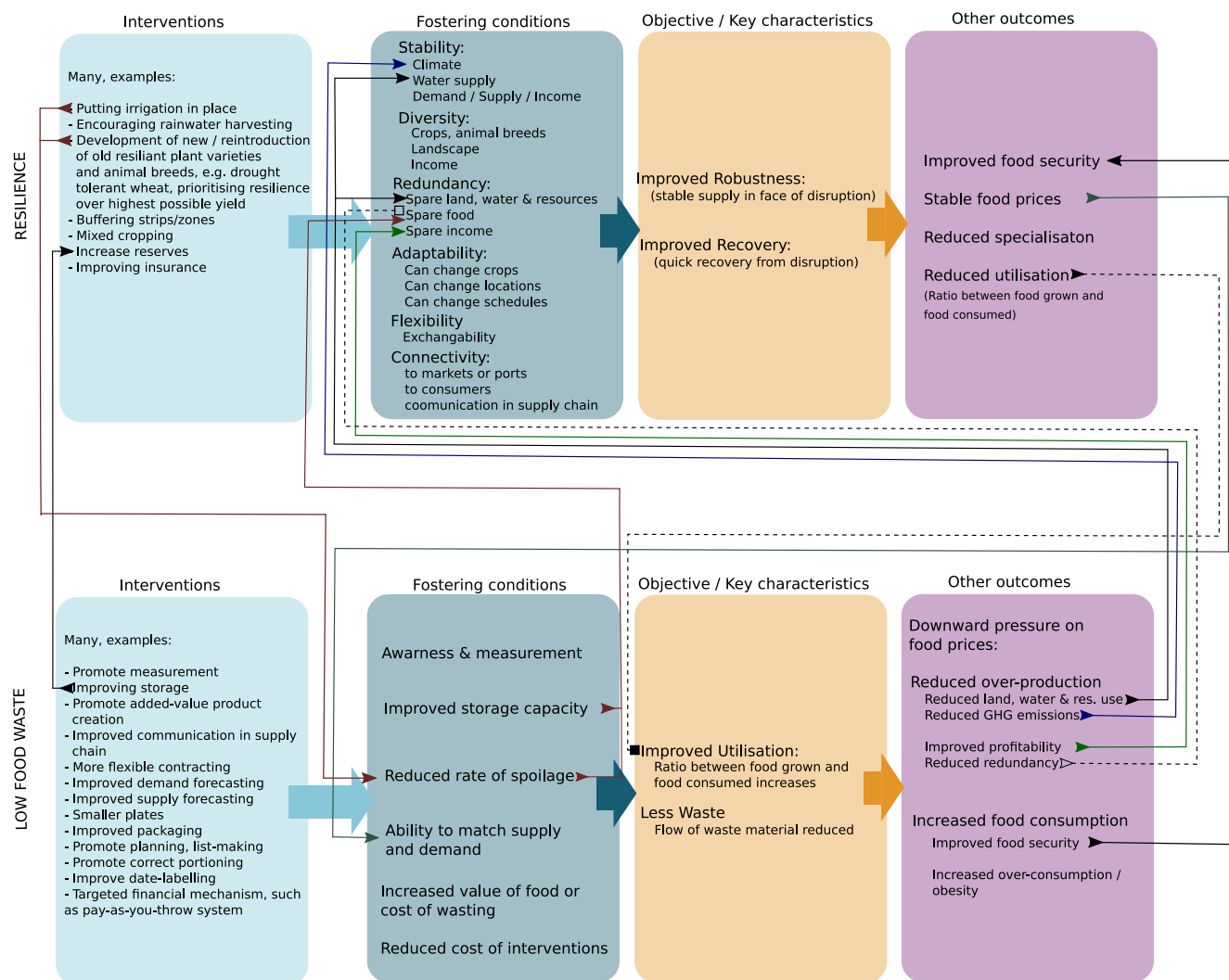


Fig. 1. Main linkages between food waste reduction and food system resilience.

role of food waste reduction on resilience (not vice-versa; although we also touch on that in the initial step – conceptual mapping).

As **fostering conditions** for resilience we considered:

- **Stability**, mainly reduced likelihood and magnitude of disruption events themselves, such as extreme weather events leading to crop failures, and the ongoing increase in mean temperatures affecting crops, livestock, pest and pollinators in various ways, water scarcity, pest and disease outbreaks (IPCC, 2019), and also shocks to supply chains including disrupted access to labour and markets, as the ongoing (2020) disruptions to the food systems due to the new corona virus epidemic exemplifies.
- **Diversity** of crops, livestock, production systems, inputs, landscapes, income streams, customers and suppliers increases resilience according to Biggs et al., 2012 and Schipanski et al., 2016). The principle of resilience in diversity is that individual crops, communities or products will carry different responses to the disruptive condition. Diversity of crops and landscape may also for example prevent or slow down the spread of pest and disease outbreaks (Schipanski et al., 2016).
- **Redundancy**, which can mean either interchangeability (according to Biggs et al. (2012), however we will consider this under flexibility) or spare capacity (of food itself, but also land, water, income, inputs (e.g. fertilisers and fuels), supporting and regulating

ecosystem services), according to Tendall et al. (2015). Spare food capacity emerges as a critical issue with apparent trade-offs between resilience and low waste/efficiency.

- **Flexibility** and interchangeability, being able to use the food that you have for several purposes (Biggs et al., 2012), swap one food for another, or derive income in different ways from different sources. E.g. pigs were traditionally valued as domestic animals that could take a variety of different feeds, but modern livestock systems use breeds and systems that are specialised, increasing efficiency at the expense of flexibility. Today food supply chains are quite inflexible through pursuit of efficiency. Inflexibility (e.g. strict cosmetic specification, strict contracting in time and quantity) can also lead to waste on farm levels.
- **Adaptability** is related to flexibility, but refers to the relative ease of making significant changes, i.e. adaptation to the way food is produced and procured. For example, farmers changing crops, calendars, locations. Transformational (i.e. abrupt) adaptation may be needed due to the pace of climate change and change in weather patterns – not just step-wise adaptation to the signals as they come, but a pre-emptive, fundamental shift in practices and locations (Vermeulen et al., 2018). Adaptation also includes technical innovations such as more resilient breeds.
- **Connectivity** in food system includes trade, communication along the supply chain, as well as the connection between different kinds

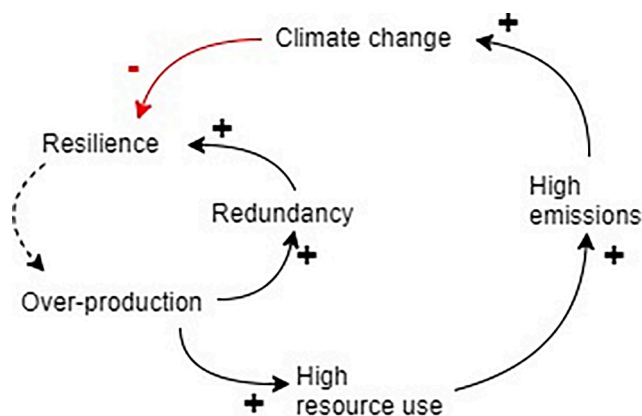


Fig. 2. Simplified causal loop diagram showing the short-term and long-term effects of over-production (of which food waste is a symptom of) on resilience. Dashed line signifies that over-production is often a result of seeking resilience.

of ecosystem services, for example the proximity of pollinator habitats to crops requiring pollination (Biggs et al., 2012). The downside of high connectivity is that diseases and other disturbances can spread faster.

**The objectives** are defined as stable supply in the face of disruption and quick recovery from disruption.

**Other outcomes. Improved food security and stable food prices** are two of the outcomes that are desired from a resilient food system. However, redundancy, flexibility and diversity may lead to reduced efficiency. Diversity typically reduces economies of scale associated with specialisation (compare a large farm growing few crops in rotation with specialised equipment to a farm that grow many crops), while redundancy may lead to not all food produced being eaten.

## 2.2. Analyses

We mapped the interlinkages between the objectives, outcomes, and fostering conditions of the two desired system states on a long-term food systems level, by laying them out and examining where the causes and interactions (both synergetic and opposing) might occur between the systems, and represented them graphically on Fig. 1 using a similar technique also used to produce causal loop diagrams (e.g. Foresight, 2015).

To further untangle potential synergies and trade-offs, and move from abstract to concrete examples, we assessed how individual food waste interventions influence short-term resilience, as represented by fostering condition of the resilience (as described above in conceptual framework). The list of food waste interventions and resilience conditions were obtained from the literature as explained above. We grouped the interventions by different stages of the supply chain in three tables: primary production, then grouping together processing, manufacturing, distribution, retail and food service, and finally the consumer stage.

In the tables we considered how a large-scale implementation of each intervention would impact on food system resilience, looking at each fostering condition at the time. Three of the four co-authors, giving a good spread of expertise across food waste along the supply chain, and food system resilience, scored the influences individually and independently, by posing themselves the question: would the system be more or less resilient after the intervention in question, and through what mechanisms. Scores were there compared, and we had a discussion, focusing particularly on any scores that diverged, agreeing the final scores.

We scored the impact with a '+' if the intervention would impact positively on that fostering condition for resilience, a '-' if it was negative, a '0' if it had little or no effect and a '+/-' if it had an mixed

effect. If we all felt that the effect was unclear, we marked it with a '?'.

In regard to stability, as we have already established that successful food waste prevention will have positive effects on climate stability, and the supply of ecosystem goods and services including water, we have focused on more short-term aspects such as their effect on stable supply and demand (otherwise all interventions would be scored positively for stability).

## 3. Results

### 3.1. Linkages between food waste reduction and food system resilience on a system level

Fig. 1 shows the interlinkages between the objectives, outcomes, and fostering conditions of the two desired system states. Solid lines show reinforcing interactions, and dashed lines show opposing interactions.

The magnitudes of the links are difficult to quantify, although it is clear that some of the links are more significant and more direct than others. One link that has been quantified in the literature is between the reduced over-production and reduced GHG emissions, land and water use. Bajželj et al. (2014) and Springmann et al. (2018) for example quantified these for hypothetical, global future scenarios, and most recently by Philippidis et al. (2019) for current situation in the European Union.

Through this analysis we concluded that food waste reduction is essential for long-term food system resilience (through substantial reduction of resource use and GHG emissions, both of which are critical for long-term resilience), but that the issue of 'redundancy' was a hot-spot where both trade-offs and synergies between food waste reduction and resilience in the short-term may occur. This is further illustrated with Fig. 2.

Actors in the food chain cannot exactly predict how much food they will produce and/or require. Under-supply typically has graver short-term consequences compared to over-supply, leading to actors, who want to achieve resilience, systemically over-producing and over-supplying. High levels of waste are, in part, a symptom of such resilience-motivated over-production, at the expense of long-term resilience, as it depletes natural capital, reduces supply of ecosystem services and contributes to de-stabilisation of climate.

Another direct link between food waste reduction and resilience occurs when increased food consumption is needed and positively affects consumers, directly increasing food security. In these cases, food waste reduction (most often through prevention of spoilage) directly improves resilience. Food waste reduction can also help with food affordability if prices rise. This is partially what we understand happened in the UK between 2007 and 2012, when the food waste reduction information campaign (Love Food Hate Waste) in combination with economic downturn and rising food prices, helped reduce household food waste by estimated 24% whilst also helping people to save money and maintain the quality of their food purchases (Britton et al., 2014; WRAP, 2019). We can assume a similar effect in low-income settings as it follows from economic theory (Rutten, 2013). However, we lack empirical data to test this hypothesis.

### 3.2. Food waste reduction interventions interactions with short-term food system resilience

#### 3.2.1. Primary production

Table 1 shows the result of assessing individual interventions in primary production, focused mostly on farms with some interventions that also apply to other types of primary production, e.g. fishing. Primary production is a hotspot for both waste and resilience, as it is exposed to two sources of variability and uncertainty: 1) the variability of natural systems and growing conditions and therefore yields and timing, and 2) the variability of the social system, reflected in

**Table 1**

The interactions between food waste reduction interventions and resilience at primary production level. For definitions and description of the resilience conditions, see the Methodology section. ‘+’ marks positive impact of the intervention on that fostering condition for resilience, ‘-’ a negative impact, ‘0’ little or no effect, ‘+ / -’ mixed effect, and ‘?’ if effects are unclear (Bradford et al., 2018; CBI, 2014; Gitonga et al., 2013; Morante et al., 2010; Neff et al., 2015; Springer et al., 2013).

Intervention	Examples	Case studies	References	Potential for synergies or trade-off with food system resilience						
				Stability (supply, climate, etc.)	Diversity (crops, landscape)	Redundancy (spare food to use)	Flexibility (in income etc.)	Adaptability (able to change crops)	Connectivity (to markets, information)	Overall
<b>Optimal storage</b>	Steel silos Satellite coolers Hermetically-sealed bags for grains Plastic crates instead of traditional baskets	Hermetically-saleable bags can help farmers store maize and other grains, and protect it from insect, rodents and moisture, to sell at a later time at a better price. (At harvest time, the price of maize on the market is low, but many farmers are forced to sell due to lack of safe storage). Bags are straightforward to use, cost \$2/bag, with a monthly return on investment of 23% The bags reduce the average post-harvest loss from 14% to 1%. (Gromko and Abdurasulova, 2018)	Gitonga et al. 2013 Gromko and Abdurasulova, 2018	+	0	+	+	-	0	Improving storage & optimally preparing food beforehand can provide and improve redundancy without encouraging over-production, with more food stored in different places. It also give farmers a greater flexibility on when (and who to) sell his/her products, and has the potential to improve stability of supply to local markets as well (Gromko and Abdurasulova, 2018). There may be small risk on reducing adaptability though lock-in depending on how crop-specific storage is, and in the form of an introduction of new potential point of fragility.
<b>Improve storage preparation processes</b>	Mobile drying units Reusable desiccant-based systems	Grains need to be dried from their harvest moisture content of ~30% to much dryer 12-14%, to prevent spoilage from moulds (Bradford et al., 2018). This is problematic in humid areas where air drying is not possible, and can be addressed with mobile drying units or use of desiccants. Another case is drying fish from Victoria lake (HLPE, 2014) by deploying raised rack with protective covers to use on the beach as an improvement of traditional methods, adapted to local conditions and cost effective.	HLPE, 2014 Bradford et al. 2018	+	0	+	+	-	0	
<b>Robust varieties and animal breeds</b>	Cassava breeds with reduced post-harvest deterioration. Fruit breeding for low ethylene (gas that speeds-up ripening) Robust lettuce with longer shelf life.	Here we refer to robustness of crop after harvest rather than drought and pest tolerance pre-harvest, which is an intervention directly related to resilience. For example, cassava is a major crop valued for its resilience to drought and some flexibility in harvest times, but which deteriorates within hours to days after harvest, limiting its use, distribution and marketing. New breeds were introduced that improved its shelf life for up to three weeks.	Springer et al. 2013 WRAP 2017 Morante et al., 2010	+	+/-	+	+/-	+/-	0	To some degree it depends on the attributes of the variety / breed. For example, while the longer shelf life of new crop varieties carries same benefits as improved storage, the impact on adaptability, flexibly and diversity depend on the costs and condition of the new variety, and any trade-offs with yield, nutritional value etc.
<b>Promote alternative markets by adding value</b>	Dried fruit Jams and chutneys Frozen slices juicing	Mangos mature in a narrow time frame, resulting in gluts of mangoes that are difficult to sell on local markets. Dried mangoes can earn mango growers prices that are four-times higher than fresh mangoes, and they can sell them at times when it suits them best (CBI, 2014), but requires capital investment.	FAO 2018 Feedback 2016 Springer et al. 2013	+/-	0	+/-	+	-	+	Synergetic as it also increases storage capacity, gives farmers more flexibility, stability and connects them to different markets. Investment in additional equipment can lock-in farmers to certain crops. Changing to long-shelf goods for foreign markets can reduce the redundancy and availability of fresh crops on the local markets however, making those more volatile.
<b>Flexible contracting (distributing risks more evenly across supply chain)</b>	Flexible contracts Relaxed quality specifications Minimum price contracts	This intervention is championed by NGOs (Feedback, 2016). Contracts offer some certainty for both producer and their customer (e.g. wholesaler or retailer). Given that producers face most uncertainty, a contract that sets a minimum price and volume reduces farmers second-guessing the amount they need to grow and therefore preventing unnecessary overproduction. Contracts that heavily penalise farmers for not meeting minimal volume order also incentivise over-production.	Feedback 2016 Springer et al. 2013 WRAP 2017	+	0	-	+	0	+	Mixed, as the over-production and cosmetic specifications offer some ‘redundancy’ that can be used in scarcity events. More flexible contracts also give farmers flexibility to sell to other buyers (also affecting connectivity). If contracts are also done to guarantee a purchase from farmer at a minimum price that covers production costs, this can also increase stability.
<b>Demand forecasting</b>	Advanced order schedules	Forecasts provided by buyers can provide additional guidance for suppliers, but are non-binding on the buyer part. One of preferred methods by farmers in the strawberries and lettuce studies (WRAP, 2017)	WRAP 2017 Feedback 2016	+	0	-	0	+	+	Synergetic, with a risk coming from the possibility of forecasts being wrong and reducing redundancy. Increases connectivity with cross-supply chain communication and stability in introducing option to negotiate a more production-friendly ordering in time. Adaptation is facilitated by better understanding of trends.
<b>Supply side forecasting</b>	Weather forecasting (to better time harvest) Yield harvesting (to reduce over-planting).	In addition to changes to contracts (see above), this is the other most commonly promoted intervention against systemic overplanting (WRAP, 2017). Should be combined with insurance to reduce risks of relying on forecasts. By improving real time forecasting of field production and picking cycles the 5-10% loss of lettuce in field was reduced by matching supply with demand fluctuations in a UK case study (WRAP 2017)	WRAP 2017	+	0	-	0	+	0	Advance understanding of yields can reduce over-planting and improve the stability of the total output, but farmers & the food system have less redundancy (taking a risk that forecasts are wrong). Adaptation is facilitated by better understanding of trends.
<b>Gleaning / food recovery and redistribution</b>	Programs recovering fresh produce from farms and redistributing to people in need	Gleaning is becoming more common in the United States (e.g. Society of St. Andrew) and the UK (e.g. Feedback), by engages volunteers in gathering unharvested produce for donation.	Neff et al. 2015	0	0	+/-	0	0	+	Food recovery is aimed to shift food that is at risk of being wasted to provide food security to vulnerable populations. It is an example of how food at risk of being wasted provides redundancy. The act of recovery does not increase redundancy (the act of over-planting does), but it transforms redundancy into increased food security. It also connects farmers to different end users. However, as the farmer is typically not rewarded to provide this resilience to the food system, this is not a long-term solution to waste and resilience problems.

fluctuations in the demand quantities, prices on the market and demand timing.

Some of the interventions are aimed at reducing the variability (e.g. robust varieties), or help farmers match the levels of production and demand (forecasting) or bridge them in time (storage). These interventions generally help reduce both food waste and improve resilience, provided that they are done well and are resilient themselves (for example, storage could be sensitive to disturbances e.g. floods or disruptions in energy supply). Overall, we have found that even in the short-term, most food waste interventions at primary production level have positive, synergetic influences on various aspects of resilience, particularly stability and flexibility, and a few also for connectivity. The implementation of these farm-level interventions, particularly if aimed at small-holders, will require provision of financing, equipment and training.

As expected, redundancy was one aspect for which the scores were mixed. Some interventions, mostly those directly or indirectly related to storage and food longevity, were scored as positive, while others that reduce the amount of surplus without increasing longevity scored negatively. Interventions that reduce over-production without compensating for redundancy in another way may pose some risk in reducing short-term resilience, but may still be worthwhile doing to improve long term resilience.

For farmers, losses of crops due to something unexpected can be catastrophic for their business and livelihood. The surplus has comparatively small effect, even if wasted (Feedback, 2016; Johnson et al. 2012). It is therefore farmer's need for resilience that leads to this type of 'systemic over-production' and waste. However, this 'need for redundancy' could be reduced if the risks associated with variability were more evenly distributed along the supply chain (e.g. by wholesalers and retailers giving more flexibility to their suppliers), though improved insurance, forecasting and storage. Interventions that directly target resilience, such as increasing income diversity and improving water supply, can also remove some of the farmer's need to over-plant and therefore reduce waste.

Adaptability was the other aspect that could be negatively affected by food waste interventions, when the intervention created a lock-in to certain location and crop. For example, a construction of silo or an immobile drying unit can further lock the farmer to a specific crop and location, depending on how crop-specific and mobile the intervention is. We have found that the food waste interventions seemed neutral for the diversity of crops, breeds and foods (and only linked to landscape diversity in the long-term through land resource savings).

### 3.2.2. Processing, manufacturing, distribution, packaging, retail, hospitality and food service

We grouped the intermediate stages in the supply chain because some of the interventions are common, for example those that refer to a seller and buyer relationship. Another reason is that, compared to primary production and the end-consumer, the rest of supply chain receives relatively little coverage in the academic literature and grey literature, and therefore the number of suggested interventions and case studies is relatively low. Similarly, existing food resilience literature mainly considers primary production as the stage that is most exposed to natural variability, or consumers and their availability to access safe and nutritious food.

Many interactions were given a neutral score, especially for diversity and adaptability. We did not find as much synergistic potential with improving stability as we did for the primary production. However, connectivity stood out as the resilience condition that would benefit from many food waste interventions in the middle of the supply chain. Similar to primary production, some food waste interventions were scored as positive, some negative and some as mixed for redundancy.

### 3.2.3. Consumers

Interventions targeted at household waste have the highest potential when it comes to freeing-up resources and reducing food waste related GHG emissions, and therefore, long-term resilience through stability, for two reasons: in high and middle-income settings, the volume of waste is the largest at the consumption stage, and secondly, this food has accumulated more impact as it processed through the supply chain (for example, it has been transported, stored, perhaps processed and pre-prepared).

There are many different interventions targeted at households. They broadly fall in two categories:

- a) behavioural interventions – promoting behaviours that lead to lower wastage of food; aimed at householders themselves, such as storing and using up leftover food, including incentives to reduce over-buying, improved understanding of date labels, correct portioning when cooking, use of leftovers, optimal storage (including keeping fridges at a temperature below 5 degrees Celsius), freezing of food that will not be used in time, and use of long shelf life products (canned and dried foods) (Quested and Luzecka, 2014; Reynolds et al., 2019; Schanes et al., 2018)
- b) technical interventions – changes to products themselves, for example a change in packaging that increases shelf-life and therefore increases the likelihood that the food will get eaten before it spoils, including changes in pack-sizes and pricing structures to discourage over-buying; increasing shelf-life and open-life through innovative packing, changes to food itself (e.g. using different bacteria cultures in cheese or yoghurt), or reducing the time it takes to get food to market (Lee et al., 2015); changing the date labelling to avoid overly-cautious discarding of food; improving storage and freezing guidance on packs (WRAP et al., 2017).

Consumer behaviour can affect the stability of demand and cause spikes and dips in food demand. In the UK for example, foods such as burgers, strawberries and lettuce are typical foods that will sell very well in sunny weather and spike around sporting events, whilst demand plummets in rainy weather. Growers and producers aim to meet surges in demand, however if expected demand does not materialize produce remains in the field (WRAP, 2017) or is wasted elsewhere. Some of this waste could be prevented with better forecasting, however the consumption habits could also adapt; for example, by aiming to match consumption to the growing season.

Most interventions investigated were scored positively for improving stability. The scores were mixed again for redundancy and also more mixed for flexibility and adaptability, with some interventions potentially reducing the number of options households have in any given moment when it comes to food. There were more links with diversity than in other stages of supply chain – as some interventions promote specific types of foods, typically long-life products, which either add or reduce diversity, but very little identified impact on connectivity.

### 3.3. Key synergies and trade-offs in food waste reduction and resilience across the whole supply chain

Key interventions that emerged as synergistic for food waste and are improved storage, transport, surplus valorisation, increased shelf life, and promotion of long shelf life products.

Food storage can take place in many stages of the supply chain and can take many forms, for example grain stores, which can be operated from national to village or individual farm scales. Food is stored in many other ways as well (not necessarily labelled as storage): on farms, in warehouses, cold stores and industrial freezers, in supermarkets, while in transport on ships and trucks, and also individual households' cupboards, fridges and freezers. Each one of these stages adds up to the overall storage capacity of the food system, and each could potentially

**Table 2**

The interactions between food waste reduction interventions and resilience at intermediate steps in the food supply chain (Blanke, 2014; WRAP, 2013a; Cohen et al., 2014; Dora et al., 2019; Freedman and Brochado, 2010; Kallbekken and Sælen, 2013; Parfitt et al., 2016; ReFED, 2016; Stöckli et al., 2018; Wansink and van Ittersum, 2013; Williamson et al., 2016; WRAP, 2013b).

Intervention	Examples	Case studies	References	Potential for synergies or trade-off with food system resilience						Overall
				Stability	Diversity	Redundancy	Flexibility	Adaptability	Connectivity	
Improve transport	Closed cooled trucks instead of open trucks Tarpaulin cover on open trucks Adding vents in transport of fresh food and live animal Transport at night when temperatures are lower	Gromko and Abdurasulova, 2018 provide a case study on milk transport in Tanzania.	Gromko and Abdurasulova, 2018 HLPE, 2014	+	0	+	+	?	+	Improved transport, processing and handling, has similar effects to improved storage, and in addition can also improve connectivity. Additional investment in specialised transport may mean difficulty in adapting to different products but transport is generally more adaptable than storage.
Make changes to the processes and machinery	Add rails to the sides of conveyer belts to prevent food from falling off; Reduce the number of times machinery needs to be cleaned due to re-deployment etc.	Dora et al. 2019 found interrupted production and machine maintenance issues to be two of the leading causes of waste in Belgian processing sector.	Dora et al. 2019 Parfitt et al. 2016	0	0	0	0	0	0	Difficult to see any significant influence on resilience, mostly neutral (apart from long-term effects)
Improve stock / inventory management system	Implementation of first in - first out system. Reprioritise from avoidance of under-stocking to reduction of waste. Transparent communication to suppliers	Retailers and manufacturers already employ advanced systems, but these could also be used in hospitality, households and other stages. Advanced systems prioritise prevention of being out of stock which leads to over-stocking. Can be linked to communication e.g. so that suppliers could see their customers stocks in real time (see below).	ReFED 2016	+	0	+/-	0	0	+	Could improve stability as stocks were better managed preventing both over- and under-stocking. Could lead to less stock, but that stock could be better utilised, hence +/- in redundancy. Could lead to more timely ordering from suppliers and warning of scarcity to consumers (see below)
Improve demand forecasting, supply chain communication and matching of supply and demand through order/package size	Demand forecast based on weather (e.g. strawberries for sunny days). Changes to rounding rules. Agree timing of order with supplier. Increase frequency of communications between suppliers and buyers (e.g. scheduled calls and emails) Change the timings and sizes of delivery.	Applied Data Corporation claims a 35% food waste reduction for their clients by using enhanced analytics that integrates forecasting, inventory management and ordering (also includes above, ReFED 2016). Improved forecasting and communication between a UK retailer and ready-meal manufacturer reduced waste product at the point of manufacture by 33% WRAP (2010).	WRAP 2010 WRAP 2013b ReFED 2016 Parfitt et al. 2016	0	0	-	0	0	+	Clearly improves connections in the supply chain through communication, but could reduce redundancy by reducing reserves at all stages of supply chain (at risks that forecasts are wrong)
Improve storage in supply chain	Control ethylene levels in supply chain.	Add vents or ethylene scrubbers in warehouses, cold stores, packing lines and packaging.	Blanke 2014	+	0	+	+	-	0	Similar to improving storage in the primary production level.
Valorisation of surplus for non-food uses	Facilitate connecting food producers and users of food surplus (as e.g. animal feed, or as inputs into novel bio-processes). Whole crop purchases.	Retailers may be better suited to find valorisation uses than farmers. They can engage in 'whole crop purchases' and buy crops both in an out of specification (e.g. as class I).	Parfitt et al. 2016	0	0	+	+	0	+	Continuing over-production but instead of wasting food finding other uses for it, could mean these flows of material are available to serve as food again in times of need. However long-term this may still mean an over-use of resources (compared to reduction of over-production).
Redesign buffets	Encouraging buffet-diners to only take what they'll eat / take smaller amounts and come back for more if necessary.	Literature includes range of methods to achieve this from use of messages based on social-norm approach, messages on buffets and napkins, changing the 'disposability' of the buffet plate size.	Kallbekken and Sælen, 2013 Williamson et al., 2016 Wansink and van Ittersum, 2013 Stöckli et al., 2018	0	0	0	0	0	0	These changes are mostly neutral when it comes to direct resilience.
Changes to menus and portions	Smaller plates in buffets. Optional side orders.	Types of food and amounts served have both been investigated and shown to affect food waste levels. WRAP (2013a) shows large portions sizes are the biggest driver for plate waste.	Cohen et al., 2014 Freedman and Brochado, 2010	0	0	0	0	0	0	These changes are mostly neutral when it comes to direct resilience.

be improved. (see Tables 1–3 for examples).

Preparing and storing food optimally creates a buffering capacity different to a continuous surplus production by creating a reserve. In systems dynamics terminology, better storage replaces a need for a constant additional 'flow' with increasing the 'stock' (from which occasionally an additional flow can be drawn). For example, families could rely more on having well-stocked cupboards with long-life cupboard essentials that can also be made into a nutritious meal, rather

than constantly buy more perishable foods than they use. Surplus production could be diverted to become a reserve by extending shelf life through canning and dehydration of fruit, meat, dairy and vegetable products, to be used in times of scarcity and disruptions in food supply due to a variety of different reasons from droughts to epidemics. This would be a much more resource-efficient way of providing resilience compared to over-production year on year. Improved storage is not necessarily about only the size of storage (warehouse, fridge etc.), but



**Table 3**

The interactions between food waste reduction interventions and resilience at consumer level (Devaney and Davies, 2017; Fisher and Whittaker, 2018; Ganglbauer et al., 2013).

Intervention	Examples	Case studies	References	Potential for synergies or trade-off with food system resilience						
				Stability (of demand)	Diversity (of foods)	Redundancy (spare food)	Flexibility (plans)	Adaptability	Connectivity	Overall
Promote planning to reduce over-buying	Promote writing of shopping lists	All of these behaviours were promoted through a range of campaigns (e.g. Love Food Hate Waste campaign in the (UK), Stop Spild Af Mad (Denmark), Zu gut für die Tonne (Germany), Qui jette un oeuf, jette un boeuf (France), De menjär, no en llencemni mica (Spain), Stop Food Waste (Ireland)		+	0	+/-	+/-	+	0	These impacts are likely to be relatively weak and some could go both ways. Planning could lead to more stable demand, but does not lead to more or less different types of food. As it is aimed at reducing over-purchasing and it can reduce redundancy, but good planning may mean that there are some 'long life' options for food. Better planning may mean that people have fewer options towards the end of their shopping 'cycle' (so less flexibility), but also that there are some 'long life' options for food (so more flexibility). Better planning might make people better prepared to adapt to changes in food availability.
Promote correct portioning when cooking	Using household items as measures for rice and pasta	Other methods to influence households involve intensive engagement / education (e.g. Devaney and Davies, 2017), use of technology (e.g. fridge cameras and videos to model desirable behaviour (Ganglbauer et al., 2013).	Questa et al., 2013 Reynolds et al. (2019) Stöckli et al. (2018) Ganglbauer et al., (2013) Devaney and Davies, (2017)	0	0	0	0	0	0	Impacts are quite weak, although potentially we could argue some redundancy could be lost through improved portioning. That is not to say that incorrect portioning is not a large driver of waste (Questa et al. 2013).
Promote use of leftovers	Use of dinner leftovers for next-day lunch			0	-	+	+/-	0	0	Impact on redundancy and flexibility depends on if leftovers (with a short shelf life) add to food available or replace other food available. It could reduce flexibility as same foods is eaten for more than one meal.
Promote optimal storage to increase shelf-life and likelihood of food being eaten	Make changes to storage and freezing guidance on pack Ensure fridge is at optimum temperature.	Because these were delivered through comprehensive campaigns such as Love Food Hate Waste, there is little evidence about the effectiveness of the individual interventions listed (Reynolds et al. 2019 and Stöckli et al. 2018), even if campaign on the whole was evaluated.		+	0	+	+	0	0	Can contribute to overall storage capacity and increase life-span of food. It helps to reduce fluctuation in demand (stability).
Promote freezing of food that will not be used in time	Snowflake logo			+	0	+	+	0	0	Can contribute to overall storage capacity, and give individual user greater flexibility; but comes at some GHG emissions cost.
Promote use of long shelf-life products	Providing lists of store-cupboard essentials of canned and dried foods			+	+/-	+	+/-	0	0	The impact on diversity depends on what consumers predominately eat now (e.g. if they only eat fresh food, canned food would add diversity and vice versa). Can contribute to overall storage capacity in food system, and therefore improve redundancy. Flexibility could increase as one can choose between these foods, but also reduce if they are limited to a few types.
Reducing over-buying of food by adopting best practice on offering promotions and pack-sizes.	Retailers reduce heavy promotions Food packs sizes offer in ranges so that every household size can finish it in its live-span.	Changes to promotions have been made by several UK grocery retailers, no longer offering 'multi-buy' promotions (i.e. those that require purchase of more than one item to obtain a saving).	Questa et al., 2013	+/-	+	-	0	0	0	The effect depends on the nature of promotions and foods in question, e.g. effects may be different for processed foods, long-life foods, fresh foods and weather the promotion is run to increase market share or move food that are over-abundant. Reduced use of promotions redundancy reduced on a household level but also at a food system, however it also gives people a chance to buy more diverse products by not incentivising them to buy large amount of same foods.
Increasing shelf-life and open-life through	Innovative packing innovative food processing	Fisher and Whittaker (2018) lists improvements in hygiene, and extra centrifugal cleaning stage and ultra-filtration as options to add more than 7 days to the shelf-life of milk without changing the taste.	Questa et al., 2013 Schanes et al. 2018 Fisher and Whittaker, 2018	+	0	+	+	+	0	Increased shelf-life could contribute to overall storage capacity.
Make changes to date labels	Change from use-by to best before. On-pack messaging highlighting how to check if food is edible.	Guidance to support food businesses to achieve these changes has been produced and adopted in the UK.	WRAP, FSA, Defra 2017	+	0	+/-	+	+	0	Labels today tend to be conservative. Reducing this could reduce some resilience, but provide a quick reduction to waste. There are parallel examples in medicine, where medication after expiration date was approved for use in times of scarcity (e.g. EpiPens in UK in 2018, The Lancet Child & Adolescent Health, 2018). This would not be possible without expiration dates being conservative in the first place. On the other hand, it would give more time for a range of foods to be eaten.

conditions (e.g. temperature, air moisture) and preparation of food stored (drying, pre-cooling, mould-free).

It should be noted that there are some challenges associated with having a higher proportion of food as reserves. Stock management in both the supply chain and in homes may need to be improved to ensure that the food in storage is circulated correctly. Secondly, on a food-system basis, having a larger proportion of overall food in storage may mean that on average, the time between harvest and consumption increases, highlighting the need to monitor not only food safety, but also food quality and nutritional value. Thirdly, there are trade-offs between increasing some types of storage capacity, especially cooling and freezing, and energy use – increased energy use leading to increases in GHG emissions and cost. And lastly, the resilience of storage against some of different kinds of disturbances that effect food production should also be considered (e.g. energy supply, susceptibility to pests etc.).

Improved storage should reduce price volatility. At harvest time, especially in good years, the price of produce (e.g. grains, vegetables) on the market is low, but farmers without safe storage options are forced to sell despite the low prices they receive. Similarly, consumers without storage or access to food with longer shelf-life cannot bulk-buy and store foods when prices are low. If neither producers or consumers can store, prices are more likely to spike outside main harvest seasons. Higher prices in one year can attract many newcomer producers in the next season, leading to over-production the next year, therefore low prices and high waste when price does not even justify harvest costs (which are significant, Johnson et al. 2012) perpetuating a boom and bust cycle. Price volatility is therefore not only a sign of a system with low resilience, but it can also lead to waste. In a market economy, changing prices are unavoidable, and are valuable signals about scarcity and over-production, and distorting them through some market mechanism may lead to unintended consequences. However improved storage, preparation of food for storage, diversification into longer-life products and innovation in insurance could reduce some of the high demand volatility and make optimal production decisions easier for farmers and other actors in the food supply chain.

Reducing food waste in most cases leads to a good return on investment (WRAP, 2015; Hanson and Mitchell, 2017; Gromko and Abdurasulova, 2018), improving the profitability and income of the people involved in the point of the stage of supply chain where food waste is being reduced. As such, food waste reduction leads to increased resilience of that actor in the chain, say a farmer or manufacturer. This also applies to consumers. For example, data in the UK (Britton et al., 2014) suggests that in the context of reducing disposable income and rising food prices, people that reduced the food that they wasted were able to continue buying the same quality of food they were buying before. Reduced food waste can also present an opportunity to increase added value in the supply chain. When customers save money but not over-buying in quantity, they are often happy to spend more on 'quality' (Britton et al., 2014). However, assuming food waste reduction at consumer level does lead to financial savings, these could result in rebound effects if they are spent on other polluting activities, diminishing some of the environmental gains (Martinez-Sanchez et al., 2016; Saleemdeen et al., 2017).

In this paper we focused on reducing food waste 'at source' (i.e. food waste prevention). However, there are other mitigating actions that also count as food waste reduction: for example, feeding the surplus food material or food scraps to livestock (zu Ermgassen et al., 2016) and using it as feedstocks in bio-economy, for example extracting limonene from waste orange peel (WRAP, 2015). These 'surplus valorisation activities' too can lead to significant resource savings, although typically less than prevention. zu Ermgassen et al. (2016) for example calculated that feeding food scraps to pigs through advanced centralised swill operations similar to those operating in Japan and South Korea could also lead to significant land-use savings of 1.8 million hectares in Europe, compared to 6.0 million hectares calculated for food waste

prevention by Philippidis et al. (2019). They can also potentially contribute to increased resilience if the flows of material out of the food system can be used to feed humans during times of crisis, and should be pursued in addition to food waste prevention to reduce pressure on resources.

## 4. Discussion

### 4.1. In which cases does food waste provide redundancy and therefore contribute to resilience?

Some surprising linkages between food waste and resilience emerged through our investigation. Some food waste can be seen as a consequence of actors wanting to achieve resilience through redundancy: over-production and over-purchasing, so that they call on this surplus if something unexpected happens; these 'unexpected events' could be a grave issue such as a farmer experiencing a low yield, or relatively small things like consumers entertaining unexpected guests or not finding the time to go to your weekly shop at the regular time. However, some wasted food did not provide resilience at any point in time. Generally, if the 'food at risk of becoming waste' can be tapped into relatively quickly (for example, by relaxing cosmetic standards), then that quantity *does* provide redundancy and therefore some short-term resilience. But if there are no means of preventing the spoilage and waste, then waste food never provided any resilience.

Some of the types of food waste that provide short-term resilience are also some of the easiest to address to reduce over-production. Interventions such as relaxing cosmetic standards and reducing over-purchasing through better planning are examples of changes that can be implemented fairly easily, and therefore also get implemented when something unexpected occurs, i.e. in time of scarcity. For example, in 2012 untypical weather resulted in poor yields of fruits and vegetables, in response to which UK's supermarkets relaxed their rules on their cosmetic appearance (Vidal, 2012), evening the supply. The relative ease of intervention implementation provided redundancy. However 'saving' these interventions for times of scarcity comes with cost a of diminishing natural capital and contribution to climate change from over-production. Therefore, the recommendation of the authors is not that the interventions that reduce redundancy are not pursued (they could be considered as a priority due to their ease of implementation), but that they are balanced with complementary interventions that compensate for lost redundancy, most notably improved storage.

This investigation of food waste and resilience led us to a new proposal to conceptualise wasted food, depending on whether it represents mainly a) a **loss of needed nutrition** (a direct loss of food security) or b) a **loss of resources** used to produce it (leading to indirect, long-term loss of resilience). In practice it may be difficult to allocate a loss of an individual item of wasted food between the two, as the mechanisms and causes of loss may be identical, but the consequences are not. They also depend on the context, particularly the socio-economic status of the actor. As actors improve their socio-economic status, they often seek to improve their food security through increasing over-production, rather than through reducing food loss through interventions, for a variety of different reasons. Therefore, the nutrition loss shifts to resource loss, even though the causes and mechanisms (the actual process of food becoming inedible) may remain unchanged. The short-term resilience of the actor improves, but the long-term resilience of the whole food systems diminishes through increased depletion of natural capital and reduced stability.

As progress is made towards halving food waste, it would be helpful to track the nutrition loss and the resource loss (over-production) separately at a large/global scale. For this, better production and consumption statistics would be needed.

#### 4.2. Policy implications and links to ecosystem services

To complement food waste reduction, and also to encourage it, policy should carefully consider which of the two outcomes of reduced food waste are preferable for the circumstances: reduced production or increased consumption. At national food policy levels, food waste reduction targets are rarely linked to other outcomes. (If anything, they are vaguely linked to improving import–export balance). This lack of systemic food policy represents a missed opportunity to strengthen other desirable food system transitions, including increased short-term or long-term resilience. Long-term resilience could be doubly-encouraged for example, by gradual internalisation of externalities so that food price would be stable despite downwards pressure from food waste reduction (Benton and Bailey, 2019; Rutten, 2013). This should lead to reduction of over-production, and therefore reduction of GHG emissions and increase in other ecosystem services that can be provided by spared land. The delivery of specific ecosystem services, many of which can again be conducive to long-term resilience, can be then further encouraged with compatible financial incentives, and would, through competition for resources, further reduce food over-production. The opportunities include: farmers being able to build in more resilience-inducing features that protect soils, pollinators and other resources on the spared land (for example: buffer zones, hedgerows, stony habitats, pollinator habitat enhancement and lagoons, see Gardner et al., 2019); reduced use of fertiliser (and its negative impacts) not only through reduced production but also reduced fertiliser subsidies; water reservoirs and aquifers re-filling (or being used less intensely), increasing the resilience of water supply in the future; healthier ecosystems on and surrounding the agricultural lands. Reduction in food loss and waste combined with an ecosystem services approach can therefore steer the food system to a more resilient and sustainable future.

On the other hand, in circumstance where an increase in consumption is preferred to directly improve food security, prices can be allowed to decrease through food waste reduction interventions. This is particularly appropriate for highly nutritious foods that are under-consumed in the population. However, an increase in consumption is not helpful in all circumstances and for all types of food. Particularly for food with high energy and poor nutrient values amongst populations with an obesity problem, without taking a systemic approach pursuing food waste reduction in isolation may contribute to exacerbating the problems.

The lack of systemic approach also reduces the chances of food waste reduction incentives succeeding. The first signal from a significant reduction of food waste at one point in the supply chain at either demand or supply side is bound to be a reduction in price (Rutten, 2013). This can encourage waste at another stage in supply chain, or at another geography. For this reason, it is important that food waste reduction is being pursued on a global scale and in all stages of supply chain. Good monitoring systems are needed to be put in place to ensure that waste is not pushed from one end of the supply chain to another, and from one place to another. Global monitoring frameworks are currently being set up by UN FAO and UNEP, but the challenges associated with the monitoring of food waste should not be underestimated. In the future, however, it would be beneficial to monitor other separate indices at critical points in transition to high-resilience, low waste system, particularly the total storage capacity and over-production as indicators of food system resilience and efficiency. This could mean for example an introduction of food reserves targets and monitoring on national, business or even household level (% of total food reserves, % of households with access to safe food storage options in kg/capita).

The discourse on food waste for the past ten years have been quite simplistic: food waste is big, bad, and it must be reduced. This was justifiable given the low awareness surrounding food waste, its scale and missed opportunities it embodies. Now that awareness has increased, at least amongst policy makers, researchers and businesses

(Flanagan et al., 2019), it is time we enter the next stage in food waste policy and discourse: one that is more nuanced and realistic, and tackles both synergies and trade-offs with other food system sustainability goals more explicitly, achieving better outcomes for all goals.

In the EU, food waste reduction measures on farm are currently not considered as a part of Circular economy package (European Commission, 2019), however it could be something that is encouraged through the Common Agricultural Policy. Common Agricultural Policy has a potential to increase farm resilience by encouraging resource efficiency, establishment of resilience features and encourage supporting and regulating ecosystem services. The parallel pursuit of food waste reduction should help free up the resources needed to do this, without sacrificing productivity.

#### 4.3. Shortcomings and need for future research

In this paper, we used a theoretical approach to try to structure and characterise complex interactions between different parts of and changes to the food system, focusing interactions between interventions aimed at food waste and resilience. This approach was largely based on the experiences and knowledge of the experts involved. Where possible we tried to base the judgements on potential causes and effects on observed data; however, this was not possible for all identified linkages. Furthermore, while we strived to be comprehensive by taking a systemic approach, it is possible that some important linkages were missed entirely, which could be improved in the future by involving a wider range of stakeholders in the system mapping process. Nonetheless, we believe this approach and its conclusions have value, and will hopefully provide a basis for future research on these questions fundamental to food sustainability.

### 5. Conclusions

There are strong linkages between reducing food waste and food system resilience, that through the analysis in this paper we separated into:

- a) **Long-term linkages:** food waste prevention interventions influence long-term resilience of the food system through its sustainability, by reducing GHG emissions and therefore climate change and variability, and potential to increase natural capital and improve supporting and regulating ecosystem services. These interactions are overwhelmingly positive for resilience and significant in strength and scale.
- b) **Short term-linkages** where food waste interventions interact with stability, diversity, redundancy, flexibility, adaptability and connectivity of the system through interventions that lead to changes in livelihoods, storage capacities, variability in supply and demand etc. These interactions can be positive or negative. They form two clusters: one around redundancy – where trade-offs are most apparent, and one around stability and reduced volatility (of supply, demand and price), where synergies are most apparent. The scale and strength of these linkages are not yet known.

Individual food waste prevention interventions that focus on reducing over-production, for example the relaxation of cosmetic standards, do reduce redundancy and therefore short-term resilience. However, these interventions should not be discouraged as they present a vital opportunity to improve resilience in the long-term. The trade-offs should be recognised so that they can be adequately addressed and compensated for. One example is by improved storage, which by reducing the variability of supply and demand, smoothing prices provides redundancy not in the form of surplus, but a reserve.

Policy recommendations and implications of this work are the following:

- 1. Replace surplus with reserves.** Current approach to food resilience relies on over-production. This is exemplified by a notion that 30% of food over-supply is required for adequate food supply and security. However, such reliance on over-production undermines food system resilience in the long-term. The approach to food system resilience needs to shift from over-production to reserves (storage and extension of shelf life e.g. through dehydration), with accompanying storage-related incentives and targets.
- 2. Recognise trade-offs and pursue complementary interventions.** Food waste reduction should be easier to achieve when it is recognised that for many actors, the need to provide resilience is the driver for over-production and therefore waste. The actors need to be reassured that the food waste reduction activity is going to improve rather than reduce their resilience.
- 3. Increasing resilience can indirectly reduce food waste.** Over-production for the sake of resilience can be replaced through other resilience conditions, e.g. through increased diversity, by installing irrigation or alternative producer income opportunities related to other ecosystem services. For that purpose, it is important to have an understanding of ways to support resilience alternative to redundancy.
- 4. Approach food policy systemically.** Food waste reduction policy should consider two of its possible outcomes: reduced production and increased consumption, and actively steer towards the one that is considered more desirable depending a range of circumstances ranging from food resilience, security, public health, state of the environment and ecosystem services.

Food waste reduction would both facilitate and be facilitated by pricing-in of externalities into food production as well as diversifying the income from other ecosystem services. Reducing food waste on its own is less likely to succeed and result in positive food system changes, but such combination of strategies can steer the food system to a more resilient and sustainable future. Food and agricultural policy should not overlook this opportunity.

The covid-19 epidemic (ongoing at the time of writing) highlights the importance of food system resilience, as it is disrupting food supply chains in many different ways though e.g. order cancellations by the entire hospitality sector, creation of supply chain choke-points (such as the closure of slaughter-houses in the US), harvest-labour shortages (in India and Europe). All of this seems to be leading to a large increase in waste food - so not only does waste lead to lower resilience, low resilience may also lead to waste. The amount of food that is wasted instead of being supplied to people is particularly tragic, as at the same time, people are also becoming increasingly food insecure primarily due to slumps in incomes (World Food Programme, 2020). The interventions that we recommended in this paper, such as improved storage options and strategic well-managed stocks of long-life foods at household, business and regional/national level would help to alleviate such pressures.

#### Declaration of Competing Interest

Tom Quested, Richard Swannell and Bojana Bajželj are associated with WRAP, a UK-based charity with a longstanding history of working on food waste reduction. No other potential conflict of interest is declared.

#### References

Bajželj, B., Richards, K.S., Allwood, J.M., Smith, P., Dennis, J.S., Curmi, E., Gilligan, C.A., 2014. Importance of food-demand management for climate mitigation. *Nat. Clim. Change* 4. <https://doi.org/10.1038/nclimate2353>.

Benton, T.G., Bailey, R., 2019. The paradox of productivity: agricultural productivity promotes food system inefficiency. *Glob. Sustain* 2, 1–8. <https://doi.org/10.1017/sus.2019.3>.

Biggs, R., Schlüter, M., Biggs, D., Bohensky, E.L., BurnSilver, S., Cundill, G., Dakos, V.,

Daw, T.M., Evans, L.S., Kotschy, K., Leitch, A.M., Meek, C., Quinlan, A., Raudsepp-Hearne, C., Robards, M.D., Schoon, M.L., Schultz, L., West, P.C., 2012. Toward principles for enhancing the resilience of ecosystem services. *Annu. Rev. Environ. Resour.* 37, 421–448. <https://doi.org/10.1146/annurev-environ-051211-123836>.

Blanke, M.M., 2014. Reducing ethylene levels along the food supply chain: a key to reducing food waste? *J. Sci. Food Agric.* 94, 2357–2361. <https://doi.org/10.1002/jsfa.6660>.

Bradford, K.J., Dahal, P., Van Asbrouck, J., Kunusoth, K., Bello, P., Thompson, J., Wu, F., 2018. The dry chain: reducing postharvest losses and improving food safety in humid climates. *Trends Food Sci. Technol.* 71, 84–93. <https://doi.org/10.1016/j.tifs.2017.11.002>.

Britton, E., Brigdon, A., Parry, A., LeRoux, S., 2014. Econometric modelling and household food waste.

CBI, 2014. Product competitiveness for dried mangoes. <https://www.cbi.eu/market-information/processed-fruit-vegetables-edible-nuts/dried-mango-west-africa/>.

Chaboud, G., Daviron, B., 2017. Food losses and waste: navigating the inconsistencies. *Glob. Food Sec.* <https://doi.org/10.1016/j.gfs.2016.11.004>.

Chen, Q., Sipiläinen, T., Sumelius, J., 2014. Assessment of Agri-Environmental Externalities at Regional Levels in Finland, pp. 3171–3191. <https://doi.org/10.3390/su6063171>.

Cohen, J.F.W., Richardson, S., Parker, E., Catalano, P.J., Rimm, E.B., 2014. Impact of the new U.S. department of agriculture school meal standards on food selection, consumption, and waste. *Am. J. Prev. Med.* <https://doi.org/10.1016/j.amepre.2013.11.013>.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., Turner, R.K., 2014. Changes in the global value of ecosystem services. *Glob. Environ. Change.* <https://doi.org/10.1016/j.gloenvcha.2014.04.002>.

Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., Grasso, M., 2017. Twenty years of ecosystem services: how far have we come and how far do we still need to go? *Ecosyst. Serv.* 28, 1–16. <https://doi.org/10.1016/j.ecoser.2017.09.008>.

Devaney, L., Davies, A.R., 2017. Disrupting household food consumption through experimental HomeLabs: outcomes, connections, contexts. *J. Consum. Cult.* <https://doi.org/10.1177/1469540516631153>.

Directorate-General for Research and Innovation, 2019. The added value of a Food Systems Approach in Policy Brief Strategic Working Group on Food Systems. <https://doi.org/10.2777/407145>.

Dora, M., Wesana, J., Gellynck, X., Seth, N., Dey, B., De Steur, H., 2019. Importance of sustainable operations in food loss: evidence from the Belgian food processing industry. *Ann. Oper. Res.* <https://doi.org/10.1007/s10479-019-03134-0>.

European Commission, 2019. Report on the implementation of the Circular Economy Action Plan (COM(2019) 190 final), Archives of The Roentgen Ray. <https://doi.org/10.1259/arr.1905.0091>.

FAO, 2018. The future of food and agriculture Alternative pathways to 2050. Licence: CC BY-NC-SA 3.0 IGO.

FAO, Ifad, UNICEF, WFP and WHO, The State of Food Security and Nutrition in the World 2018 2018 Rome, FAO Building climate resilience for food security and nutrition 10. 1093/cjres/rst006.

Feeback, 2016. Causes of Food Waste in International Supply Chain. London, UK.

Fisher, K., Whittaker, D., 2018. Opportunities to Reduce Waste along the Journey of Milk, from Dairy to Home. Banbury.

Flanagan, K., Robertson, K., Hanson, C., 2019. Reducing Food Loss and Waste: Setting a Global Action Agenda. Washington, D.C.

Foley, J.A., Defries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. *Science* 309, 570–574. <https://doi.org/10.1126/science.1111772>.

Foresight, 2015. Tackling Obesity: Future Choices-Obesity System Atlas.

Freedman, M.R., Brochado, C., 2010. Reducing portion size reduces food intake and plate waste. *Obesity.* <https://doi.org/10.1038/oby.2009.480>.

Ganglbauer, E., Fitzpatrick, G., Comber, R., 2013. Negotiating food waste. *ACM Trans. Comput. Interact.* <https://doi.org/10.1145/2463579.2463582>.

Gardner, S.M., Ramsden, S.J., Hails, R.S. (Eds.), 2019. *Agricultural Resilience: Perspectives from Ecology and Economics*. Cambridge: Cambridge University Press (Ecological Reviews).

Gitonga, Z.M., De Groote, H., Kassie, M., Tefera, T., 2013. Impact of metal silos on households' maize storage, storage losses and food security: an application of a propensity score matching. *Food Policy* 43, 44–55. <https://doi.org/10.1016/j.foodpol.2013.08.005>.

Godfray, C., Garnett, T., 2014. Food security and sustainable intensification. *Philos. Trans. R. Soc. B Biol. Sci.* 369. <https://doi.org/10.1098/rstb.2012.0273>.

Gromko, D., Abdurusulova, G., 2018. Climate Change Mitigation and Food Loss and Waste Reduction: Exploring the Business Case, pp. 54.

Gustavsson, J., Cederberg, C., Sonesson, U., Otterdijk, R. van, Meybeck, A., 2011. Global food losses and food waste.

HLPE, 2014. Food losses and waste in the context of sustainable food systems. Rome.

Hanson, Craig, Mitchell, Peter, 2017. *The Business Case for Reducing Food Loss and Waste. Champions 12.3*, Washington, DC.

Ingram, J., 2011. A food systems approach to researching food security and its interactions with global environmental change. *Food Secur.* 3, 417–431. <https://doi.org/10.1007/s12571-011-0149-9>.

IPCC, 2019: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Shee, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S.

- Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)).
- Johnson, L.K., Dunning, R.D., Gunter, C.C., Bloom, J.D., Boyette, M.D., Creamer, N.G., Science, H., Carolina, N., States, U., 2018. Field measurement in vegetable crops indicates need for reevaluation of on-farm food loss estimates in North America. *Agric. Syst.* 167, 136–142.
- Kahneman, D., 2012. *Thinking, fast and slow*. Penguin, London, London.
- Kallbekken, S., Sælen, H., 2013. “Nudging” hotel guests to reduce food waste as a win-win environmental measure. *Econ. Lett.* <https://doi.org/10.1016/j.econlet.2013.03.019>.
- Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O., Ward, P.J., 2012. Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Sci. Total Environ.* 438, 477–489. <https://doi.org/10.1016/j.scitotenv.2012.08.092>.
- Lee, P., Osborn, S., Whitehead, P., 2015. *Reducing food waste by extending product life*. Wrap 1.
- Maleksaeidi, H., Karami, E., 2013. Social-ecological resilience and sustainable agriculture under water scarcity. *Agroecol. Sustainable Food Syst.* <https://doi.org/10.1080/10440046.2012.746767>.
- Martinez-Sanchez, V., Tonini, D., Møller, F., Astrup, T.F., 2016. Life-cycle costing of food waste management in Denmark: importance of indirect effects. *Environ. Sci. Technol.* <https://doi.org/10.1021/acs.est.5b03536>.
- Morante, N., Sánchez, T., Ceballos, H., Calle, F., Pérez, J.C., Egesi, C., Cuambe, C.E., Escobar, A.F., Ortiz, D., Chávez, A.L., Fregene, M., 2010. Tolerance to postharvest physiological deterioration in cassava roots. *Crop Sci.* 50, 1333–1338. <https://doi.org/10.2135/cropsci2009.11.0666>.
- National Research Council, 2012. *Exploring Health and Environmental Costs of Food*. Washington, DC. <https://doi.org/10.17226/13521>.
- Neff, R., Kanter, R., Vandevijvere, S., 2015. Reducing food loss and waste while improving the public’s health. *Health Aff.* 34, 1821–1829. <https://doi.org/10.1377/hlthaff.2015.0647>.
- Papargyropoulou, E., Lozano, R., Steinberger, K., Wright, J., Ujang, N., Bin, Z., 2014. The food waste hierarchy as a framework for the management of food surplus and food waste. *J. Clean. Prod.* 76, 106–115. <https://doi.org/10.1016/j.jclepro.2014.04.020>.
- Parfitt, J., Barthel, M., Macnaughton, S., 2010. Food waste within food supply chains: quantification and potential for change to 2050. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 365, 3065–3081. <https://doi.org/10.1098/rstb.2010.0126>.
- Parfitt, J., Woodham, S., Swan, E., Castella, T., Parry, A., 2016. Quantification of Food Surplus, Waste and Related Materials in the Grocery Supply Chain.
- Philippidis, G., Sartori, M., Ferrari, E., M’Barek, R., 2019. Waste not, want not: A bio-economic impact assessment of household food waste reductions in the EU. *Resour. Conserv. Recycl.* 514–522. <https://doi.org/10.1016/j.resconrec.2019.04.016>.
- Quested, T., Luzecka, P., 2014. Household Food and Drink Waste: A People Focus.
- Quested, T.E., Marsh, E., Stunell, D., Parry, A.D., 2013. Spaghetti soup: the complex world of food waste behaviours. *Resour. Conserv. Recycl.* <https://doi.org/10.1016/j.resconrec.2013.04.011>.
- ReFED, 2016. *A Roadmap to Reduce U.S. Food Waste by 20 Percent*.
- Reynolds, C., Goucher, L., Quested, T., Bromley, S., Gillick, S., Wells, V.K., Evans, D., Koh, L., Carlsson Kanyama, A., Katzeff, C., Svenfelt, Å., Jackson, P., 2019. Consumption-stage food waste reduction interventions – what works and how to design better interventions. *Food Policy* 7–27. <https://doi.org/10.1016/j.foodpol.2019.01.009>.
- Röös, E., Bajželj, B., Smith, P., Patel, M., Little, D., Garnett, T., 2017. Greedy or needy? Land use and climate impacts of food in 2050 under different livestock futures. *Glob. Environ. Change* 47. <https://doi.org/10.1016/j.gloenvcha.2017.09.001>.
- Roostaie, S., Nawari, N., Kibert, C.J., 2019. Integrated sustainability and resilience assessment framework: from theory to practice. *J. Clean. Prod.* 232, 1158–1166. <https://doi.org/10.1016/j.jclepro.2019.05.382>.
- Rutten, M.M., 2013. What economic theory tells us about the impacts of reducing food losses and/or waste: implications for research, policy and practice. *Agric. Food Secur.* 2. <https://doi.org/10.1186/2048-7010-2-13>.
- Saleemdeen, R., Font Vivanco, D., Al-Tabbaa, A., Zu Ermgassen, E.K.H.J., 2017. A holistic approach to the environmental evaluation of food waste prevention. *Waste Manage.* 59, 442–450. <https://doi.org/10.1016/j.wasman.2016.09.042>.
- Schanes, K., Dobernick, K., Burcu, G., 2018. Food waste matters – a systematic review of household food waste practices and their policy implications. *J. Clean. Prod.* 182, 978–991. <https://doi.org/10.1016/j.jclepro.2018.02.030>.
- Schipanski, M.E., MacDonald, G.K., Rosenzweig, S., Chappell, M.J., Bennett, E.M., Kerr, R.B., Blesh, J., Crews, T., Drinkwater, L., Lundgren, J.G., Schnarr, C., 2016. Realizing resilient food systems. *Bioscience.* <https://doi.org/10.1093/biosci/biw052>.
- Smil, V., 2004. Improving efficiency and reducing waste in our food system. *Environ. Sci.* 1, 17–26. <https://doi.org/10.1076/evms.1.1.17.23766>.
- Springer, N., Flaherty, R., Robertson, K., 2013. *Losses in the Field: An Opportunity Ripe for Harvesting*.
- Springmann, M., Clark, M., Mason-D’Croz, D., Wiebe, K., Bodirsky, B.L., Lassaletta, L., de Vries, W., Vermeulen, S.J., Herrero, M., Carlson, K.M., Jonell, M., Troell, M., DeClerck, F., Gordon, L.J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., Godfray, H.C.J., Tilman, D., Rockström, J., Willett, W., 2018. Options for keeping the food system within environmental limits. *Nature* 562, 519–525. <https://doi.org/10.1038/s41586-018-0594-0>.
- Stöckli, S., Niklaus, E., Dorn, M., 2018. Call for testing interventions to prevent consumer food waste. *Resour. Conserv. Recycl.* <https://doi.org/10.1016/j.resconrec.2018.03.029>.
- Tendall, D.M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q.B., Kruetli, P., Grant, M., Six, J., 2015. Food system resilience: defining the concept. *Glob. Food Sec.* <https://doi.org/10.1016/j.gfs.2015.08.001>.
- UNEP, 2016. *Food Systems and Natural Resources. A report of the working Group on Food Systems of the international Resource Panel*.
- Urruty, N., Tailliez-Lefebvre, D., Huyghe, C., 2016. Stability, robustness, vulnerability and resilience of agricultural systems. A review. *Agron. Sustain. Dev.* <https://doi.org/10.1007/s13593-015-0347-5>.
- Vermeulen, S.J., Dinesh, D., Howden, S.M., Cramer, L., Thornton, P.K., 2018. Transformation in practice: a review of empirical cases of transformational adaptation in agriculture under climate change. *Front. Sustain. Food Syst.* <https://doi.org/10.3389/fsufs.2018.00065>.
- Vidal, J., 2012. “Ugly” fruit and veg make the grade on UK supermarket shelves | Environment | The Guardian. <https://www.theguardian.com/environment/2012/sep/12/ugly-fruit-veg>.
- Wansink, B., van Ittersum, K., 2013. Portion size me: plate-size induced consumption norms and win-win solutions for reducing food intake and waste. *J. Exp. Psychol. Appl.* 19, 320–332. <https://doi.org/10.1037/a0035053>.
- Williamson, S., Block, L.G., Keller, P.A., 2016. Of waste and waists: the effect of plate material on food consumption and waste. *J. Assoc. Consum. Res.* <https://doi.org/10.1086/684287>.
- World Food Programme, 2020. *COVID-19 will double number of people facing food crises unless swift action is taken* [WWW Document]. URL: <https://www.wfp.org/news/covid-19-will-double-number-people-facing-food-crises-unless-swift-action-taken> (accessed 5.13.20).
- WRAP, 2013. *Understanding out of home consumer food waste*. WRAP, Banbury. <https://wrap.org.uk/sites/files/wrap/OOH%20Report.pdf>.
- WRAP, 2013b. *Waste Prevention Case Studies*. Banbury, UK.
- WRAP, 2015. *Food Futures*. Banbury, UK.
- WRAP, 2017. *Food waste in primary production – a preliminary study on strawberries and lettuces*. Banbury, UK.
- WRAP, 2019. *Food Surplus and Waste in the UK*. Banbury, UK.
- WRAP, FSA, DEFRA, 2017. *Labelling guidance*. Banbury, UK.
- zu Ermgassen, E.K.H.J., Phalan, B., Green, R.E., Balmford, A., 2016. Reducing the land use of EU pork production : where there ’ s swill , there ’ s a way 58, 35–48. <https://doi.org/10.1016/j.foodpol.2015.11.001>.