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1 **The Future of Food: Environmental Lessons from E-commerce**

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9 **TOC Art**

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11

12 **Abstract**

13 Our food system is experiencing dramatic changes. The expansion of e-commerce,
14 introduction of new products, and innovations in supply chain structures are all
15 poised to transform how we buy, sell, and distribute food. However, the
16 environmental impacts of these transformations remain unclear. This feature
17 reviews existing literature on environmental implications of e-commerce, discusses
18 relevant trade-offs, and identifies pressing gaps in research.

1.0 Background

Without intervention, research shows that our current food system will exceed planetary bounds as early as 2050¹. The food supply chain produces approximately 13.7 billion tonnes of carbon dioxide equivalent (CO₂e), 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 & 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 discussed³⁻⁵, 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.^{3,4,10–19} However, few studies focus specifically on food e-commerce.^{4,15,16,20,21} 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 pre-prepared meals coming from a central distributor. The scope of the study 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 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. Figure 1 details the relevant supply chains.

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.*

For grocery delivery services, consumers pick out and purchase items online to be delivered to their doorstep. Although most grocery delivery services are limited to individual foods, pre-prepared 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). For meal-kit delivery, companies ship pre-portioned ingredients with corresponding recipes directly to consumers'

doorsteps. This feature article discusses both structural and non-structural elements of food e-commerce and conventional retail, focusing on areas of substantial difference that affect the overall environmental impacts of the food system. The discussion starts with agricultural production and moves to retail and last-mile transportation before segueing into packaging, food loss and waste, and consumer behavior.

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).²² Huber (2018) found that food production contributes 9% of annual GHG emissions in the US.²³ Weber and Matthews (2008) found that production contributes about 6.7 tons of carbon dioxide per household per year.²⁴ Heard, Bandekar, Vassar, and Miller (2019) found that 59% 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).²⁵ Because of the large impact of production, choice in food and food-source is likely to have a substantial influence on the 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.^{26,27} Though food retailers, both e-commerce and conventional grocers,

typically lack control over agricultural production methods, they might be able to leverage their buying power to influence some changes.

The competition to attract customers by promoting sustainability might have upstream ripple effects, as previous research suggests that retailers have the ability to influence their suppliers and producers^{28,29} Conventional retailers with large buying power might have an advantage over smaller e-commerce options that have less leverage.²⁹ In general, the degree to which a company can influence producers is likely less connected to differences between e-commerce and traditional retail but more to the size and scale of a company. Larger companies might have greater buying power and influence over producers, but smaller companies might be able to be more selective in their overall product offerings as they sell fewer items. The influence of retailers over suppliers warrants further discussion given the importance of production methods to the overall lifecycle impact of food.^{2,30}

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.^{25,31} 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.^{20,32} But US grocers are still growing, adding 30% more square footage in 2018 than 2017.³³ Some are also experimenting with different formats like smaller stores that are optimized for in-house e-commerce operations.³⁴ Other stores hope to attract

customers by adding restaurants and bars.³⁵ 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.^{12,36,37} Grocery stores must balance these priorities and customer experience, leading to inefficient features like open refrigerated display cases that can consume 30% more energy than a doored alternative.³⁸ Refrigeration alone can comprise 50% of a supermarket's electricity use.³⁹ While initial studies indicate fulfillment centers reduce energy use and emissions compared to grocery stores^{25,31}, very little data exist on the environmental impact of food-related fulfillment centers specifically, and most estimates are indirect.^{16,25,31} 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.^{12,36,37} Furthermore, grocery delivery services can operate multiple different kinds of fulfillment centers.

Grocery delivery services can operate large centralized fulfillment centers, smaller 'micro-fulfillment' centers, or 'dark stores' or 'warerooms' that are attached

to existing grocery stores.^{40,41} 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.⁴¹ Some fulfillment centers are also automated, which can increase overall energy use.⁴² However, this increase might be ameliorated by a subsequent increase in order throughput that reduces the effective impact per order.⁴³ In July of 2018, online grocer FreshDirect opened a 400,000 ft² automated fulfillment center in the Bronx, NY with 15 different temperature zones and nine miles of conveyor belts.⁴⁴ 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.^{45,46} And while changes in upstream transportation (farm-to-retail, see Figure 1) can also influence miles travelled and thus environmental impact^{47,48}, 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.^{49,50} 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.⁵¹ The benefits of delivery vans could be negated, however, by smaller delivery time-windows. Greater consumer control over delivery time window can prevent failed deliveries but can also prevent delivery services from fully optimizing their routes to reduce miles travelled. 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 if the delivery service delivered once per week to a set reception box.⁴ Delivery benefits can also be negated by vehicular refrigeration.⁵² A recent study from Berlin, Germany reports lower reductions in emissions from grocery delivery than other studies due to refrigeration in the delivery vehicles.²⁰ Transportation-related benefits 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.^{31,48} 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 passenger 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.⁵³ However, recent work has found decentralized systems to show greater promise.²¹ 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.⁵⁴ Closer stores would also push freight activities closer to consumers, exacerbating congestion in some areas. The location of stores, closer or further away from consumers, might have a larger impact on households without cars who use alternative transportation modes and are thus distance-limited in their store options.⁵⁵ 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.⁵⁶ But while receiving a delivery instead of walking to the store would increase emissions and congestion, e-commerce orders might more typically replace driving trips.³² On the other hand, lower-emitting transit options would also be available to grocery delivery service workers, and could be used to deliver smaller orders. Still, increased vehicle-based deliveries could also impact road congestion and increase last-mile emissions due to idling.⁵⁷ 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.⁵⁸ Delivery services might 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.^{12,15,20,31,46} However, most of these studies extrapolate these findings from results of urban study areas. However, 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.¹² 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 mi⁵⁹ compared to city delivery routes that might fit over 100 stops in 40 miles.⁶⁰ 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.^{61,62} 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.⁶³ 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.^{64,65} Grocery delivery services

235 seem best poised to replace trips entirely, but complete substitution is unlikely.^{62,64–}
236 ⁶⁷ ‘Trip-chaining,’ or combining multiple activities in one trip, complicates the
237 comparison of conventional retail to delivery as it reduces the emissions associated
238 with individual activities but makes allocation of miles-travelled to each task
239 difficult.⁶⁸ The transportation benefits of e-commerce might be overstated in
240 literature because trip chaining is often overlooked.⁶⁷ Furthermore, there is the
241 question of how consumers spend the time freed up by ordering delivery.

242 Research seems to indicate e-commerce can result in both an increase and
243 decrease in aggregate shopping trips when e-commerce services are used, though
244 this is not specific to food.⁶⁷ Given the routine nature of grocery shopping, delivery
245 could free up substantial time for consumers. But consumers may use that time to
246 travel to another store or activity. On the other hand, some consumers might replace
247 a post-work trip with a delivery just to have more free time at home or reduce ‘end-
248 of-day time pressure.’⁶⁹ But a study in Delaware found that, while the growth in
249 general e-commerce was lower than projected in 2001 (albeit online food purchases
250 increased substantially), traffic conditions and emissions were worse than
251 predicted.⁷⁰ Another found evidence for either neutral or greater travel when time is
252 freed up through e-commerce.⁵⁵ The degree to which a shopping trip is considered a
253 recreational or social activity might also influence changes in travel patterns.⁵⁵ More
254 research is warranted on how consumers use time freed up by deliveries.

255
256 *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 FLW⁷¹ and that it contains the equivalent of 2% of U.S. greenhouse gas emissions.⁷² 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 pre-portioning ingredients.

Fulfillment centers used in meal-kit delivery and centralized grocery delivery services might reduce FLW compared to grocery stores. Decentralized grocery delivery services often operate out of existing storefronts and are much less likely to impact retail FLW. According to the USDA, about 10% of food is wasted at the retail level in the U.S.⁷³ A 2016 study of meal-kit supplier Blue Apron found the service wasted just over 5% of food at their fulfillment centers⁷⁴, and the UK-based online grocer Ocado announced in early 2017 that they achieved 0.2% waste at their fulfillment centers.⁷⁵ Some of this reduction might be attributed to lower inventory, 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, grocery delivery might further reduce inventory at fulfillment centers because they have more freedom to design for food preservation.^{44,76,77} Meal-kit delivery services are even better poised to reduce FLW because they supply pre-portioned ingredients, preventing consumers from over-buying. Meal-kits made for in-store

purchase might be more likely to be wasted however, as grocers can overstock meal-kits whereas delivery kits are made to order. Overall, more studies assessing retail FLW are needed for e-commerce; most existing estimates of FLW are for the conventional supply chain and highly variable.⁷⁸ Indirect 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.^{25,74,79} These studies all find that meal-kits reduce consumer FLW, though waste is still possible if consumers don't like or don't want to cook the provided meals.⁸⁰ Additionally, unattended delivery could result in kits being unrefrigerated for too long and spoiling.⁸¹ There are even fewer studies on grocery delivery FLW. Grocery e-commerce could be helpful for meal-planning, which can prevent overbuying,⁸² but research has also found that consumers are more likely to waste food purchased online because they feel less ownership of the items.⁸³ Subscription-based grocery delivery models might reduce food waste more than pay-per-order models by incentivizing more frequent, smaller basket sizes.⁸⁴ The impact of e-commerce on consumer FLW is a present data gap. Additionally, store closures due to competition from e-commerce and a consequential decrease in store density could actually increase food waste; if stores are more difficult to get to, consumers will go less frequently and purchase more food, thus increasing the likelihood of waste.⁸⁵

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 pre-portioned ingredients usually means a higher packaging-to-food ratio.^{86–88} 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.⁸⁹ 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^{16,31,90,91}, 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.¹⁶ 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.⁶⁸ Research indicates that basket sizes tend to be larger for e-commerce services like grocery delivery.^{32,92} On the other hand, e-commerce is also associated with smaller, more frequent orders ('order fragmentation'), which increases energy intensity.⁶² Ordering items from multiple different services increases the overall number of deliveries and consequential emissions.^{37,46,65} Fragmentation could be due to e-commerce options carrying fewer items than a 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.⁹³ Fragmentation can also occur in conventional retail if consumers go to multiple stores for their items, though it is unclear whether the use of delivery vans exacerbates the negative impacts of fragmentation or not. Furthermore, while smaller grocery stores might promote fragmentation just as small e-commerce services would, it is possible that a consumer who typically shops at a large store would switch to shopping from multiple small e-commerce companies for convenience. The effect of e-commerce on shopping habits and

willingness of a consumer to order multiple deliveries over making one shopping trip requires 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 shopping habits, food waste, and retail infrastructure, particularly large fulfillment centers.

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; micro-fulfillment centers could reduce last-mile transportation burden	Aggregate impact of large fulfillment centers or micro-fulfillment 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 micro-fulfillment center performance

<i>Impact of food e-commerce in rural communities</i>	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
<i>International development</i>	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

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

368 Delivery vans can be more fuel efficient than personal transportation, but
 369 food-specific considerations like refrigeration might negate savings.²⁰ Newer
 370 technologies like eutectic refrigeration or electric vehicles might help, while others,
 371 like solar photovoltaics (PV), have been used for refrigeration as early as 1997.^{20,52}
 372 Food transportation might also benefit from Connected and Autonomous Vehicles
 373 (CAVs), which can increase efficiency but might also increase the overall number of
 374 deliveries.⁹⁴ Drone-based delivery also has unclear impacts, with the potential for
 375 emission reductions tied to the source of electricity used for charging.⁹⁵ In addition
 376 to transportation, e-commerce companies are also looking towards advancements
 377 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 these companies to focus on reducing their packaging impact. HelloFresh devoted an entire section to packaging in their 2019 Sustainability Report.⁹⁶ Conventional grocers benefit from packaging advancements like ‘active’ or ‘intelligent’ strategies, such as those that use sensors or incorporate compounds to promote freshness or track foods using Radio Frequency Identification (RFID), that can help reduce FLW.⁹⁷ Grocers can use advanced packaging materials or strategies for their store-branded products or possibly leverage their scale and buying power to help influence other suppliers. Given the variety of design priorities like durability, weight, or aesthetics, different packaging might be used in the future for food items destined for delivery vans than those for stores. Still, both can be designed to reduce environmental impact. Less certain than direct 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 possibly their own subconscious behaviors regarding FLW. Certain benefits, like pre-portioned ingredients in meal-kits reducing FLW, are intuitive. But the impact of e-commerce, particularly grocery delivery, on habits like 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 to shop. The behaviors that win out will have significant influence on environmental impact with direct

effects on transportation and food waste, among other factors, as well as possible indirect impacts guiding 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 pre-consumer food losses than developed systems, but less consumer-level FLW.⁹⁷ The possibility of reducing pre-consumer 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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