Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Environmental Sustainability

Transforming wasted food will require systemic and sustainable infrastructure innovations

Callie W Babbitt[1], Roni A Neff[2], Brian E Roe[3], Sauleh Siddiqui[4], Celeste Chavis[5] and Thomas A Trabold[1]

Currently, 40% of food produced in the U.S. is never eaten, leading to lost resources, economic costs, decreased food security, and the wasted food itself, which has immense climate and ecological impacts. However, unwanted food can be leveraged towards sustainability aims by, for example, diverting high-quality surplus to food-insecure communities, recycling carbon and nutrients into agricultural production, and converting food wastes into bioenergy. This transformation will require co-evolution of both *physical infrastructure* systems that produce, deliver, and manage food and waste and *human infrastructure*, from front-line workers to governance and institutions. This contribution will synthesize current knowledge and research in support of this transition, drawing from recent literature and two NSF-funded workshops on wasted food management in sustainable urban systems.

Addresses
[1] Golisano Institute for Sustainability, Rochester Institute of Technology, United States
[2] Department of Environmental Health & Engineering, Johns Hopkins Bloomberg School of Public Health, United States
[3] Department of Agricultural, Environmental & Development Economics, Ohio State University, United States
[4] Department of Environmental Science, American University, United States
[5] Department of Transportation & Urban Infrastructure Studies, Morgan State University, United States

Corresponding author: Babbitt, Callie W (cwbgis@rit.edu)

Current Opinion in Environmental Sustainability 2022, **54**:xx–yy

This review comes from a themed issue on **The role of infrastructure in societal transformations**

Edited by **Melissa R Gilbert**, **Hallie Eakin** and **Timon McPhearson**

Received: 16 July 2021; Accepted: 11 January 2022

https://doi.org/10.1016/j.cosust.2022.101151

Introduction

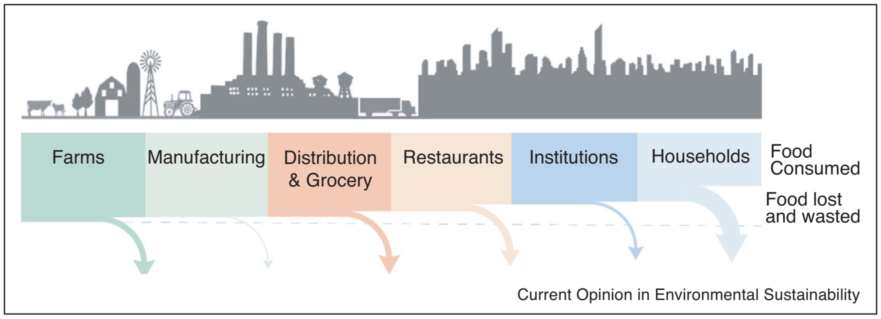
A safe, sustainable, and nutritious food supply is essential to population health and well-being. But modern food systems and their physical, human, and information infrastructures often fall short: they are expensive, resource-intense [1,2], and create ecological damages [3–5] and climate change impacts [6]. One in 10 Americans (and one in four globally) reported food insecurity [7], even before COVID-19, which caused unprecedented disruptions leading to food shortages, insecurity [8], and waste [9,10•]. Food system infrastructures are also vulnerable to climate change [11], natural disasters, geopolitical instability, cyberthreats, contamination [12], and global health crises, underscoring the need to enhance food system resilience [13•,14–16].

Food systems are also wasteful, with 30–50% of food produced never being consumed [17]. Food is lost and wasted across the supply chain (Figure 1), from farms, processors, restaurants, groceries, and households [18,19]. The wasted food itself is a complex organic waste stream whose management can strain often aging and overloaded waste, wastewater, transport, and energy infrastructures. In the U.S., wasted food is typically landfilled, leading to methane emissions and climate impacts [20,21]. Globally, wasted food accounts for 8% of all greenhouse gas emissions — more than the entire airline industry [22•].

While wasted food reflects inefficient food production and consumption practices, it also represents an opportunity for environmental, economic, and social gains. It can be re-envisioned as a resource by recovering carbon and nutrients from crop loss back into agricultural production; consuming more of what is purchased; diverting high-quality surplus to food-insecure communities; and converting wastes into bio-products and energy. Realizing this transformation is challenging, due to the food system's complex web of activities and actors that interact to produce, process, transport, consume, and waste nutritious substances [24]. Past efforts to minimize or manage waste have often met limited success because they fail to consider economic, social, policy, technology, and environmental interconnections inherent to this system [25••].

We argue that without enhancing the infrastructure systems comprising food supply chains, efforts to address wasted food will not achieve intended sustainability and resilience co-benefits. New research and solutions are needed to address the physical infrastructure systems that produce, deliver, and manage food and waste; the human infrastructure, from front-line workers to governance and institutions; and the information infrastructure that enhances coordination and management [26]. As a

Figure 1



Food lost and wasted along the food supply chain, from 'farm-to-fork'. Arrow size corresponds to estimated flows of food consumed, lost, or wasted [23]. Graphic by Liz Sisk.

step towards such a research agenda, two workshops funded by the U.S. National Science Foundation were held on the topic of wasted food solutions [27,28]. This article synthesizes the workshop findings with nascent literature, to present knowledge and practice gaps we must address to realize resilient and sustainable food systems.

A framework for food system transformations

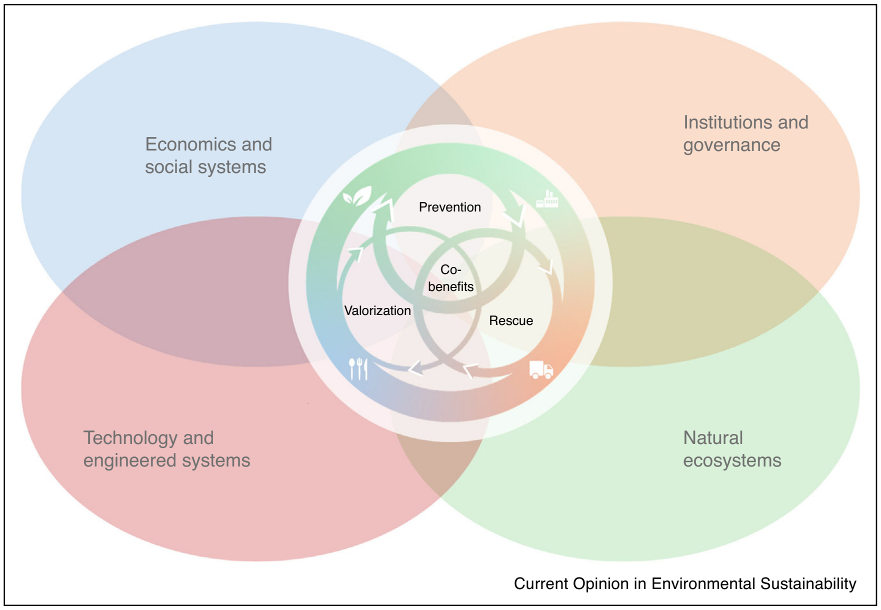
A circular framework for food production and wasted food management (Figure 2) offers a compelling alternative to inefficient and vulnerable linear food systems. Circular economy decouples economic growth from resource extraction and waste generation, and involves the interconnected strategies of narrowing, slowing, and closing resource loops [29•,30,31]:

- Narrowing resource loops refers to using resource-efficient processes that fulfill societal needs but demand less net resource input per unit of economic output [32]. In food systems, these strategies reduce overproduction and ensure food reaches a consumer, thus preventing wasted food.
- Slowing resource loops refers to retaining the use and value of materials for as long as possible [33]. In food systems, this approach can enhance resilience and retain nutritional value by rescuing surplus food before it becomes waste. Ideally, this surplus would feed people, but where food deviates from nutritional, cultural, or practical needs of consumers, it can be downcycled for animal feed.
- Closing resource loops involves recovering an end-of-life resource and returning it to productive use [34]. Closed-loop material flows take inspiration from cycling of nutrients and energy in nature, where waste from one organism becomes 'food' for another [35,36]. These processes are often termed 'valorization' because they convert waste into higher-value resources by recovering energy, carbon, nitrogen, phosphorus, and water.

Collectively, circular strategies can provide sustainability benefits spanning the food system, including improved diets [37], particularly among the food insecure [38]; reduced food system resources and costs [39•]; reduced stress on waste treatment systems [40]; enhanced urban agriculture practices [41]; increased generation of renewable energy [42]; improved health for workers and communities near waste management sites [43,44]; and enhanced food system resilience to shocks [13•]. Circular economy also offers a more holistic perspective than conventional waste management frameworks, which is particularly important due to the resource-intense nature of food systems and the potential for significant sustainability benefits from upstream interventions that prevent food loss in the first place [45,46].

While the benefits are clear, the pathway to implementing circular economy strategies is complicated; current estimates suggest just over 3% of food is recaptured and just over 30% recycled annually in the U.S. [47•]. The next sections synthesize literature and discuss future research outlooks on the human and physical infrastructure systems at the heart of these interactions. Here, physical (or 'human-built') infrastructure includes all technological and engineered systems required for food systems to function and maintain quality of life, including energy and water provisioning, solid waste and wastewater management, transportation, and the built environment. The term 'human infrastructure' became more widespread in U.S. discourse with the Biden Administration's infrastructure policy goals [48], referring to workforce capacity and human needs. We use the term more narrowly to focus on people, governance, institutions, and sociocultural and market forces addressing wasted food. Lastly, we discuss 'computational and data infrastructures' that facilitate food's transformation and allow

Figure 2



Circular economy framework for wasted food, depicting intersections and co-benefits between prevention, rescue, and valorization and between the food system's social, natural, technological, and governance systems.

us to model systemic interconnections and analyze outcomes.

Physical infrastructure systems

At the core of food system infrastructure are the processes involved in food production, manufacturing, packaging, transportation, and distribution, which are collectively responsible for over 100 million tons of wasted food each year [19]. At the farm scale, some degree of food loss may actually prevent downstream waste, by removing and re-tilling food with defects that may spoil during handling or be rejected and landfilled by consumers [49,50•]. Beyond these losses, further wastes can be minimized by extending harvest [51], relaxing cosmetic standards [52], creating economically viable routes for farmers to donate or recover excess [53], and innovating technologies that can improve overall efficiency through sustainable agricultural intensification [54] or precision agriculture [55,56]. In developing economies, loss reduction hinges on basic infrastructure improvements in roads, post-harvest storage, and information exchanges between farms and local markets [57]. Recently, advances in controlled environment agriculture, including hydroponic, vertical, and rooftop gardens and novel greenhouse systems, have been suggested as a means to minimize waste during production [58,59]. However, a critical research need is proactive evaluation of such solutions to ensure that they can feasibly be scaled to meet demand and do not create unintended economic or environmental impacts compared to conventional agriculture [60,61].

Food is a widely transported commodity, and packaging and distribution play key roles in reducing losses and enabling downstream loop-closing approaches. Food packaging is necessary to prevent spoilage and maximize shelf life, but may itself add other sustainability concerns [62,63•]. Once packaging has served its role in the food supply chain, it usually becomes an added waste to manage or a contaminant in downstream food waste treatment. One opportunity is to consider packaging and edible material as parts of one integrated food system, opening new research directions regarding design of polymers that are durable during transport and distribution but then can degrade at the same time scale and within the same processes as the food scraps with which they are commingled [64•,65,66]. However, despite recent advances in degradable bioplastics, broader research is required to understand their suitability for treatment in existing composting and anaerobic digestion infrastructure [67•,68] and to evaluate consumer food safety for novel materials and applications.

Transport infrastructure is a critical component of all three circular economy approaches for wasted food. Market forces and the dynamic urban landscape have resulted in locations with limited grocery store access, forcing consumers to make tradeoffs between location, affordability, and quality of food [69], possibly limiting broader adoption of prevention and rescue strategies. Transportation is also central to downstream management of surplus and wasted food, which typically involves source separation followed by transportation and distribution (for food rescue) or transportation, pre-treatment, conversion, and distribution of the biofuels, energy, or other products ultimately recovered (for valorization) [70]. Food pickup and routing can be particularly difficult in urban settings characterized by congestion and narrow streets. Advances in logistics and systems design will be critical to improving efficiency. For example, many food rescue business models leverage digital platforms to create micro-networks used to collect and redistribute food [71]. Emerging businesses in this space are often small, and models for upscaling and partnering can address inefficient transportation and logistics [72] or establish networks of sufficient size to make food waste hauling economically viable [73].

Even with expanded efforts to narrow and slow food system resource loops, some waste will be inevitable, requiring significant expansion of waste management infrastructure [74]. This infrastructure must be resilient to variability in wasted food composition [75] and generation volume [76,77]. Siting new food waste recovery facilities must balance competing objectives, including local regulations, transport costs, revenue sources, public opinion, environmental justice and equity concerns, and downstream systems to treat residual organic waste after the primary conversion process [70,78]. A central challenge is 'matching' the heterogeneous food waste stream to the valorization technology and associated infrastructure that can recover the most value with the lowest economic cost and environmental impact [79•]. The aim is twofold: creating products that displace fossil fuel-derived chemicals or energy sources, while also diverting food waste from landfills [80,81]. Revenues for firms operating waste-to-value systems arise both from charging tipping fees to food waste generators and from selling the produced electricity, natural gas, or bio-products [74,82].

Waste-to-infrastructure matching is challenging because some feedstocks are better suited for incumbent technologies, such as anaerobic digestion or composting, while others are ideal for emerging processes, such as thermochemical treatment [83] or conversion to high value chemicals [84]. For example, relatively dry waste (<30% moisture) can be converted at much higher energy efficiency via gasification or pyrolysis [85,86]. The resulting mix of products from valorization may include syngas, biochar, specialty chemicals [87], fertilizers [88•], compost, biofuels, electricity, or other bio-based products. A choice among these options will be governed by the firm's business model, social goals, market prices for co-products, local electricity and fuel demand, and climate and renewable energy policy incentives and targets [89,90]. One emerging opportunity is for integration across technologies to create food waste 'biorefineries' that convert multiple incoming feedstocks into varied co-products [91,92]. This model may provide economic benefits to firms, particularly in response to fluctuating product demand and prices [93,94]. Further research is needed to investigate the technical performance of food waste valorization pathways and the environmental, economic, and social tradeoffs between alternatives [95,96•].

Technology choice and infrastructure siting also introduce new interdependencies between critical regional infrastructures, but their interconnections have not been exploited for benefit when it comes to wasted food. The interactions of food and waste with broader regional infrastructures, such as energy, water, and transportation, can help identify hot spots where these linkages represent vulnerabilities to system resilience [97] and opportunities for joint interventions for cost-effective resource savings [98,99], along with accounting for cascading effects between infrastructures [100]. Thus, the interdependencies of waste systems with regional infrastructures that are currently seen as vulnerabilities can become targets of opportunity.

Human infrastructure systems

Transforming the food system through innovations in human infrastructure means shifting the capacities, incentives, and default actions that lead to poor waste prevention and management. While we focus here on humans' infrastructural role as consumer and worker, humans are, of course, more than infrastructure. The multi-dimensionality of people's lives beyond this role is core to the challenges and opportunities we consider, in consumer behavior, industry practice and policy, educational institutions, and the workforce.

With about 37% of U.S. wasted food directly attributable to decisions made by consumers in their homes and another 29% in retail and foodservice [47•], the human infrastructure shaping consumer behavior is ripe for transformation. A 2020 National Academies of Science, Engineering and Medicine report adopts a systems framework for understanding consumer food waste causes and solutions, and recommends pathways for transforming human infrastructure to reduce waste in the United States [25••], while highlighting a significant research gap in intervention evaluation. While the report focuses on the U.S., findings are applicable for other high income countries.

One pathway focuses on directly changing behavior by addressing consumer motivation, ability and opportunity to reduce waste [101,102], including via a customizable Federal platform for behavior change campaigns. This pathway acknowledges the importance of cultural and educational infrastructures in amplifying behavior change

[103,104], with media influencers increasingly shaping social norms. A second pathway suggests changes to policy and industry practice that support consumers to make less wasteful decisions. For example, food date labels have been implicated as a cause of wasted food [17,105]; the National Academies report recommended parties work towards Federal harmonization of date labels with accompanying education programs [106•]. Outside government policy, many commercial food enterprises are increasingly engaged with broad voluntary sustainability certification programs [107]. Realizing these transformations, however, will require parallel research on efficacious and scalable waste reduction interventions [108•] and new technologies that support reduction and redirection of wasted food.

The education sector is a critical enabler of the pathways discussed above and a cornerstone of human infrastructure, with nearly 140 000 primary, secondary and post-secondary educational institutions in the U.S. [109] poised to address wasted food through schools' triple role of educating, socializing, and feeding students. Schools generate tremendous food waste due to the volume of meals served (29+ million US children in 2019 [110]), children's preferences, food quality, and the ways meals are implemented [111]. Food waste education in schools can shape a generation's behaviors and attitudes through developing food and food waste literacy at a time of plasticity when lifelong behavioral patterns are established, as well as contributing to current household practices [25••]. Particular benefit may come from linking the classroom and cafeteria [112,113]. Several school food waste interventions have shown potential, including classroom and teacher education [114]; engaging students in intervention design [115•]; and using nudges to shift portion size [116]. Suggestive evidence exists for other types of interventions, including tracking and communicating about waste through audits [113], improving meal quality [117,118], and scheduling recess before lunch [119]. Overcoming the barriers to broader adoption of these approaches will require research in two main domains: well-designed studies to clarify what interventions work, and in what context, and to test at scale; and research to quantify co-benefits on critical outcomes, including cost savings, educational alignment, and staff burden.

The food waste human infrastructure comprises nearly 22 million workers in the U.S. alone, many of whom are contracted rather than directly employed [120], plus an additional large group of waste management workers in governmental and private settings. Workers engage in food waste prevention and management through both direct job roles and indirect opportunities that arise or which can be created with sufficient motivation, opportunity, and ability to take action. While the chance to 'do good' through work cannot substitute for sufficient pay or good working conditions, it may enhance feelings of pride and improve workplace climate [121•]. Intervention research suggests engagement is a valuable strategy for addressing waste of food [25••]. While addressing waste can benefit workers, it also carries risks. In some food and waste management sectors, injury and illness rates exceed twice the national average, while workers in waste management, truck transportation, and waste collection have fatalities four to eleven times the US average [44].

Several challenges limit the transformations needed. First, there is virtually no research on worker engagement to address waste of food. Second, formative studies suggest that workers and their managers often differently perceive protocols, challenges, and opportunities for addressing food waste [121•], but given the low level of workforce power and high turnover, managers may eschew worker input into responses. Employers often have low incentives to reduce workers' risks, due to low regulatory enforcement and absent standards, and opportunity to avoid legal responsibility for contract worker injuries [122]. Research needs include gaining insight directly from frontline workers to understand their perceptions of challenges, hazards, and specific strategies that could be adopted to improve waste prevention and management; piloting and testing worker-engaged interventions in a range of regional contexts and workplace types; and examining co-benefits and co-harms of interventions for workers, firms, and society, including spillover effects such as waste prevention in workers' personal lives. In particular, cost-benefit assessment may help make the case to employers to adopt interventions. Approaches and theories used in related fields such as medical errors and food safety should also be evaluated.

Computational and data infrastructures

Human and physical infrastructure systems give rise to complex interactions that are challenging to model or assess but important to capture to ensure that transformations lead to overall sustainability benefits and avoid unintended consequences. This challenge is further compounded by the lack of high quality data to characterize the magnitude and drivers of wasted food flows. This challenge presents an opportunity for research to expand and enrich computational infrastructures by leveraging advances in data science and modeling.

Food system data are often fragmented across case studies of varying scales from household to aggregate national food production and loss data. Existing data on wasted food in the US do not uniformly capture the full food system and are subject to significant variability in accounting method [39•] and food flows [77] and reliance on self-reporting by consumers or organizations [123•]. Interdisciplinary collaborations can expand and refine the toolbox of data collection approaches [124•], while partnerships with governmental, commercial, and nongovernmental actors are needed to validate and visualize new data streams to facilitate decision making. Such efforts require an architecture supporting data harmonization to capture food system complexities [125•] in the context of wasted food.

Ideally such a data architecture would be flexible, multi-depth, and geo-referenced to facilitate multiscale analyses and model-building efforts. Flexibility is required as it must both store diverse qualitative and quantitative data types and content (waste quantities; nutrient and chemical compositions; technology specifications; economic, financial, environmental, and social outcomes) and enable data-driven research efforts. Geo-referencing enables regionalizing and localizing models and analyses and articulating spatial linkages and interactions. Multi-depth capabilities are crucial to integrate micro to macro data layers and accommodate different granularities. To ensure harmonization across data sources and facilitate modeling and assessment, relevant ontologies for food [126] and wasted food [127] must be expanded and linked to capture potential waste sinks (landfills, incinerators), prevention activities and outcomes (campaigns, intervention effect sizes), and circular material flows (rescue, valorization) embedded in the various infrastructure systems detailed above.

Even with these data advances, two main knowledge gaps still remain in computational modeling of wasted food in a circular economy context: explicitly representing the interactions within and beyond the food system and quantifying environmental, social, and health outcomes and tradeoffs that result from these interactions and potential solutions. Food systems and their interactions are often represented with input output models (I–O) [128•], computable general equilibrium (CGE) models [129], or within integrated assessment models (IAMs) [130]. While I–O models can provide bottom-up representations of exchanges between sectors, they are based on linear input-output matrices, and are aggregate and not granular to specific processes. Further, I–O models hold macroeconomic variables such as population change and economic growth as exogenous. CGE and IAMs are top-down models that study the economy as a whole, and can represent macroeconomic changes, but cannot represent detailed bottom-up processes such as agricultural production technologies, anaerobic digestion placement decisions, and transportation infrastructure.

Life cycle assessment (LCA) can be applied to create estimates of metrics relevant to sustainability, including cumulative emissions and damages that arise from the food supply chain processes and from food loss and waste [131•]. Historically, LCA research has used data-intense process models to characterize mass and energy flows associated with specific industry or infrastructure systems, but has less frequently captured economic [132] or social [133•] outcomes. LCA can, however, be integrated with economic models of food system interactions using either I–O models (classified as 'attributional' because they describe a system as is) or CGEs (classified as 'consequential' because they model outcomes of a simulated change) [134–136]. One advantage of consequential LCA is the ability to quantify marginal impacts of complex system shifts through connected dual variables, thus capturing potential change in food systems after interventions [137]. Yet LCA still faces a number of challenges when applied to the food system, including the difficulty of drawing boundaries between coupled human and natural systems involved in food provisioning and the potential bias of valuation methods that prioritize efficiency over resilience and other desirable but difficult-to-measure sustainability attributes [138].

Thus, we need modeling advancements that can leverage both explicit process representation and marginal changes as a result of decisions or interventions. Studies can accomplish these goals by integrating the process representation of optimization models, the aggregation of I–O models, and the marginal, nonlinear representation of equilibrium models. Capturing the full spectrum of food system sustainability [139] will require both novel LCA approaches applied to circular economy solutions [140] and the integration of complementary methods that account for resilience and equity [138]. As an example, if food waste valorization via anaerobic digestion provides an energy source in a region, we could quantify systemic sustainability outcomes while accounting for both supply and demand changes in the energy sector [74]. Such advancement would allow flexibility to expand modeling capabilities to quantify uncertainty [141] or to further couple analyses with climate [142,143], hydrology [142,144], and integrated assessment models [145] as has been done with other sectors.

Conclusion and research outlook

A safe, sustainable, resilient food supply is a necessary facet of a sustainable future. Research described herein offers the potential to transform the food system by preventing or minimizing food loss, managing unavoidable food waste, and improving resilience, public health, equity and sustainability co-benefits. However, the solutions encompassed within the circular economy framework described here also face broad challenges to adoption. One such challenge is the complexity underlying the infrastructures that comprise the food system and their interactions across other technical, social, institutional, and ecological systems. Here, we propose that a transformational approach will involve identifying critical food system infrastructure components, testing interventions aimed at preventing, rescuing, or valorizing wasted food, and ultimately assessing the systems-level outcomes using advances in data science and modeling methods.

However, carrying out research to achieve these visions faces broader barriers. For example, identifying and testing human infrastructure solutions will require deep collaboration between academic researchers and food system stakeholders that go beyond traditional academic structures. Similarly, creating the data and models required to analyze physical infrastructure interactions will require collaboration across disparate fields and knowledge domains. The emerging domain of convergence science provides an approach to 'holistically understand, create, and transform a system' [146•] through team-based collaborations organized around complex societal challenges. Carrying out research within this framework offers a path to build generalizable insights that are transferable to other infrastructure systems and to realize a circular food system with less resource use and waste and greater benefits to societal health and wellbeing.

Conflict of interest statement

Nothing declared.

Acknowledgements

Funding for this work was provided by the National Science Foundation (Award numbers 2115405, 1929881, 1639391, 1745375, 1639214, and 1929791). Roe recognizes support from Ohio State University's Van Buren Fund and USDA National Institute of Food and Agriculture (NIFA) (Hatch project OHO01419). Neff recognizes support from USDA NIFA (2018-67003-27408) and Foundation for Food & Agriculture Research (557409). Trabold recognizes support from Foundation for Food & Agriculture Research (CA19-SS-0000000013).

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Dieter CA, Maupin MA, Caldwell RR, Harris MA, Ivahnenko TI, Lovelace JK, Barber NL, Linsey KS: *Estimated Use of Water in the United States in 2015*. 2018.

2. Canning P, Rehkamp S, Waters A, Etemadnia H: *The Role of Fossil Fuels in the U.S. Food System and the American Diet*. 2017.

3. Diaz RJ, Rosenberg R: **Spreading dead zones and consequences for marine ecosystems**. *Science* 2008, **321**:926-929.

4. Robertson GP, Vitousek PM: **Nitrogen in agriculture: balancing the cost of an essential resource**. *Annu Rev Environ Resour* 2009, **34**:97-125.

5. Cordell D, White S: **Life's bottleneck: sustaining the world's phosphorus for a food secure future**. *Annu Rev Environ Resour* 2014, **39**:161-188.

6. IPCC: **Food security**. *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*. IPCC; 2019.

7. FAO, IFAD, UNICEF, WFP, WHO: *The State of Food Security and Nutrition in the World 2020. Transforming Food Systems for Affordable Healthy Diets*. 2020.

8. Niles MT, Bertmann F, Belarmino EH, Wentworth T, Biehl E, Neff R: **The early food insecurity impacts of COVID-19**. *Nutrients* 2020, **12**:2096.

9. Roe BE, Bender K, Qi D: **The impact of COVID-19 on consumer food waste**. *Appl Econ Perspect Policy* 2020, **43**:401-411.

10. • Babbitt CW, Babbitt GA, Oehman JM: **Behavioral impacts on residential food provisioning, use, and waste during the COVID-19 pandemic**. *Sustain Prod Consum* 2021, **28**:315-325

COVID-19 created impacts to consumer behavior that led to changes in food use and waste generation. This article empirically analyzes key behavioral determinants of wasted food minimization and management during the pandemic and discussed potential future-oriented consumption and waste solutions.

11. CGIAR: *CGIAR Research Program on Climate Change, Agriculture and Food Security*. 2011.

12. Talley J, Davis LB, Morin B, Liu L: **A vector-borne contamination model to assess food-borne outbreak intervention strategies**. *Appl Math Model* 2019, **66**:383-403.

13. • Bajželj B, Quested TE, Röös E, Swannell RPJ: **The role of reducing food waste for resilient food systems**. *Ecosyst Serv* 2020, **45**:101140

This article establishes the linkages between wasted food and food system resilience, identifying key interventions which may enhance resilience and at the same time reduce surplus food that may go to waste. It also emphasizes the need for systems-level evaluations to ensure that solutions do not lead to unintended tradeoffs.

14. Tendall DM, Joerin J, Kopainsky B, Edwards P, Shreck A, Le QB, Kruetli P, Grant M, Six J: **Food system resilience: defining the concept**. *Glob Food Sec* 2015, **6**:17-23.

15. Chodur GM, Zhao X, Biehl E, Mitrani-Reiser J, Neff R: **Assessing food system vulnerabilities: a fault tree modeling approach**. *BMC Public Health* 2018, **18**:1-11.

16. Hecht AA, Biehl E, Barnett DJ, Neff RA: **Urban food supply chain resilience for crises threatening food security: a qualitative study**. *J Acad Nutr Diet* 2019, **119**:211-224.

17. ReFED: *A Roadmap to Reduce U.S. Food Waste by 20 Percent*. 2016.

18. Bellemare MF, Çakir M, Peterson HH, Novak L, Rudi J: **On the measurement of food waste**. *Am J Agric Econ* 2017, **99**:1148-1158.

19. EPA US: *2018 Wasted Food Report: Estimates of Generation and Management of Wasted Food in the United States in 2018*. 2018.

20. Levis JW, Barlaz MA: **What is the most environmentally beneficial way to treat commercial food waste?** *Environ Sci Technol* 2011, **45**:7438-7444.

21. Bernstad A, Wenzel H, La Cour Jansen J: **Identification of decisive factors for greenhouse gas emissions in comparative life cycle assessments of food waste management - an analytical review**. *J Clean Prod* 2016, **119**:13-24.

22. • Project Drawdown: *Reduced Food Waste*. 2020

This report synthesizes modeling data from 80 climate change solutions, identifying a 50% reduction in waste of food as a globally impactful solution for reaching a 2°C climate scenario.

23. Gunders D: *Wasted: How America Is Losing Up to 40 Percent of Its Food from Farm to Fork to Landfill*. 2017.

24. Neff R: *Introduction to the US Food System: Public Health, Environment, and Equity*. Wiley; 2014.

25. •• NASEM: *A National Strategy to Reduce Food Waste at the Consumer Level*. National Academies Press; 2020

This consensus report reviews extant data on consumer food waste, including assessment of effectiveness of wasted food reduction interventions; makes actionable recommendations for wasted food reduction strategies; and identifies implementation strategies to reduce wasted food at the consumer level from a system perspective. The report identifies 11 categories of drivers of consumer waste and reviews more than 60 studies exploring seven categories of interventions as well as the efficacy of interventions in behaviorally adjacent areas such as water and energy conservation. Ten primary conclusions and 12 actionable recommendations are provided across three main pathways: Changing the food environment; strengthening consumer motivation, opportunity and ability; and leveraging and applying research findings and technology. The report stresses the importance of transforming the overall food system and its

various infrastructures in order to support changes in individual consumer behaviors that can lead to less waste.

26. Nogueira A, Ashton W, Teixeira C, Lyon E, Pereira J: **Infrastructuring the circular economy**. *Energies* 2020, **13**:1805.

27. Babbitt C, Trabold T, Whitney KS, Breunig H, Nicewonger T, Nicholson C, Romeiko XX: *Urban Food Waste Solutions from Farm-to-Fork: A Conference for Advancing Sustainable Urban Systems (SUS) Research Networks*. 2019.

28. Neff R, Roe BE, Siddiqui S: *Wasted Food and Sustainable Urban Systems: Prioritizing Research Needs*. 2019.

29. • Babbitt CW, Althaf S, Cruz Rios F, Bilec MM, Graedel TE: **The role of design in circular economy solutions for critical materials**. *One Earth* 2021, **4**:353-362
This article provides additional background on the circular economy field, reviewing the need for solutions and the challenges of applying circular economy interventions that aim to narrow, slow, and close resource loops.

30. Bocken NMP, de Pauw I, Bakker C, van der Grinten B: **Product design and business model strategies for a circular economy**. *J Ind Prod Eng* 2016, **33**:308-320.

31. Stahel W: **The utilization-focused service economy: resource efficiency and product-life extension**. In *The Greening of Industrial Ecosystems.* Edited by Allenby BR, Richards DJ. National Academies Press; 1994:178-190.

32. van der Voet E, Oers L, Nikolic I: **Dematerialization: not just a matter of weight**. *J Ind Ecol* 2004, **8**:121-137.

33. Bocken N, Miller K, Weissbrod I, Holgado M, Evans S: **Slowing resource loops in the circular economy: an experimentation approach in fashion retail**. *Smart Innovation, Systems and Technologies*. Springer Science and Business Media Deutschland GmbH; 2019:164-173.

34. Kirchherr J, Reike D, Hekkert M: **Conceptualizing the circular economy: an analysis of 114 definitions**. *Resour Conserv Recycl* 2017, **127**:221-232.

35. Saavedra YMB, Iritani DR, Pavan ALR, Ometto AR: **Theoretical contribution of industrial ecology to circular economy**. *J Clean Prod* 2018, **170**:1514-1522.

36. Ryen EG, Gaustad G, Babbitt CW, Babbitt G: **Ecological foraging models as inspiration for optimized recycling systems in the circular economy**. *Resour Conserv Recycl* 2018, **135**:48-57.

37. Neff RA, Kanter R, Vandevijvere S: **Reducing food loss and waste while improving the public's health**. *Health Aff* 2017, **34**:1821-1829.

38. Spiker ML, Hiza HAB, Siddiqi SM, Neff RA: **Wasted food, wasted nutrients: nutrient loss from wasted food in the United States and comparison to gaps in dietary intake**. *J Acad Nutr Diet* 2017, **117**:1031-1040.

39. • Spang ES, Moreno LC, Pace SA, Achmon Y, Donis-Gonzalez I, Gosliner WA, Jablonski-Sheffield MP, Momin MA, Quested TE, Winans KS *et al.*: **Food loss and waste: measurement, drivers, and solutions**. *Annu Rev Environ Resour* 2019, **44**:117-156
Developing comprehensive and accurate estimates of wasted food is challenging, given the variability in estimation methods and underlying uncertainties in processes that lead to food loss and waste. This article reviews the wide array of estimation methods and provides recommendations towards future improvements in data and analysis.

40. Ebner J, Babbitt C, Winer M, Hilton B, Williamson A: **Life cycle greenhouse gas (GHG) impacts of a novel process for converting food waste to ethanol and co-products**. *Appl Energy* 2014, **130**:86-93.

41. Kulak M, Graves A, Chatterton J: **Reducing greenhouse gas emissions with urban agriculture: a life cycle assessment perspective**. *Landsc Urban Plan* 2013, **111**:68-78.

42. Kothari R, Tyagi VV, Pathak A: **Waste-to-energy: a way from renewable energy sources to sustainable development**. *Renew Sustain Energy Rev* 2010, **14**:3164-3170.

43. Tait PW, Brew J, Che A, Costanzo A, Danyluk A, Davis M, Khalaf A, McMahon K, Watson A, Rowcliff K *et al.*: **The health impacts of waste incineration: a systematic review**. *Aust N Z J Public Health* 2020, **44**:40-48.

44. U.S. Bureau of Labor Statistics: *Injuries, Illnesses, and Fatalities*. 2021.

45. Redlingshöfer B, Barles S, Weisz H: **Are waste hierarchies effective in reducing environmental impacts from food waste? A systematic review for OECD countries**. *Resour Conserv Recycl* 2020, **156**:104723.

46. CEC: *Characterization and Management of Food Loss and Waste in North America*. 2017.

47. • ReFED: *ReFED Insights Engine*. 2021 https://insights.refed.org/
ReFED (Rethinking Food Waste through Economics and Data) is a nonprofit organization with a network of stakeholders that includes business, government, and nonprofit leaders committed to reducing wasted food in the US. ReFED's Data Insights Engine is a regularly updated digital-first platform that houses multi-scale data from throughout the food system and generates on-demand graphical insights on surplus and wasted food at a granular level. The Insights Engine supports analysis of trends over the 2010–2019 time-period at national and state levels as well as by sector (e.g. residential, farm, manufacturing), waste destination (e.g. landfill, composting) food type (e.g. produce, prepared foods) and waste causes (e.g. trimmings, spoiled). Each data series is fully downloadable and accompanied by a rating of the data quality on a five-point scale.

48. Greve JE: **Biden heads to Capitol Hill to boost Democrats' 'human infrastructure' plan**. *Guard*. 2021.

49. Winans K, Marvinney E, Gillman A, Spang E: **An evaluation of on-farm food loss accounting in Life-Cycle Assessment (LCA) of four California specialty crops**. *Front Sustain Food Syst* 2020, **4**:10.

50. • Gillman A, Campbell DC, Spang ES: **Does on-farm food loss prevent waste? Insights from California produce growers**. *Resour Conserv Recycl* 2019, **150**:104408
Using a qualitative approach, this article presents surprising findings that some degree on on-farm food loss may actually lead to less waste across the food supply chain. If farmers reject foods with small defects, which may lead to consumer rejection or spoilage, they are able to more easily recover the nutrients contained in the food through retiling into farm fields. On the other hand, if consumers later discard the food, it typically ends up being landfilled, which leads to greater system impacts.

51. Johnson LK, Dunning RD, Bloom JD, Gunter CC, Boyette MD, Creamer NG: **Estimating on-farm food loss at the field level: a methodology and applied case study on a North Carolina farm**. *Resour Conserv Recycl* 2018, **137**:243-250.

52. Porter SD, Reay DS, Bomberg E, Higgins P: **Avoidable food losses and associated production-phase greenhouse gas emissions arising from application of cosmetic standards to fresh fruit and vegetables in Europe and the UK**. *J Clean Prod* 2018, **201**:869-878.

53. Campbell D, Munden-Dixon K, Campbell D, Munden &: **On-farm food loss: farmer perspectives on food waste**. *J Ext* 2018, **56**:6-7.

54. Chartres CJ, Noble A: **Sustainable intensification: overcoming land and water constraints on food production**. *Food Secur* 2015, **7**:235-245.

55. Sim DHH, Tan IAW, Lim LLP, Hameed BH: **Encapsulated biochar-based sustained release fertilizer for precision agriculture: a review**. *J Clean Prod* 2021, **303**:127018.

56. Mikula K, Izydorczyk G, Skrzypczak D, Mironiuk M, Moustakas K, Witek-Krowiak A, Chojnacka K: **Controlled release micronutrient fertilizers for precision agriculture – a review**. *Sci Total Environ* 2020, **712**:136365.

57. Stathers T, Holcroft D, Kitinoja L, Mvumi BM, English A, Omotilewa O, Kocher M, Ault J, Torero M: **A scoping review of interventions for crop postharvest loss reduction in sub-Saharan Africa and South Asia**. *Nat Sustain* 2020, **3**:821-835.

58. Dsouza A, Price GW, Dixon M, Graham T: **A conceptual framework for incorporation of composting in closed-loop urban controlled environment agriculture**. *Sustain* 2021, **13**:2471.

59. Benke K, Tomkins B: **Future food-production systems: vertical farming and controlled-environment agriculture**. *Sustain Sci Pract Policy* 2017, **13**:13-26 http://dx.doi.org/10.1080/15487733.2017.1394054.

60. Nicholson CF, Harbick K, Gómez MI, Mattson NS: **An economic and environmental comparison of conventional and controlled environment agriculture (CEA) supply chains for leaf lettuce to US cities**. *Food Supply Chains in Cities*. Cham: Palgrave Macmillan; 2020, 33-68.

61. Wu F, Ghamkhar R, Ashton W, Hicks AL: **Sustainable seafood and vegetable production: aquaponics as a potential opportunity in urban areas**. *Integr Environ Assess Manag* 2019, **15**:832-843.

62. Brennan L, Langley S, Verghese K, Lockrey S, Ryder M, Francis C, Phan-Le NT, Hill A: **The role of packaging in fighting food waste: a systematised review of consumer perceptions of packaging**. *J Clean Prod* 2021, **281**:125276.

63. Williams H, Lindström A, Trischler J, Wikström F, Rowe Z:
• **Avoiding food becoming waste in households – the role of packaging in consumers' practices across different food categories**. *J Clean Prod* 2020, **265**:121775
While packaging is often viewed negatively due to the environmental impacts of single-use packaging, this article outlines the more complex perspective on packaging, which may actually provide some benefit in minimizing upstream food losses.

64. Hegde S, Diaz CA, Dell EM, Trabold TA, Lewis CL: **Investigation of**
• **process parameters on the anaerobic digestion of a poly (hydroxyalkonate) film**. *Eur Polym J* 2021, **148**:110349
This article explored the role of anaerobic digestion (AD) operating conditions on the degradation of poly(hydroxyalkonate) (PHA), a general class of biopolymers synthesized by microorganisms that can readily degrade in marine and composting environments. Co-digestion of bio-plastic and food waste contributed to a reduced lag phase before significant biogas production, and also improved the biomethane potential of PHA. These findings can be used to develop guidelines for the operation of anaerobic digesters processing mixed food waste that may contain bioplastics such as PHA.

65. Diaz CA, Shah RK, Evans T, Trabold TA, Draper K: **Thermoformed containers based on starch and starch/coffee waste biochar composites**. *Energies* 2020, **13**:6034.

66. Samadi K, Francisco M, Hegde S, Diaz CA, Trabold TA, Dell EM, Lewis CL: **Mechanical, rheological and anaerobic biodegradation behavior of a poly(lactic acid) blend containing a Poly(lactic acid)-co-poly(glycolic acid) copolymer**. *Polym Degrad Stab* 2019, **170**:109018.

67. Degli-Innocenti F: **Is composting of packaging real recycling?**
• *Waste Manag* 2021, **130**:61-64
Some argue against inclusion of biodegradable packaging in composting processes because these materials do not contain nutrients. The authors detail how compostable packaging behaves similarly to other composting feedstocks and can be critical complementary component for creating successful composting processes and outputs.

68. Kakadellis S, Woods J, Harris ZM: **Friend or foe: stakeholder attitudes towards biodegradable plastic packaging in food waste anaerobic digestion**. *Resour Conserv Recycl* 2021, **169**:105529.

69. Chavis C, Jones A: *Understanding Access to Grocery Stores in Food Deserts in Baltimore City*. 2020.

70. Armington WR, Chen RB, Babbitt CW: **Challenges and innovations in food waste-to-energy management and logistics**. *Sustainable Food Waste-to-Energy Systems*. Elsevier; 2018:259-271.

71. Michelini L, Principato L, Iasevoli G: **Understanding food sharing models to tackle sustainability challenges**. *Ecol Econ* 2018, **145**:205-217.

72. Sedlmeier R, Rombach M, Bitsch V: **Making food rescue your business: case studies in Germany**. *Sustain* 2019, **11**:5101.

73. Armington WR, Chen RB: **Household food waste collection: building service networks through neighborhood expansion**. *Waste Manag* 2018, **77**:304-311.

74. Shahid K, Hittinger E: **Techno-economic optimization of food waste diversion to treatment facilities to determine cost effectiveness of policy incentives**. *J Clean Prod* 2021, **279**:122634.

75. Fisgativa H, Tremier A, Dabert P: **Characterizing the variability of food waste quality: a need for efficient valorisation through anaerobic digestion**. *Waste Manag* 2016, **50**:264-274.

76. Lebersorger S, Schneider F: **Food loss rates at the food retail, influencing factors and reasons as a basis for waste prevention measures**. *Waste Manag* 2014, **34**:1911-1919.

77. Armington WR, Babbitt CW, Chen RB: **Variability in commercial and institutional food waste generation and implications for sustainable management systems**. *Resour Conserv Recycl* 2020, **155**:104622.

78. Ma J, Scott NR, DeGloria SD, Lembo AJ: **Siting analysis of farm-based centralized anaerobic digester systems for distributed generation using GIS**. *Biomass Bioenergy* 2005, **28**:591-600.

79. Badgett A, Milbrandt A: **Food waste disposal and utilization in**
• **the United States: a spatial cost benefit analysis**. *J Clean Prod* 2021, **314**:128057
This article analyzes the challenge of 'matching' wasted food streams with the heterogeneous infrastructure pathways that may be available across the entire U.S. This article also addresses the relative benefits and tradeoffs of alternate options.

80. Bernstad A, la Cour Jansen J: **Review of comparative LCAs of food waste management systems – current status and potential improvements**. *Waste Manag* 2012, **32**:2439-2455.

81. Ebner JH, Hegde S, Win SS, Babbitt CW, Trabold TA: **Environmental aspects of food waste-to-energy conversion**. *Sustainable Food Waste-to-Energy Systems*. Elsevier; 2018:177-201.

82. Franchetti M, Dellinger A: **Economic feasibility of a municipal food waste collection and energy generation model**. *Energy Technol Policy* 2014, **1**:471-484 http://mc.manuscriptcentral.com/uetp.

83. Elkhalifa S, Al-Ansari T, Mackey HR, McKay G: **Food waste to biochars through pyrolysis: a review**. *Resour Conserv Recycl* 2019, **144**:310-320.

84. Matharu AS, de Melo EM, Houghton JA: **Opportunity for high value-added chemicals from food supply chain wastes**. *Bioresour Technol* 2016, **215**:123-130.

85. Cao L, Iris KM, Xiong X, Tsang DC, Zhang S, Clark JH, Hu C, Ng YH, Shang J, Ok YS: **Biorenewable hydrogen production through biomass gasification: a review and future prospects**. *Environ Res* 2020, **186**:109547.

86. Yadav S, Singh D, Mohanty P, Sarangi PK: **Biochemical and thermochemical routes of H2 production from food waste: a comparative review**. *Chem Eng Technol* 2021 http://dx.doi.org/10.1002/CEAT.202000526.

87. Hegde S, Lodge JS, Trabold TA: **Characteristics of food processing wastes and their use in sustainable alcohol production**. *Renew Sustain Energy Rev* 2018, **81**:510-523.

88. Barber ST, Yin J, Draper K, Trabold TA: **Closing nutrient cycles**
• **with biochar- from filtration to fertilizer**. *J Clean Prod* 2018, **197**:1597-1606
Biochar is a carbonaceous material with high porosity and surface area that makes it suitable as an adsorbent for heavy metals and other contaminants. This article explored the potential of using maple wood biochar to treat high strength waste from tofu processing wastewater. Biochar reduced the biological oxygen demand (BOD) of tofu wastewater by over 50%. The 'enriched' biochar was also tested as a fertilizer in greenhouse plant growth trials, and yielded statistically significant increases in fresh weight of lettuce and basil plants over the no biochar control and non-enriched biochar cases.

89. Breunig HM, Amirebrahimi J, Smith S, Scown CD: **Role of digestate and biochar in carbon-negative bioenergy**. *Environ Sci Technol* 2019, **53**:12989-12998.

90. Baker SE, Stolaroff JK, Peridas G, Pang SH, Goldstein HM, Lucci FR, Li W, Slessarev EW, Pett-Ridge J, Ryerson FJ *et al.*:

Getting to Neutral: Options for Negative Carbon Emissions in California. 2019.

91. Khoshnevisan B, Tabatabaei M, Tsapekos P, Rafiee S, Aghbashlo M, Lindeneg S, Angelidaki I: **Environmental life cycle assessment of different biorefinery platforms valorizing municipal solid waste to bioenergy, microbial protein, lactic and succinic acid**. *Renew Sustain Energy Rev* 2020, **117**:109493.

92. Teigiserova DA, Hamelin L, Thomsen M: **Review of high-value food waste and food residues biorefineries with focus on unavoidable wastes from processing**. *Resour Conserv Recycl* 2019, **149**:413-426.

93. Cherubini F: **The biorefinery concept: using biomass instead of oil for producing energy and chemicals**. *Energy Convers Manag* 2010, **51**:1412-1421.

94. Lohrasbi M, Pourbafrani M, Niklasson C, Taherzadeh MJ: **Process design and economic analysis of a citrus waste biorefinery with biofuels and limonene as products**. *Bioresour Technol* 2010, **101**:7382-7388.

95. Babbitt CW: **Foundations of sustainable food waste solutions: innovation, evaluation, and standardization**. *Clean Technol Environ Policy* 2017, **19**:1255-1256.

96. • Nordahl SL, Devkota JP, Amirebrahimi J, Smith SJ, Breunig HM, Preble CV, Satchwell AJ, Jin L, Brown NJ, Kirchstetter TW *et al.*: **Life-cycle greenhouse gas emissions and human health trade-offs of organic waste management strategies**. *Environ Sci Technol* 2020, **54**:9200-9209
This article provides an clear example of how methodologies like life cycle assessment can be applied to evaluate the relative climate and energy benefits of different wasted food management pathways and ultimately inform policy decisions.

97. Kogan F, Guo W, Yang W: **Drought and food security prediction from NOAA new generation of operational satellites**. *Geomatics Nat Hazards Risk* 2019, **10**:651-666.

98. Spang ES, Manzor S, Loge FJ: **The cost-effectiveness of energy savings through water conservation: a utility-scale assessment**. *Environ Res Lett* 2020, **15**:114031.

99. Spang ES, Holguin AJ, Loge FJ: **The estimated impact of California's urban water conservation mandate on electricity consumption and greenhouse gas emissions**. *Environ Res Lett* 2018, **13**:014016.

100. Siddiqui S, Vaillancourt K, Bahn O, Victor N, Nichols C, Avraam C, Brown M: **Integrated North American energy markets under different futures of cross-border energy infrastructure**. *Energy Policy* 2020, **144**:111658.

101. Khan F, Ahmed W, Najmi A: **Understanding consumers' behavior intentions towards dealing with the plastic waste: Perspective of a developing country**. *Resour Conserv Recycl* 2019, **142**:49-58.

102. Graham-Rowe E, Jessop DC, Sparks P: **Identifying motivations and barriers to minimising household food waste**. *Resour Conserv Recycl* 2014, **84**:15-23.

103. Nguyen TTP, Zhu D, Le NP: **Factors influencing waste separation intention of residential households in a developing country: evidence from Hanoi, Vietnam**. *Habitat Int* 2015, **48**:169-176.

104. Zhang D, Huang G, Yin X, Gong Q: **Residents' waste separation behaviors at the source: using SEM with the theory of planned behavior in Guangzhou, China**. *Int J Environ Res Public Health* 2015, **12**:9475-9491.

105. Thyberg KL, Tonjes DJ: **Drivers of food waste and their implications for sustainable policy development**. *Resour Conserv Recycl* 2016, **106**:110-123.

106. • Neff RA, Spiker M, Rice C, Schklair A, Greenberg S, Leib EB: **Misunderstood food date labels and reported food discards: a survey of U.S. consumer attitudes and behaviors**. *Waste Manag* 2019, **86**:123-132
This article provides an evaluation of how inconsistency in food date labeling ultimately leads to avoidable food waste in U.S. households. It also discusses various education and policy solutions that may be used to address this problem.

107. Tröster R, Hiete M: **Success of voluntary sustainability certification schemes – a comprehensive review**. *J Clean Prod* 2018, **196**:1034-1043.

108. • De Laurentiis V, Caldeira C, Sala S: **No time to waste: assessing the performance of food waste prevention actions**. *Resour Conserv Recycl* 2020, **161**:104946
Given the variety of ways in which food waste prevention interventions may be assessed, this article suggests a new common framework for such evaluations, developed by the European Commission Joint Research Center.

109. U.S. Department of Education NCES: *Digest of Education Statistics*. 2021.

110. USDA ERS: *National School Lunch Program*. 2021.

111. Zhao C, Panizza C, Fox K, Boushey CJ, Byker Shanks C, Ahmed S, Chen S, Serrano EL, Zee J, Fialkowski MK *et al.*: **Plate waste in school lunch: barriers, motivators, and perspectives of SNAP-eligible early adolescents in the US**. *J Nutr Educ Behav* 2019, **51**:967-975.

112. Schupp C, Getts K, Otten J: **An evaluation of current lunchroom food waste and food rescue programs in a Washington state school district**. *J Agric Food Syst Community Dev* 2018, **8**:167-186 http://dx.doi.org/10.5304/JAFSCD.2018.081.013.

113. WWF: *Food Waste Warriors: A Deep Dive into Food Waste in U.S. Schools*. 2019.

114. Martins ML, Rodrigues SS, Cunha LM, Rocha A: **Strategies to reduce plate waste in primary schools – experimental evaluation**. *Public Health Nutr* 2016, **19**:1517-1525.

115. • Prescott MP, Burg X, Metcalfe JJ, Lipka AE, Herritt C, Cunningham-Sabo L: **Healthy planet, healthy youth: a food systems education and promotion intervention to improve adolescent diet quality and reduce food waste**. *Nutrients* 2019, **11**:1869
This paper quantifies the impact of a student-driven sustainable food systems education and promotion intervention on adolescent school lunch selection, consumption, and waste behaviors. The findings suggest that food systems education can be used to promote improved dietary behaviors among adolescent youth.

116. Kim K, Morawski S: **Quantifying the impact of going trayless in a university dining hall**. *J Hunger Environ Nutr* 2012, **7**:482-486.

117. Neff RA, Zaltz DA, Hecht AA, Pate RR, Neelon B, O'Neill JR, Benjamin-Neelon SE: **Preschool healthy food policy did not increase percent of food wasted: evidence from the Carolinas**. *Nutrients* 2020, **12**:3024.

118. Cohen JFW, Richardson S, Parker E, Catalano PJ, Rimm EB: **Impact of the new U.S. Department of Agriculture School meal standards on food selection, consumption, and waste**. *Am J Prev Med* 2014, **46**:388-394.

119. Chapman LE, Cohen J, Canterberry M, Carton TW: **Factors associated with school lunch consumption: reverse recess and school "brunch"**. *J Acad Nutr Diet* 2017, **117**:1413-1418.

120. Food Chain Workers Alliance and Solidarity Research Cooperative: *No Piece of the Pie: U.S. Food Workers in 2016*. 2016.

121. • Ceryes CA, Antonacci CC, Harvey SA, Spiker ML, Bickers A, Neff RA: **"Maybe it's still good?" A qualitative study of factors influencing food waste and application of the E.P.A. Food recovery hierarchy in U.S. supermarkets**. *Appetite* 2021, **161**:105111
This qualitative study highlights grocery workers' uncertainties regarding when it is appropriate to discard foods, suggesting the need for improved worker training; and also indicates workers' discomfort with requirements to discard food they consider to be acceptable for consumption, suggesting the work-life quality benefit of engaging workers in waste reduction efforts.

122. AFL-CIO: *Death on the Job: The Toll of Neglect*. 2021.

123. • Quested TE, Palmer G, Moreno LC, McDermott C, Schumacher K: **Comparing diaries and waste compositional analysis for measuring food waste in the home**. *J Clean Prod* 2020, **262**:121263

The authors analyze data from five studies where household food waste was assessed using both food waste diaries and waste compositional analysis (bin digs) and confirm that diaries systematically underestimate the amount of waste from the bin digs by 7% to 40%, undermining their efficacy in tracking food waste and assessing food waste reduction interventions. Several reasons are hypothesized for diaries underestimates: behavioral reactivity, measurement bias, misreporting and self-selection bias.

124. • Roe BE, Qi D, Beyl RA, Neubig KE, Martin CK, Apolzan JW: **The validity, time burden, and user satisfaction of the FoodImageTM smartphone app for food waste measurement versus diaries: a randomized crossover trial**. *Resour Conserv Recycl* 2020, **160**:104858
The authors adapt an approach that has proven successful in the realm of measuring food intake and show that the resulting app-based method yields valid results for measuring the amount of food that is wasted by consumers during meal preparation, dining and occasional waste clean out events. The app-based approach was found to require less time and be preferred by the trial participants compared to the standard written food waste diary approach. In addition the app can be used to collect data concerning why and where food is wasted, to collect data concerning food purchases and to help deliver reminders and nudges to collect data and to alter food-based behaviors. While yielding highly granular and valid data, the method relies upon human raters to process photos taken by participants, and advances in automated processing of the photos and data will be needed to achieve cost-efficient data collection at scale.

125. • Zeb A, Soininen J-P, Sozer N: **Data harmonisation as a key to enable digitalisation of the food sector: a review**. *Food Bioprod Process* 2021, **127**:360-370
The authors detail how data harmonization is critical for ensuring food safety, quality and affordability but often illusive because of the fragmented structure of the food system. Suggestions are made for increasing harmonization through alterations to data collection guidelines and procedures in the food system.

126. Dooley DM, Griffiths EJ, Gosal GS, Buttigieg PL, Hoehndorf R, Lange MC, Schriml LM, Brinkman FSL, Hsiao WWL: **FoodOn: a harmonized food ontology to increase global food traceability, quality control and data integration**. *npj Sci Food* 2018, **2**:1-10.

127. Stojanov R, Eftimov T, Pinchen H, Traka M, Finglas P, Torkar D, Seljak BK: **Food waste ontology: a formal description of knowledge from the domain of food waste**. *Proc - 2019 IEEE Int Conf Big Data, Big Data 2019* 2019 http://dx.doi.org/10.1109/BIGDATA47090.2019.9006254.

128. • Lin X, Ruess PJ, Marston L, Konar M: **Food flows between counties in the United States**. *Environ Res Lett* 2019, **14**:084011
Quantifying the impacts of wasted food and the benefits that can be achieved through circular solutions requires data on not just the production and consumption of food, but how food flows in between. This paper integrates machine learning, network properties, production and consumption statistics, mass balance constraints, and linear programming to estimate particular food flows between all county pairs within the United States and provides a database that can be used by other researchers as well.

129. Cai Y: **Computational methods in environmental and resource economics**. *Annu Rev Resour Econ* 2018, **11**:59-82.

130. Fisher-Vanden K, Weyant J: **The evolution of integrated assessment: developing the next generation of use-inspired integrated assessment tools**. *Annu Rev Resour Econ* 2020, **12**:471-487.

131. • Omolayo Y, Feingold BJ, Neff RA, Romeiko XX: **Life cycle assessment of food loss and waste in the food supply chain**. *Resour Conserv Recycl* 2021, **164**:105119
This article reviews available lifecycle assessments of food loss and waste in the food supply chain. Identified research gaps included studies of prevention and donation, studies that accounted for the potential for avoided production or that distinguished avoidable and unavoidable waste. This article also notes that few LCA studies examined outcomes beyond greenhouse gases.

132. Norris GA: **Integrating economic analysis into LCA**. *Environ Qual Manag* 2001, **10**:59-64.

133. • Blackstone NT, Norris CB, Robbins T, Jackson B, Decker Sparks JL: **Risk of forced labour embedded in the US fruit and vegetable supply**. *Nat Food* 2021, **2**:692-699
The authors note that agriculture as a sector features among the highest incidences of forced labor due to several factors such as high labor requirements and inadequate legal protection for workers. Using a new forced labor risk scoring method the authors estimate identify a small number of commodities that may account for a large proportion of forced labor risks in the U.S. food supply chain.

134. Bouman M, Heijungs R, Van Der Voet E, Van Den Bergh JCJM, Huppes G: **Material flows and economic models: an analytical comparison of SFA, LCA and partial equilibrium models**. *Ecol Econ* 2000, **32**:195-216.

135. Brander M, Burritt RL, Christ KL: **Coupling attributional and consequential life cycle assessment: a matter of social responsibility**. *J Clean Prod* 2019, **215**:514-521.

136. Plevin RJ, Delucchi MA, Creutzig F: **Using attributional life cycle assessment to estimate climate-change mitigation benefits misleads policy makers**. *J Ind Ecol* 2014, **18**:73-83.

137. Vázquez-Rowe I, Marvuglia A, Rege S, Benetto E: **Applying consequential LCA to support energy policy: land use change effects of bioenergy production**. *Sci Total Environ* 2014, **472**:78-89.

138. Berardy A, Seager T, Costello C, Wharton C: **Considering the role of life cycle analysis in holistic food systems research policy and practice**. *J Agric Food Syst Community Dev* 2020, **9**:209-227.

139. Eakin H, Connors JP, Wharton C, Bertmann F, Xiong A, Stoltzfus J: **Identifying attributes of food system sustainability: emerging themes and consensus**. *Agric Human Values* 2017, **34**:757-773.

140. Singh S, Babbitt C, Gaustad G, Eckelman MJ, Gregory J, Ryen E, Mathur N, Stevens MC, Parvatker A, Buch R *et al.*: **Thematic exploration of sectoral and cross-cutting challenges to circular economy implementation**. *Clean Technol Environ Policy* 2021, **23**:915-936.

141. Sankaranarayanan S, Feijoo F, Siddiqui S: **Sensitivity and covariance in stochastic complementarity problems with an application to North American natural gas markets**. *Eur J Oper Res* 2018, **268**:25-36.

142. Sankaranarayanan S, Zhang Y, Carney J, Nigussie Y, Esayas B, Simane B, Zaitchik B, Siddiqui S: **What are the domestic and regional impacts from Ethiopia's policy on the export ban of teff?** *Front Sustain Food Syst* 2020, **4**.

143. Bakker C, Zaitchik BF, Siddiqui S, Hobbs BF, Broaddus E, Neff RA, Haskett J, Parker CL: **Shocks, seasonality, and disaggregation: modelling food security through the integration of agricultural, transportation, and economic systems**. *Agric Syst* 2018, **164**:165-184.

144. Satti S, Zaitchik B, Siddiqui S: **The question of Sudan: a hydro-economic optimization model for the Sudanese Blue Nile**. *Hydrol Earth Syst Sci* 2015, **19**:2275-2293.

145. Feijoo F, Iyer GC, Avraam C, Siddiqui SA, Clarke LE, Sankaranarayanan S, Binsted MT, Patel PL, Prates NC, Torres-Alfaro E *et al.*: **The future of natural gas infrastructure development in the United states**. *Appl Energy* 2018, **228**:149-166.

146. • Roco MC: **Principles of convergence in nature and society and their application: from nanoscale, digits, and logic steps to global progress**. *J Nanoparticle Res* 2020, **22**
This article introduces, defines, and comprehensively explains the emerging field of convergence science — a new holistic framework for addressing complex societal challenges that previous disciplinary approaches have not been able to fully comprehend.