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Feature

The Future of Food: Environmental Lessons from E-Commerce

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ABSTRACT: Our food system is experiencing dramatic changes as the expansion of e-commerce, introduction of new products, and innovations in supply chain structures all pose to transform how we buy, sell, and distribute food. However, the environmental impacts of these transformations remain unclear. This feature reviews existing literature on environmental implications of e-commerce, discusses relevant trade-offs, and identifies pressing gaps in research. Some trade-offs discussed are those between centralized and decentralized delivery service types, those unique to a rural landscape, and those within the interplay of transportation and consumer behavior. The impacts of fulfillment centers, of refrigerated logistics, of e-commerce on consumer shopping and food waste habits, and of e-commerce services in rural regions are identified as pressing knowledge gaps.

1.0. BACKGROUND

Without intervention, research shows that our current food system will exceed planetary bounds as early as 2050.[1] The food supply chain produces approximately 13.7 billion tonnes of carbon dioxide equivalent (CO_2e), amounting to 26% of anthropogenic emissions.[2] The largest contributor is food production (61%), with emissions associated with food waste totaling over 2 billion tonnes, and those from processing, transportation, packaging, and retail totaling less than one billion tonnes each. A combination of dietary changes, technological advancements, and reductions in food loss and waste (FLW) can help us avoid exceeding planetary bounds.[1]

E-commerce, the buying and selling of items online, might play a role in reducing the environmental impacts of the food system. The environmental implications of general e-commerce have been well discussed,[3−5] but only recently has food e-commerce been successfully deployed at a large scale. Growth in e-commerce is also expected to accelerate in response to the recent COVID-19 pandemic, which has spurred grocery stores to establish and scale e-commerce platforms and prompted a broader segment of consumers to try them. Grocery delivery service Instacart reported a 500% year-over-year sales increase in April 2020, while meal-kit delivery service Sun Basket reported a weekly doubling in sales in early 2020.[6,7] Overall online shopping rates have doubled in the past few years, and sales are expected to grow 40% in 2020 compared to 22% in 2019, bringing online grocery to $38 billion and 3.5% of all U.S. food and beverage sales.[8] Analysts expect e-commerce to continue to grow after the pandemic,[6,9] underscoring their importance to the greater environmental footprint of the food system.

Recent literature indicates that e-commerce across a broad range of sectors tends to have a lower environmental impact than traditional retail.[3,4,10−21] However, fewer studies focus specifically on food e-commerce.[4,12,13,17,18,22] Food e-commerce requires additional discussion as it interacts with consumer behavior in unique ways and adds the complexity of perishability to logistics. This feature discusses both the environmental impacts and trade-offs of food e-commerce services and identifies knowledge gaps where future research is necessary. Overall, the discussion highlights the ways by which lessons from e-commerce could help point us toward a more sustainable food system.

For this discussion, food e-commerce, unless specified otherwise, includes direct-to-consumer delivery of food items in the form of groceries, meal-kits, or preprepared meals coming from a central distributor. Sources for this feature were selected from both academic literature and popular news outlets. Relevant publications were initially identified through keyword searches (e.g., food, e-commerce, delivery, grocery, meal-kit) and then chosen based on scope. The scope of this feature is limited to new mechanisms and modes of direct-to-consumer delivery that have been recently enabled by e-commerce. Therefore, meals procured from restaurants via delivery or curbside pickup are not included in this study, as

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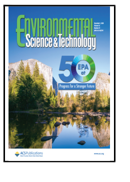

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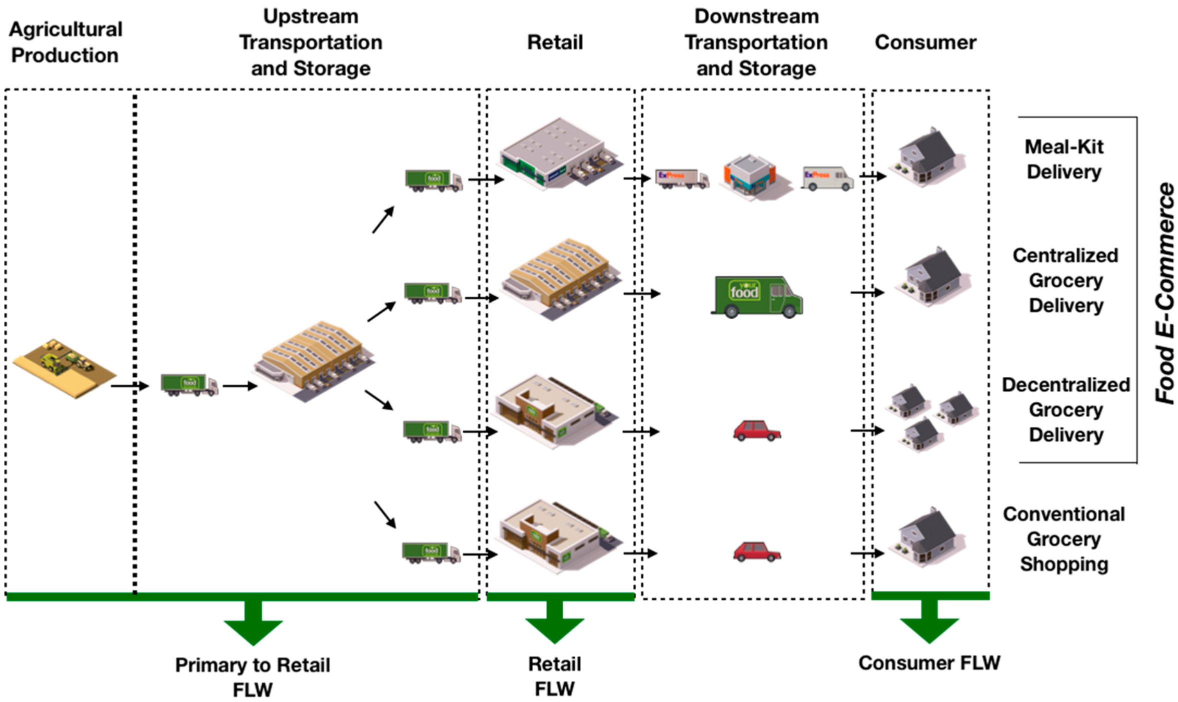

Figure 1. Supply chains for meal-kit delivery, centralized grocery delivery, decentralized grocery delivery, and conventional grocery shopping. *Food is produced on the farm and travels through warehouses and storage facilities before reaching the retail stage (either a storefront or fulfillment center), then is transported to the consumer household by delivery van or personal vehicle.*

these are more mature services that have merely been enhanced by online ordering platforms. In particular, this piece focuses on meal-kit delivery and grocery delivery services. The structure of this feature follows the supply chains (Figure 1), moving from upstream to downstream considerations and concluding with a discussion of supply side elements like packaging and consumer behavior.

For grocery delivery services, consumers purchase items online to be delivered to their doorstep. Although most grocery delivery services are limited to individual foods, preprepared meals are increasingly available as well. Grocery delivery can be decentralized, where orders are fulfilled from existing grocery stores (e.g., Instacart), or centralized, where the orders are fulfilled from a dedicated fulfillment center or warehouse (e.g., FreshDirect). Meal-kit delivery companies ship preportioned ingredients with corresponding recipes directly to consumers' doorsteps. This feature article discusses both structural and nonstructural elements of food e-commerce and conventional retail, focusing on areas of substantial difference that affect the overall environmental impacts of the food system.

2.0. COMPARING CONVENTIONAL RETAIL AND E-COMMERCE

Agricultural Production and Sourcing. Agricultural production substantially contributes to the environmental impact of food, though estimates vary.[2] Production is responsible for 50−90% of total greenhouse gas emissions for a variety of food types across multiple life cycle assessments (LCAs).[23] Huber (2018) found that food production contributes 9% of annual GHG emissions in the U.S.[24] Weber and Matthews (2008) found that production contributes about 6.7 tons of carbon dioxide per household per year.[25] Almost 60% of an average meal-kit's greenhouse gas (GHG) emissions and 47% of an average grocery meal's emissions are associated with food production (excluding FLW).[26] Because of the large impact of production, choice in food type and source are likely to have substantial influence over environmental impacts of different services. Retailers might also be motivated to offer more sustainable products due to increasing consumer demand for transparency and sustainability, especially within important demographics like millennials.[27,28] Though both e-commerce and conventional grocery retailers typically lack control over agricultural practices, they might be able to influence some change.

Previous research suggests that consolidated retailers with large buying power have the ability to influence upstream suppliers and producers.[29,30] These retailers could encourage suppliers or producers to improve the sustainability of their offerings, sparking upstream ripple effects in overall production trends. Conventional retailers might thus have an advantage over smaller or newer e-commerce options that have less leverage.[30] In general, the ability to influence producers is likely less connected to type of retailer and more to size. In the meantime, smaller retailers that sell fewer items might be able to compete on sustainability by being more selective in their overall product offerings. The influence of retailers over suppliers warrants further discussion given the large impact of food production.[2,31]

Retail Operation. Retail operation is one of the largest structural differences between e-commerce and conventional grocery. E-commerce often circumvents brick-and-mortar stores, which are energy and emissions-intensive.[26,32] Physical grocery stores are deploying multiple strategies to compete with e-commerce, as some studies predict that a rise in e-commerce will result in store closures.[22,33] But U.S. grocers are still growing, adding 30% more square footage in 2018 than 2017.[34] Some are also experimenting with different formats like smaller stores that are optimized for in-house e-commerce

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operations.[35] Other stores hope to attract customers by adding restaurants and bars.[36] Grocers could use in-house restaurants to intercept and repurpose potential FLW, but more research is required to determine practicality and ease of implementation for grocers. This approach will likely increase the overall environmental impact of grocery stores by requiring additional space and equipment, but the impact per-weight of food could be reduced depending on store conditions. Grocers are likely to combine multiple approaches, in contrast to single-purpose fulfillment centers.

E-commerce fulfillment centers tend to be more resource-efficient than stores because they are purpose-designed for food preservation and order processing rather than shopper experience.[14,37,38] Grocery stores must balance these priorities with customer experience, leading to inefficient practices like overstocking to keep shelves full, resulting in waste, and open refrigerated display cases that can consume 30% more energy than a doored alternative.[39] Refrigeration alone can comprise 50% of a supermarket's electricity use.[40] While initial studies indicate fulfillment centers reduce energy use and emissions compared to grocery stores,[26,32] little data exist on the environmental impact of food-related fulfillment centers specifically, and most estimates are indirect.[18,26,32] Many existing estimates reflect unrefrigerated warehouses when food-specific fulfillment centers require refrigeration for food safety and handling. The exclusion of refrigeration can lead to underestimation of environmental impacts.[14,37,38] Furthermore, grocery delivery services can operate multiple different kinds of fulfillment centers.

Grocery delivery services can operate large centralized fulfillment centers, smaller "microfulfillment" centers, or "dark stores" or "warerooms" that are attached to existing grocery stores.[41,42] Each of these approaches will have unique environmental implications. For example, large fulfillment centers might be able to process a greater volume of product more efficiently and achieve economies of scale, but micro-fulfillment centers can be located closer to cities and reduce last-mile logistical burdens.[42] Some fulfillment centers are also automated, which can increase overall energy use.[43] However, this increase might be ameliorated by a subsequent increase in order throughput that reduces the effective impact per-order.[44] In July of 2018, online grocer FreshDirect opened a 400 000 ft^2 automated fulfillment center in the Bronx, NY with 15 different temperature zones and nine miles of conveyor belts.[45] As centers like these become more common, researchers should investigate their environmental footprints in more detail.

Last-Mile Transportation. Last-mile transportation refers to the final stage of the supply chain before reaching the consumer (i.e., driving to the grocery store or local delivery vans dropping off a package), and is typically the least efficient and most expensive stage of transportation throughout the supply chain.[46,47] And while changes in upstream transportation (farm-to-retail, see Figure 1) can also influence miles traveled and thus environmental impact,[48,49] there are fewer unique structural differences between e-commerce and conventional retail for upstream transportation. E-commerce changes the structure of last-mile transportation by replacing personal trips with deliveries.

E-commerce primarily reduces the impact of last-mile transportation by grouping orders and using delivery vans or trucks. While vans or trucks can be more energy and emission-intensive than cars per-mile, they spread out their impacts over much more cargo, reducing the per-item impact.[50,51] Electric vans might have a greater advantage. A study of grocery delivery in Munich found that electric vans provide greater emissions and energy reductions than diesel compared to personal transportation.[12] Decentralized grocery delivery services that use cars instead of vans can reduce their last-mile impact by clustering nearby orders together, which has well documented advantages.[52] The benefits of vans could be negated, however, by small delivery time windows. Greater consumer control over time windows can prevent failed deliveries but can also prevent delivery services from fully optimizing their routes to minimize miles traveled. In a study of grocery home delivery in Finland, Siikavirta et al. (2003) find a potential emissions reduction of 18% for a one-delivery-per-hour model compared with conventional shopping, but an 87% reduction for a once-per-week model with a reception box.[4] While shorter time windows might seem inevitable, one study has found that consumers will choose a more sustainable yet inconvenient delivery option if made aware of the environmental consequences.[53] Still, delivery benefits can be negated by vehicular refrigeration.[54] A recent study from Berlin, Germany reports lower reductions in emissions from grocery delivery than others due to refrigeration in the delivery vehicles.[22] Transportation effects of e-commerce will also depend on consumer location and service implementation.

Delivery distances are highly variable. Meal-kit delivery services tend to have relatively few fulfillment centers (∼3) from which they serve the entire contiguous United States.[32,49] Grocery delivery services can fulfill orders from either centralized warehouses or existing stores. There seems to be a trade-off between centralized delivery services with remote fulfillment centers but efficient van-based delivery and decentralized services using drivers with personal vehicles to deliver from a large network of existing stores that are closer to consumers. Gee (2019) found that centralized grocery delivery services have a much greater potential to reduce energy use compared to conventional retail than do decentralized services, mostly because of the combined benefit of delivery vans and lean fulfillment centers.[55] However, recent work has found decentralized systems to show greater promise.[13] Locating stores closer to consumers might reduce last-mile distances for shoppers while increasing upstream travel distance, though the efficiency of freight could compensate for this trade-off.[56] Closer stores would also push freight activities closer to consumers, exacerbating congestion in some areas. The location of stores relative to consumers might have a larger impact on households without cars who use alternative transportation modes and are thus distance-limited in their store options.[57] These effects might become more apparent with increasing urbanization.

Urbanization may hamper reductions in last-mile emissions if customers order deliveries when they could otherwise walk, cycle, or take public transportation to stores.[58] However, grocery delivery workers could possibly use these same transit options to deliver smaller orders. Additionally, e-commerce orders might more typically replace car-based consumer trips.[33] Even so, increased vehicle-based deliveries could also impact road congestion and increase last-mile emissions due to idling.[59] Research also suggests that a mix of consumers ordering home deliveries and in-store pick-ups is less favorable for road congestion than the bulk of consumers using one or the other, highlighting a potential downside of multiple service options.[60] Delivery from the stores to centralized collection points for consumer pick-up might have environmental

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advantages over home delivery in dense areas[61] or when preventing multiple failed home-delivery trips,[62] but home delivery might still provide the greatest travel reductions.[18] Home delivery services might also have a greater environmental advantage outside of cities, where consumers are less likely to walk, bike, or bus to grocery stores.

Previous findings suggest that e-commerce might produce greater environmental benefits in rural areas.[14,17,22,32,47] However, most of these studies extrapolate these findings from results of urban study areas. Williams and Tagami (2003) studied urban, suburban, and rural areas specifically and found that e-commerce has a greater potential to save energy in rural areas than urban for the case of books in Japan.[14] This potential could be larger for groceries, which are purchased more frequently than books. Longer travel distances in low-density rural areas would magnify the benefits of replacing personal trips with deliveries but could also decrease the number of orders deliverable in one trip. One route for grocery delivery service PeaPod recorded 17 stops in 173 mi[63] compared to city delivery routes that might fit over 100 stops in 40 miles.[64] An inability to cluster more orders together might actually diminish the relative benefits of e-commerce over conventional shopping in rural areas in some cases.[65,66] This trade-off between reductions in passenger transport and increase in delivery distances in rural zones should be further studied. This trade-off may also be complicated if a rise in e-commerce causes rural stores to close, potentially increasing personal shopping trip distance or dependence on delivery services. Additionally, the aggregate benefits of rural delivery could be limited as not all rural zones are considered deliverable.[67] Another complicating factor is the potential for trip substitution.

The ability of e-commerce to reduce last-mile impact greatly depends on its ability to reduce or replace personal shopping trips.[32,68] Grocery delivery services seem best poised to replace trips entirely, but complete substitution is unlikely.[32,66,68−70] "Trip-chaining", or combining multiple activities in one trip, complicates the comparison of conventional retail to delivery as it reduces the emissions associated with individual activities but makes allocation of miles-traveled to each task difficult.[71] The transportation benefits of e-commerce might be overstated in the literature because trip chaining is often overlooked.[70] Furthermore, there is the question of how consumers spend the time freed up by ordering delivery.

Research seems to indicate e-commerce can result in both an increase and decrease in aggregate shopping trips, though this is not specific to food.[70] Given the routine nature of grocery shopping, delivery could free up substantial time for consumers, though they may use that time to travel to another store or activity. On the other hand, some consumers might replace a postwork trip with delivery just to have more time at home or reduce "end-of-day time pressure".[72] But a study in Delaware found that, while the growth in general e-commerce was lower than projected in 2001 (albeit online food purchases increased substantially), traffic conditions and emissions were worse than predicted.[73] Another found evidence for either neutral or greater travel when time is freed up through e-commerce.[57] The degree to which a shopping trip is considered a recreational or social activity might also influence changes in travel patterns.[57] More research is warranted on how consumers use time freed up by deliveries.

Food Loss and Waste. When food is lost or wasted, all the embedded resources required to grow, process, transport, and store the food are wasted with it. And when FLW decomposes in a landfill, it can release carbon dioxide or, under some conditions, methane. It has been estimated that about 2% of the United States' annual energy consumption is embedded in FLW[74] and that it contains the equivalent of 2% of U.S. greenhouse gas emissions.[75] E-commerce can affect FLW through supply chain differences and through behavioral differences in how consumers interact with food purchased through different pathways. Structurally, e-commerce can reduce FLW by circumventing grocery stores or by preportioning ingredients.

Fulfillment centers used in meal-kit and centralized grocery delivery services might reduce FLW compared to grocery stores due to differences in structure and purpose. According to the USDA, about 10% of food is wasted at the retail level in the U.S.[76], while the meal-kit supplier Blue Apron reported to waste just over 5% of food at their fulfillment centers in 2016[77] and the UK-based online grocer Ocado announced in early 2017 that they achieved 0.2% waste at their fulfillment centers.[78] Some of this reduction might be attributed to lower inventory and lack of consumer-facing displays, as reducing food stored on-site can help reduce waste. And, while both stores and e-commerce services can use predictive analytics to streamline sourcing and prevent loss, fulfillment centers might further reduce inventory because they have more freedom to design for food preservation.[45,79,80] Because they often operate out of existing storefronts, decentralized grocery delivery services are less likely to impact retail FLW unless the stores change their structure or ordering practices to better complement delivery operations. For meal-kits, those made for in-store purchase might be more likely to be wasted from overstocking while kits for delivery are made-to-order. More studies assessing retail FLW are needed for e-commerce; most existing estimates of FLW are for the conventional supply chain and highly variable.[81] Impacts of e-commerce on consumer food waste is similarly opaque.

Relatively few studies have quantified consumer FLW from e-commerce services, and most do so for meal-kits.[26,77,82] These studies find that meal-kits reduce consumer FLW, potentially because they supply preportioned ingredients and prevent consumers from overbuying. Though, waste is still possible if consumers do not like or do not want to cook the provided meals.[83] Additionally, unattended delivery could result in kits being unrefrigerated for too long and spoiling.[84] Even fewer studies measure grocery delivery FLW. Schanes, Dobernig, and Gözet (2017) review literature on general consumer food waste practices but do not discuss effects of e-commerce.[85] Grocery e-commerce could be helpful for meal-planning, which can prevent waste from overbuying.[85] Subscription-based grocery delivery models might reduce food waste more than pay-per-order models by incentivizing more frequent, smaller basket sizes.[86] A recent modeling study of grocery delivery also relates a higher frequency of shopping trips to lower household food waste.[13] Our psychological relationship to food might also impact waste. Ilyuk (2017) found that consumers are more likely to waste food purchased online because they feel less ownership of the items.[87] Another study found that habits strongly influence food waste behavior and that individuals with more negative emotions toward food waste intend to reduce their waste but actually increase it in practice.[88] This discrepancy is in line with other findings that suggest the intention to reduce food waste does not always translate to action.[89] The impact of e-commerce on consumer

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FLW is a present data gap. Additionally, grocery store closures due to competition from e-commerce and a consequential decrease in store density could increase FLW. If stores are more difficult to get to, consumers will go less frequently and purchase more food, thus increasing the likelihood of waste.[90]

Packaging. E-commerce services tend to use more packaging materials than conventional retail because of the delivery leg. Meal-kit delivery in particular uses more packaging materials than groceries because they require boxes and insulation, and preportioned ingredients usually means a higher packaging-to-food ratio.[91−93] However, as purported by the founder of HelloFresh, meal-kits might use less packaging than grocery stores overall because they eliminate upstream packaging from wholesale and distribution.[94] Grocery delivery services, in contrast, may not see as substantial a difference in packaging because of the supply chain overlap with conventional retail.

Grocery delivery services likely do not heavily impact packaging use because their supply chains are somewhat similar to that of conventional retail. Services that pack and fulfill orders from existing stores likely have negligible impact on packaging unless the company's shoppers use more paper or plastic bags for groceries than the consumer would have. Centralized grocery delivery services that operate their own supply chain might have a greater ability to affect packaging. Some e-grocers might choose to deliver items in various types of crates or bags. Also, online grocers with their own brand of products might choose packaging that is designed to be lighter or more easily packed for transport than to be eye-catching for consumers. As packaging can have a considerable environmental impact in food retail and e-commerce,[18,32,95,96] the degrees to which e-commerce services can actually reduce packaging impact should be further studied.

Consumer Behavior. Consumer behavior refers to how consumers shop, including what consumers buy, where they choose to buy those items, and how they get there. "Basket size", the number items purchased in one transaction, strongly influences the relative environmental impact of grocery delivery.[18] As basket size increases, the per-item impact decreases for the same delivery or shopping trip. Edwards, Mckinnon, and Cullinane (2009) find that purchasing 24 items from a store produces the same per-item emissions as the delivery of one item.[71] Research indicates that basket sizes tend to be larger for e-commerce services than for conventional retail.[33,97] On the other hand, e-commerce can also be associated with smaller, more frequent orders ("order fragmentation").[66] Ordering items from multiple different services increases the overall number of deliveries and consequential emissions.[38,47,68] However, Belavina, Girotra, and Kabra (2017) found that ordering smaller, more frequent deliveries from the same store reduces food waste and offsets the increase in transportation emissions. The range of conditions under which this offset holds should be further investigated.

In general, fragmentation could be due to e-commerce options carrying fewer items than large retailers, causing consumers to split up an otherwise consolidated order, or due to an increase in impulse purchasing that generates additional deliveries. However, one study found that impulse purchases are less likely in e-commerce than conventional retail.[98] Fragmentation can also occur in conventional retail if consumers go to multiple stores for their items, though it is unclear whether delivery exacerbates the impacts of fragmentation or how fragmentation combined with delivery interacts with food waste. Furthermore, it is possible that a consumer who typically shops at one large store would switch to shopping from multiple small e-commerce companies for convenience. The aggregate effect of e-commerce on shopping habits and the relationship between delivery, fragmentation, and food waste require further study.

3.0. GOING FORWARD

While much existing research has focused on e-commerce more broadly, there is a need to study food-related e-commerce in particular. Table 1 summarizes identified data gaps and their possible environmental ramifications while also pointing to possible future research. The greatest areas of uncertainty include the relationship between e-commerce and consumer habits, transportation, food waste, and retail infrastructure, particularly large fulfillment centers.

While there is a lack of data surrounding e-commerce fulfillment centers specifically, the research available indicates that fulfillment centers likely have a lower overall impact than grocery stores, partly by eliminating the consumer interface. This interface limits the ability of stores to change their operations, and stores adding experiential offerings to attract customers will have unclear impacts. However, stores might be able to lean on these attractions to retain customers while they better tailor their retail configuration to food preservation. This preservation also impacts transportation.

Further research on the intersection of consumer behavior and transportation is needed, such as how online shopping influences transportation patterns or number of items purchased and what kids of trips delivery replaces (e.g., regular or last-minute). While it is known that delivery vans can be more fuel efficient than personal transportation, food-specific considerations like refrigeration might negate savings.[22] Newer technologies like eutetic refrigeration or electric vehicles might help, while others, like solar photovoltaics (PV), have been used for refrigeration as early as 1997.[22,54] Refrigeration remains an area in need of more data on its energy and environmental impacts. Food transportation might also benefit from Connected and Autonomous Vehicles (CAVs), which can increase efficiency but might also increase the overall number of deliveries.[99] Drone-based delivery also has unclear impacts, with the potential for emission reductions tied to the source of electricity used for charging.[100] In addition to transportation, e-commerce companies are also looking toward advancements in packaging technologies.

Food e-commerce companies, particularly meal-kit delivery services, can be leaders in sustainable packaging as both their need for durable packaging to keep food safe in delivery and public criticism of this packaging might motivate companies to focus on reducing their packaging impact. HelloFresh devoted an entire section to packaging in their 2019 Sustainability Report.[101] Conventional grocers benefit from packaging advancements like "active" or "intelligent" strategies that help reduce FLW, such as those that use sensors or added compounds to promote freshness or those that track foods using radio frequency identification (RFID).[102] Grocers can use advanced materials or strategies for their store-branded products or possibly leverage their scale and buying power to help influence suppliers. Given the variety of design priorities like durability, weight, or aesthetics, different packaging might be preferred for food items destined for delivery vans than those for stores. Still, both can be designed to minimize

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Table 1. Food E-Commerce Uncertainties and Data Gaps

data gap	possible environmental benefit	possible environmental detriment	research required
impact of e-commerce on consumer FLW	meal-planning and lack of impulse purchasing lowers FLW	lack of ownership leads to increased likelihood of waste	more studies required that measure consumer FLW from food purchasing online versus in-store
impact of in-store meal-kits	can be used to reduce consumer FLW at home as well as utilize excess inventory at stores	could increase in-store FLW if not purchased	life cycle assessments of in-store meal kits and data on store stocking practices
impact of food delivery on consumer trips to the grocery store	reduction in trips likely to lower overall environmental impact	using delivery for supplemental shopping creates additional transportation energy and emissions	behavioral studies focusing on food-related e-commerce shopping habits and how consumers spend time freed up by deliveries
impact of e-commerce on order habits	reduction in impulse purchasing and larger basket size can consolidate orders and reduce unnecessary trips	increase in order fragmentation means multiple deliveries for items that otherwise could be purchase in one big trip	behavioral studies focusing on food-related e-commerce ordering habits
impact of fulfillment centers	highly automated, centralized centers might increase fulfillment efficiency and better design for reduction in resource use/emissions per-order; microfulfillment centers could reduce last-mile transportation burden	aggregate impact of large fulfillment centers or microfulfillment centers might be greater than for grocery stores	life cycle assessments and annual-impact studies of food e-commerce fulfillment centers and comparison between centralized- and microfulfillment center performance
impact of food e-commerce in rural communities	replacing multiple, long, consumer trips to the store with a more efficient delivery service can reduce emissions	low consumer density may lead to more emission-intensive delivery routes	rural-specific food e-commerce transportation studies
international development	leapfrogging may help developing countries reach sustainability goals earlier	further adoption of unsustainable practices and technologies in even more countries	different adoption and use patterns for food and e-commerce technologies in different countries

impact. Less certain than structural differences or technological advancements are changes in consumer behavior.

The unique ways in which consumers interact with food e-commerce options might impact both their purchasing patterns as well as possible subconscious behaviors regarding FLW. Certain benefits, like preportioned ingredients in meal-kits reducing FLW, are intuitive. But the impact of e-commerce on shopping frequency, basket size, or impulse purchasing are less easily defined over the long-term, particularly as consumers use both conventional and e-commerce pathways. The behaviors that win out will have direct effects on factors like transportation and food waste, as well as possible indirect impacts that determine the dominant services offered. Because of their ambiguous and potentially substantial environmental ramifications, the impacts of e-commerce on consumer behavior should be a primary area of future study.

Finally, while not directly discussed here, the adoption of grocery e-commerce in developing economies should also be given attention. One potential benefit from adoption in developing food systems could be reductions in food waste.[96] Developing food systems typically have higher preconsumer food losses than developed systems, but less consumer-level FLW.[97] The possibility of reducing preconsumer FLW through technology adoption and logistics development while limiting increases in consumer FLW would be a substantial achievement for sustainability and food security.

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Notes

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