A Comparative Analysis of Carbon Emissions of Grocery Pickup and Delivery in Urban and Rural Regions

by

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Abstract

The majority of life cycle studies on E-Commerce indicate that direct-to-consumer delivery models tend to have lower environmental impacts than traditional retail; however, most studies contain assumptions associated with relatively high population densities, rather than rural consumption patterns. This study quantifies the greenhouse gas (GHG) emission differences between grocery pickup and grocery delivery in urban and rural areas comparing multiple operational logistics scenarios. The study's results showed that grocery E-Commerce has lower GHG emissions in both urban and rural areas compared with brick and mortar (14-55% GHG and 15-52% GHG improvement), but the overall values of urban grocery shopping are lower than rural grocery shopping with moderate difference (116 Kg GHG/wk vs. 122.2 Kg GHG/wk). In addition, E-Commerce that involves delivering directly from a distribution center has greater benefits than E-Commerce models that involve a physical store (110.5- 115.6 Kg GHG/wk vs. 114.9-120 Kg GHG/wk). If the availability and convenience of grocery delivery increases the frequency of grocery shopping, the overall GHG benefits of e-commerce will likely be reduced. Although the study showed substantial variation in last-mile emissions across the scenarios analyzed, delivery method is significantly less important than the embodied emissions of food and food waste of groceries (6-8 % downstream vs 34-38 % food and 24-27 % food waste). Any induced changes to food consumption patterns resulting from E-commerce will likely have a much greater effect on the impacts of the food system than any last-mile differences.

Introduction

Rural systems are generally understudied in the life cycle assessment (LCA) literature, despite having different structural and cultural patterns that could impact results [1]–[4]. E-commerce is an industry where urban-rural differences may be particularly pronounced due to last-mile considerations as the final link in the supply chain between production, terminals and end consumers [5], [6]. Last-mile considerations alter the overall results of e-commerce studies, which is particularly important when studying rural e-commerce since rural areas contain about one fifth of the US population but make up nearly a third of personal vehicle miles travelled [7]. In addition, consumers in urban and rural areas have very different purchasing habits and behaviors with respect to frequency of shopping trips, number of items purchased during a shopping trip, and combining multiple activities in one trip (i.e. “trip-chaining”)[8].

The Covid-19 pandemic has shifted consumers’ grocery purchasing preferences from going to the store to more buying online. As a result, there has been an increased demand for grocery delivery services, yet the environmental implications remain not fully understood. The global food system is a major contributor to climate change, responsible for about 34% of total GHG emissions [9], [10]. Meanwhile, the food supply chain ranging from transportation, storage, refrigeration, retail, packaging, and waste management account for 20% of total food system emissions [11]. Given that global food supply operations are predicted to become more energy-intensive and higher share of total food system emissions from advanced refrigeration and packaging processes [9], reducing emissions in the food supply chain requires a combination of strategies, including technical advancements, improved efficiencies in supply chain management and reducing food waste [4], [12].

In 2020, 50% of consumers indicated that they purchase food online at least once a week and will likely continue to do so [13]. Consequently, the food delivery market in the U.S market is predicted to grow by approximately 5% over the next three to five years [13]. The differences in supply chain operations applied to urban and rural consumers directly affect the life cycle carbon footprint of grocery products [2].

Previous literature has shown that E-Commerce tends to emit lower carbon emissions in non-food commodities compared to a traditional retail supply chain [14]–[20]. E-commerce has the potential to lower emissions through the utilization of micro-fulfillment centers (16-54%), adoption of electric vehicles by customers (18-42%), or offering grocery delivery services (22-65%) [1]–[6]. This study investigates whether the trends identified by previous studies are applicable to rural as well as urban settings, which is a significant gap in the literature.

Consumers in urban and rural areas also have different purchasing habits and behaviors with respect to frequency of shopping trips, number of items purchased during a shopping trip, and trip chaining behaviors. Thus, in addition to exploring structural considerations associated with last-mile delivery of groceries, this study includes a sensitivity analysis to examine how induced changes in consumer shopping behavior could impact the environmental profile of E-Commerce.

Materials and Methods

Goal and Scope

This study uses the Life Cycle Assessment (LCA) methodology to compare the GHG emissions of grocery procurement via brick and mortar (B&M) stores and E-Commerce for urban and rural customers. The system boundary includes agriculture production, harvesting, handling and storage, distribution, and last-mile transportation to customers.

The current landscape of food retailers encompasses a variety of retail formats including grocery stores, supercenters, convenience stores, specialty food stores, and dollar stores, among others [21]. E-Commerce operation enacts different distribution models, including delivery from a centralized distribution, or delivery from smaller fulfillment centers via centralized distribution, as well as delivery from an existing retail store. The retail landscape also differs based on geographic locations as rural areas tend to rely more on regional supply chain models, whereas national supply chain logistics are more prevalent in urban areas [22].

Figure 1 shows the supply chain pathways that were modeled for this study: one B&M scenario and two E-Commerce scenarios, which are explored for both urban and rural systems. The B&M grocery shopping pathway involves the transportation of products from the farm to a handling facility, then transported by truck to a midway stop at a larger regional distribution fulfillment center, products then are being transported from the regional distribution center to a B&M store, and customers travel to the store with their personal vehicles to pick up the products. Two forms of E-Commerce are considered. The first e-commerce scenario includes an identical supply chain from farm to a B&M store, with groceries delivered to customers from that store via local van. The second e-commerce scenario does not include a physical store, but delivers products directly to the consumer via a regional distribution center [14].

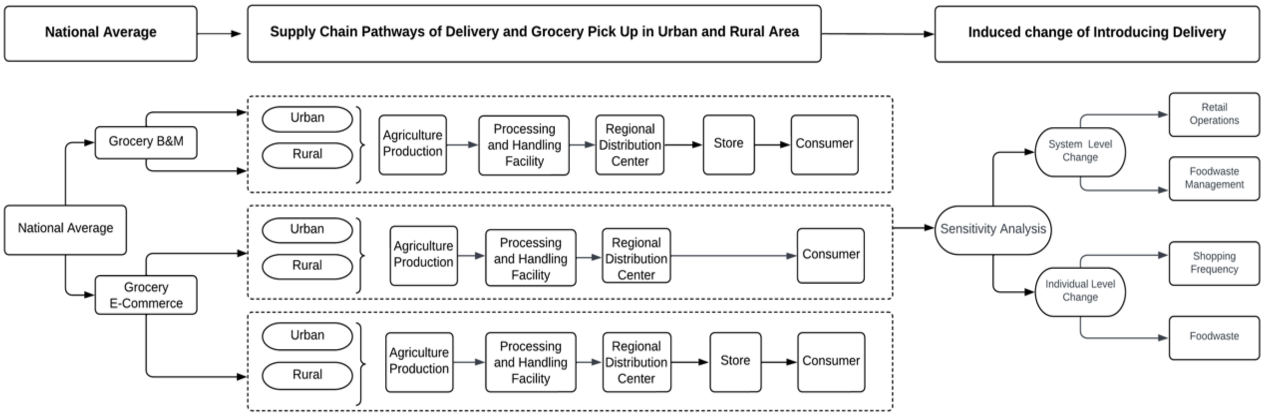

Figure 1: Figure 1 shows three supply chain pathways modeled for this study: one B&M scenario and two E-Commerce scenarios, which are explored for both urban and rural systems. The traditional B&M grocery shopping pathway involves the transportation of products from the farm to a handling facility, then transported by truck to a midway stop at a larger regional distribution fulfillment center, products then are transported from the regional distribution center to a B&M store, and customers travel to the store with their personal vehicles to pick up the products. Two forms of E-Commerce are considered. The first e-commerce scenario includes an identical supply chain from agriculture production site to the retail store, with groceries delivered to customers from that store via a local van. The second e-commerce scenario does not include a physical store but delivers products directly to the consumer via a regional distribution center (van Loon et al., 2015a). A sensitivity analysis is conducted to examine the parameters associated with the supply chain and individual shopping behaviors, as depicted on the right.

An initial assumption of this model is that consumers maintain similar shopping behaviors for both B&M and E-Commerce operations. In reality, E-Commerce has the potential to change shopping behaviors, including increasing shopping frequency and choices of purchased items [23], [24]. Although there are insufficient data to support analysis of induced changes to shopping behavior at this time, a sensitivity analysis on shopping behavior parameter provides some insights on potential induced behavior changes could impact the comparative results of B&M and E-Commerce scenarios.

Functional Unit

The functional unit of this study is the estimated weekly grocery purchases for a household of three. According to the U.S Census Bureau, the average size of household in the U.S. is estimated to be around 2-3 people, constituted as two adults and one teenager with daily calories intake of 2200 and 1000, respectively [25]. Based on the nutritional intake suggested by U.S. Department of Agriculture (USDA), this study estimates a total of 32.69 kg of weekly groceries for a household of three. [25]. (See the Supporting Information for more details.) The calculated emission results are reported in $kgCO_2e$/week.

In this study, 11 food items are evaluated as 32.69 kg of consumed food weight and 49.36 kg of agriculture production weight at the upstream farm gate, accounting for a food loss rate of approximately 34% from agricultural production to consumption. The 11 items are selected to fulfill the USDA suggested nutritional intake category including lettuce, orange, dry bean, corn, tomato, apply, wheat grain, milk, chicken, fish, soybean seed and soybean oil. The food loss rate is categorized and allocated across each supply chain stage from production to end consumers. The transportation and distribution loss is estimated to be at 2% at the national average. At the retail level, food waste might occur due to damaged packaging, overstocking, blemished food, or spillages [26].Each individual food type is considered with its associated food loss rate at both the retail and consumer level depending on each produce’s perishability [27].

Prior literature suggests that functional units for food LCA studies have been predominantly mass based, which has several limitations as it may not capture all the nuances associated with nutrition [28]. Nonetheless, a mass-based functional unit associated with time can be sufficiently appropriate to capture the differences of shopping frequency between last-mile grocery E-Commerce and B&M, since the focus is on the supply chain rather than the food itself.

Model Assumptions

The upstream emission of purchased groceries is calculated as the sum of food embedded emissions, transportation emissions from agriculture production to post harvesting facility, and then to regional distribution center, and finally the operational energy emission at the regional distribution center. The emission factors are allocated to each type of grocery purchased in the agriculture and processing stages. The model assumes that groceries are delivered from post harvesting facility to regional distribution center in 53’ freight trucks and the vehicle fuel economy is modeled based on GREET 2021 emission factor data [29]. The distance between post harvesting facility and regional distribution center is assumed to be an average of 134 miles [22], and a total of 22,500 items are assumed to be delivered to the regional distribution center from each truck[30].

While the model in this study takes into account upstream emissions, emissions at regional distribution centers, emissions at the retail level, and last mile delivery emissions, the main emphasis of the study is on downstream emissions despite including the major stages of the supply chain in the model. Regional distribution center electricity and energy consumption is calculated based on a single level, 25,600 square foot refrigerated warehouse with 20-foot ceilings. The annual electricity usage is assumed to be 60 kilowatt-hours per square foot per year [31] The emission factor is calculated based on the mass of each individual grocery products equivalent to 1 square foot of storage room and the energy consumed per square foot each year [32]. Our model assumes that all grocery is stored in the regional distribution center for 24 hours before reaching to the next destination.

Emissions at the retail level are calculated based on annual electricity and natural gas consumption from heating, ventilation, and air conditioning (HVAC), lighting, walk-in cooler, and cabinet display. A supermarket is assumed to be an average of 40,000 square feet, using 50 kWh of electricity and 50 cubic feet of natural gas per square foot per year [33]. Of those energy usages, 23% of electricity consumption comes from lighting, 57% from refrigeration, and 15% from HVAC. Space heating is assumed to be 69% of the natural gas use, with 22% used for cooking. The total annual power requirement of the supermarket is 285 kW, 65 kW for the store lighting, 42 kW for HVAC, and 163 kW for refrigeration. The breakdown of electricity consumption estimated in this model is similar to the values reported by a specific retailer in previous literature [30]. Other activities such as office operation, cooking and unloading are not considered in this model.

The calculations also consider shelf life- the amount of time a product remains in the store, from the moment of arrival to the moment a consumer purchases the product. The model assumes that commodities exhibit different shelf life depending on the perishability, popularity, and store operations. For example, fresh produce such as lettuce and tomatoes have shorter shelf life compared to dry produces such as grain and dry beans and rice [32]. The model assumes that food waste scenarios in urban B&M, rural B&M, urban E-Commerce via store, rural E-Commerce via store, urban E-Commerce without store, and rural E-Commerce without store are consistent across all supply chain stages, with the exception of disregarding any food waste that occurs between regional distribution centers and retail in the E-Commerce without store scenario. However, it is important to note that food waste rates may vary across these scenarios, with the majority of rural residents managing their food waste through backyard composting or by feeding it to livestock.

The last mile transportation model in this study is based on the grocery pick-up and delivery options shown in Figure 1. Grocery pick-ups are assumed to be shopping trips to the grocery store with a personal vehicle and the associated emission is calculated with route distances, vehicle fuel economies, shopping frequency, trip chaining and emissions factors given in Table.1 [33][34][35].

Sensitivity Analysis

A sensitivity analysis is conducted to estimate the uncertainty and variability of the current model and draw an understanding of the potential effects associated with changing shopping behavior. Four data parameters are evaluated in the model: fuel economy, last mile distances, trip chaining and shopping frequency. A one-at-a time-perturbation holds all parameters in the model at their default value, and then varies individual parameters of interest across the range across its minimum to maximum values.

	National Average		***Urban Area***		***Rural Area***	
Parameters	***B&M***	***E-Commerce***	***B&M***	***E-Commerce***	***B&M***	***E-Commerce***
Fuel Economy (MPG)	29.5 [1]	10.5 [2]	25 (22.5-27.5) [1]	9 (8.1-9.9) [2]	34 (30.6-37.4) [1]	12 (10.8-13.2) [2]
Last Mile (Miles per trip)	10.2 [3,4]	n/a	6 (2-12) [3]	n/a	20 (10-30) [3]	n/a
Trip Chaining (Numbers of stops per trip)	1.5 [5]	n/a	1.9 (1-2.8) [6,7]	n/a	1.5 (2-3) [6,7]	n/a
Shopping Frequency (Numbers of trip per week)	2.5 [8]	0.9 [9]	2.05 (0.5-3.6) [9]	1.25 (0.9-3)	1.5 (0.5-2.5)[6,14]	0.9 (0.5-1.1)[3,4]
Route Distance (Miles per Trip)	n/a	88 [10]	n/a	59 (30-88) [11,12,13]	n/a	92 (50-134) [11,12,13]
#of stops (Numbers of stops per trip)	n/a	31 [14]	n/a	7.38 (2.74-12.02) [11]	n/a	55 (30-80) [8,13]

Notes

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14. Assumption
15. Estimation between Urban and Rural range

Table 1 presents the data parameters considered in our study for both B&M and E-commerce scenarios, highlighting the differences between rural and urban areas in terms of fuel economy, travel distances, shopping frequency, and trip chaining numbers. We assume that customers use a 2021 Nissan Altima to drive to the store for grocery pick up and a Ford Delivery 350 HD for grocery delivery, with fuel economy assumed to be divided between city and highway miles per gallon. For consistency, we assume a medium-sized grocery store is used for grocery purchases, resulting in an average distance of around 5 miles based on the USDA's national average of primary store distance to household. The rural and urban last mile differences are based on a SNAP (2012) study, which provides data points from a survey of households in both areas. Trip chaining numbers are based on a 1999 study, which found a national average of 1.5 stops per trip. Additionally, research studies from Zhou and Wang (2018) and Farag et al. (2013) suggest that higher population density leads to more online shopping and parcel deliveries. The national average for grocery shopping is 8 miles round trip, with the nearest store located on average 4 miles one way, according to the SNAP study.

Results and Discussion

Differences in grocery emissions in rural and urban areas are influenced by two key factors: the overall supply chain structure and individual consumption behaviors. The two models in E-Commerce demonstrate the differences in supply chain structure, particularly with respect to rural and urban areas. Getting groceries through E-Commerce delivery without a physical retail store is generally less carbon intensive than the model of grocery departing from a retail store. At the same time, transporting groceries to rural areas might result in travel longer distances, leading to higher operational energy usage and potential food loss during transportation. Both consumer purchasing preferences and shopping behaviors will affect the related emissions to B&M and E-Commerce.

As shown in Figure 4a, the national average emission per weekly grocery intake for a household of three is 116.6 kg CO2e/week, with e-commerce at 109.1 kg CO2e/week, which includes both the emissions associated with last mile and the embodied carbon of the food. The results indicate that generally, E-Commerce tends to have lower GHG emissions in both rural and urban regions ranging from 4-5% total GHG improvement than B&M, with 22-32% improvement in last mile transportation.

Emissions associated with the last mile are moderate, with B&M and E-Commerce contributing 4% and 6% of total emissions. Agriculture production and food processing are responsible for the highest portion of emissions under both B&M and E-Commerce scenarios. Emissions from agriculture production make up 25% of the total, while emissions from food loss and waste account for 24% of total emissions, which is within the spectrum across all other ratios reported in the current literature or industrial report. These findings are consistent with prior research that has highlighted the significant environmental impacts associated with food production and waste [4], [34].

If excluding the embodied emissions of food and only analyzing last-mile differences (Figure 4b), the improvement seen from E-Commerce could be up from 41%-55% emissions. It shows that refrigeration at the retail level (Cabinet Display) and last-mile transportation are the primary sources of energy consumption when comparing the differences of e-commerce and brick & mortar models. The differences in emissions between B&M and E-Commerce are mainly influenced by the supply chain structure, where the B&M model includes energy consumption from upstream transportation, regional distribution center, retail operation, and last-mile delivery and the E-Commerce model excludes the physical store operation energy usage. In terms of geographic locations, urban areas tend to have lower emissions compared to rural areas in both B&M and E-Commerce models due to shorter last-mile travel distance and shelf life.

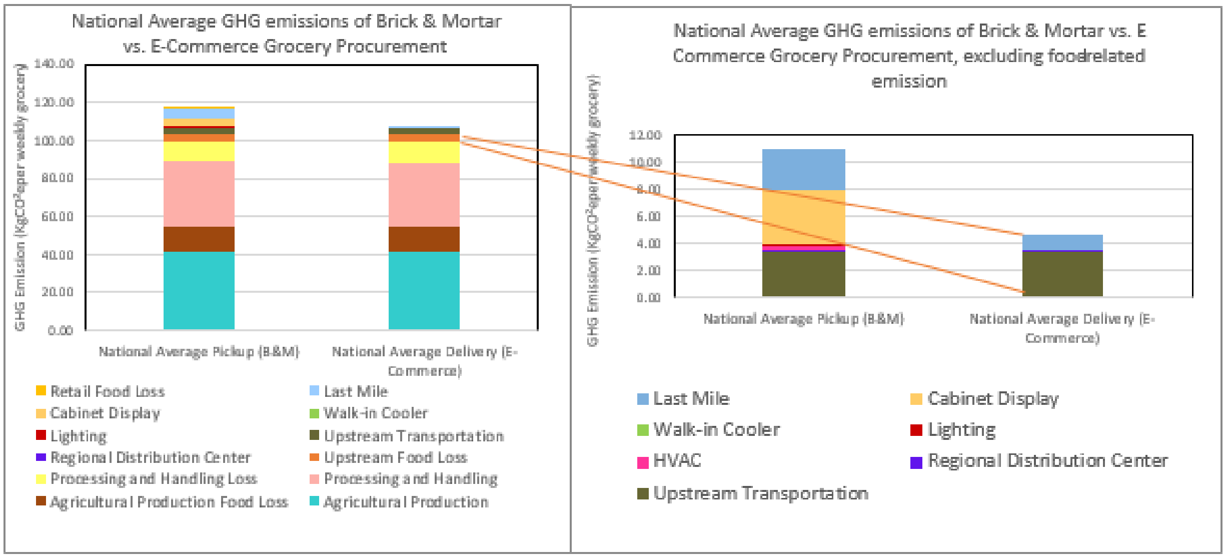

Figure 4a&4b. Figure 4a shows the total estimated emissions (kg CO2e/weekly groceries) on a national average level for getting groceries from a B&M store or through E-Commerce delivery, assuming groceries are delivered direct to consumers via a distribution center. Figure 4b excludes embodied food emissions and shows only the differences associated with B&M and E-Commerce.

Figure 5 depicts the difference in last-mile emissions when disaggregated into urban and rural scenarios. Similar to the national level depicted in Figure 4, refrigeration at the retail level (Cabinet Display) and last-mile transportation are the primary sources of energy consumption when comparing the differences of e-commerce and brick & mortar models. The differences in emissions between B&M and E-Commerce depend largely on whether a grocery store is used as a distribution hub for the E-Commerce model. When grocery stores are used as distribution hubs, the primary difference in emissions are due to overall miles traveled per week, as a function of both shopping frequency and distance traveled of a delivery van or personal vehicle. When delivering directly to a consumer from a distribution center, E-Commerce results in 47% reduced emissions in urban delivery and 41% in rural from downstream emissions. Meanwhile, the E-Commerce via store model results in 8% reduced emissions in urban and 5% in rural areas. These results correspond to the variability in the previous study where a study found that e-grocery shopping can reduce emissions by up to 75% and the low end of emission saving is 20% [35] Another study in Finland also identified around 18%-87% CO2 emissions reduction potential when traditional grocery shopping was replaced by delivery services [36].

The remainder of the discussion focuses on E-Commerce without a grocery store hub, which is substantially more different than consumer grocery pickup at a B&M. In the B&M grocery scenario, our model assumes that the primary differences between urban and rural customers are associated with travel longer travel distances, shopping frequencies, and longer residence time in the store [37]. E-Commerce models offer advantages in both urban and rural scenarios, although rural grocery supply chain tends to have larger overall GHG emissions than the same scenario in an urban context. Regardless of the delivery mechanism, grocery shopping in urban areas has approximately 10% lower emissions than rural areas under current assumptions. The results might vary depending on changes in parameters such as the aggregated transportation efficiency and more sustainable delivery options.

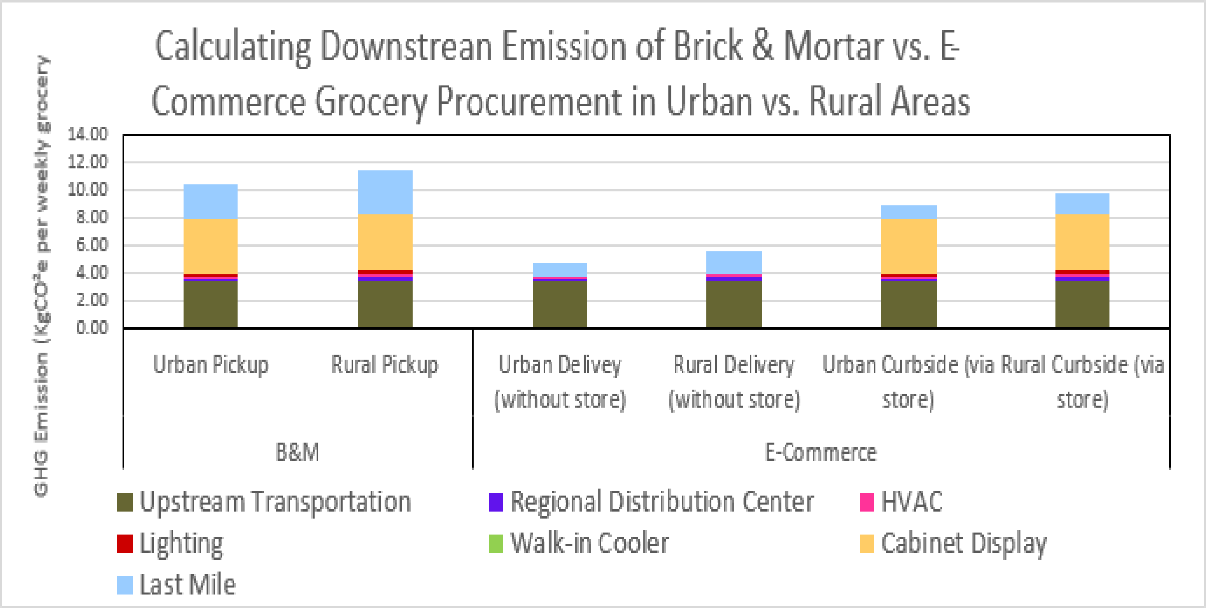

Figure 5. Last-mile emissions contributions for urban and rural grocery procurement, comparing pickup at B&M stores, as well as two E-Commerce scenarios, distribution without a physical grocery store and via a grocery store.

This analysis suggests that on a weekly grocery purchases basis emission savings are possible under the E-Commerce scenario across urban and rural areas. Figure 4b is based on the assumption that overall shopping behavior remains the same for the B&M and e-commerce scenarios. Compared to B&M, e-commerce shows an overall advantage in multiple supply chain stages such as evaluated in this study. As grocery delivery companies expand, E-Commerce will have the opportunity to maintain and improve environmental benefits, specifically in the less penetrated markets of rural areas.

Sensitivity Analysis

While E-Commerce appears to offer emissions benefits assuming grocery purchasing behavior remains identical to current shopping patterns, E-Commerce may induce a number of changes to consumer behavior that could impact these results. The sensitivity analysis helps to understand the variability and uncertainty in the model and provides insight into the relative impact of different parameters on the overall carbon emissions. These include both modeled parameters with known variability across a large range, as well as potential for induced behavior changes, which are currently unknown but may impact the results. Last-mile transportation distances, miles per gallon (MPG), weekly shopping frequency, and the number of stops made during the trip are considered four factors with known data ranges. Figure 6 demonstrates that the frequency of grocery shopping and travel distances are the two most crucial parameters affecting overall last-mile emissions. Among the four parameters, shopping frequency appears to be more sensitive in triggering larger changes in emission outcome compared to fuel economy, last mile travel distances (route distance), and trip chaining (#of stops). For example, if E-Commerce induces a behavior change that leads rural household to increase their shopping frequency from its current average of 0.9 times per week to 2 times per week, it would lead to an increase of 70% increase in last-mile transportation emissions, as shown by the difference between the mean and max value in Figure 6d. As E-Commerce grows in rural areas, the relative environmental benefit may decrease, as more consumers might change their shopping behavior and order online more frequently.

Previous literature has suggested that the travel frequency to a households' primary grocery stores is moderately influenced by the urban environment. Infrequent grocery shoppers tend to live in lower-density areas and are thus simultaneously further away from their primary grocery stores[38], [39]. Our study assumes that generally rural consumers shop less frequently than urban consumers with longer travel distances and delivery route. In the Brick& Mortar scenario, this study assumes that rural consumers tend to have multiple stops along one trip compared to urban consumers. And in the E-Commerce scenario, rural areas have fewer delivery stops due to lower population density. However, it's worth noting that these factors are not mutually exclusive and are associated with each other; any cross correlations within these factors are not considered in the calculation model.

Widespread availability of grocery e-commerce could influence shopping behaviors, which may influence the results. The sensitivity information shown in Figure 6 indicates when a change in a given parameter could make e-commerce a less favorable option than B&M. For example, Figure 6d shows that, an additional delivery stop could lead to 20% less emissions compared to the baseline in rural E-Commerce scenario.

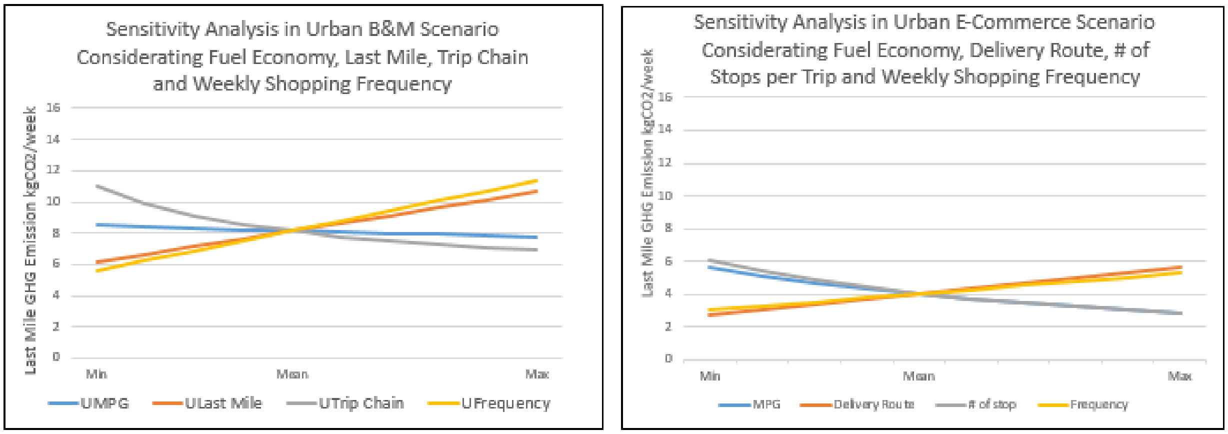

Figure. 6a &6b shows the sensitivity analysis between Urban B&M and Urban E-commerce scenarios considering Fuel Economy, Last Mile Travel Distances, Trip Chain, and Weekly Shopping Frequency

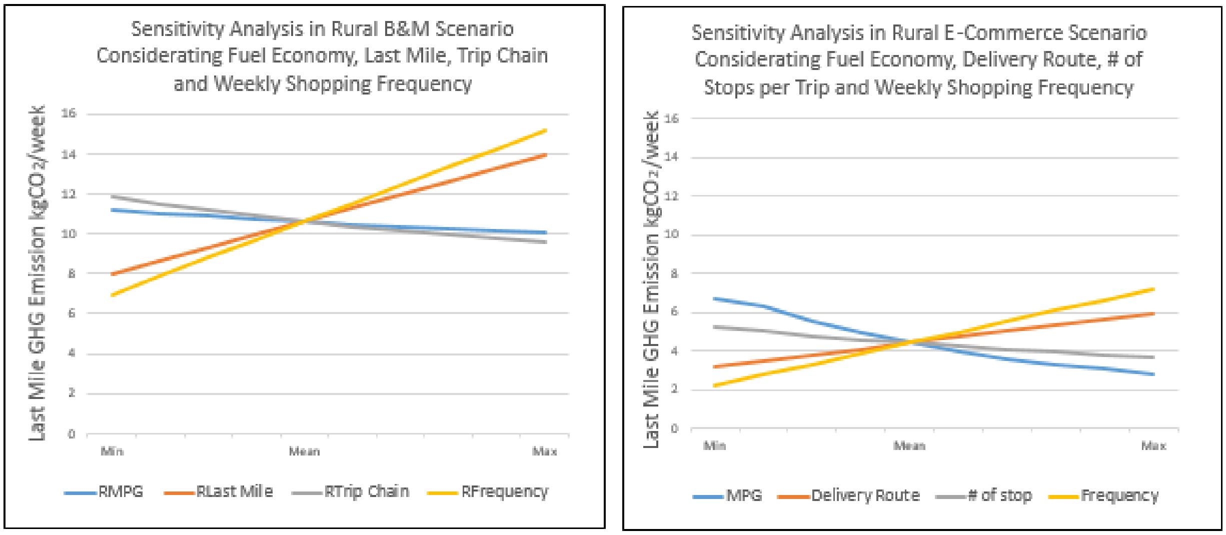

Figure. 6c & 6d shows the sensitivity analysis between Rural B&M and Urban E-commerce scenarios considering Fuel Economy, Last Mile Travel Distances, Trip Chain, and Weekly Shopping Frequency

Limitations and Future Research

The overall results of the findings were limited by the following factors. This study makes a number of simplifying assumptions and does not include any differences in packaging emissions, as well as food waste and loss discrepancy between rural and urban areas due to lack of data available. Additionally, the sensitivity analysis might be affected by correlations between variables that are not captured in the model.

Although this study focuses on the supply chain, it's important to note that the embodied carbon in agricultural production remains high and contributes significantly to emissions and energy use over the life cycle. Figure 4 breaks down the total supply chain contribution to emissions, revealing that agriculture production and food processing are responsible for the highest portion of emissions in both the B&M and E-Commerce scenarios. Therefore, changes in the types of foods purchased via e-commerce models may have a greater influence on weekly grocery shopping GHG emissions than the delivery mechanism itself. Additionally, it's worth considering that people may purchase different foods in urban and rural areas depending on the supply chain structure (regional or national) and how consumer behavior might change, leading to varying environmental impacts of consumer choices. While rural E-Commerce may have environmental benefits, there are also potential challenges to consider. The infrastructure to support the delivery processes may not be adequate in some rural areas, which could further impede the adoption of grocery delivery services, or favor adoption of e-commerce models that operate out of existing physical retail infrastructure, which has less overall benefit.

Another limiting factor is that this model assume that customers shop exclusively online or in-store, yet often times customers shop both online and in-store within the same week. According to the Spryker report, about 34% of the in-store customers shop exclusively in-store and 18% of the online grocery customers shop exclusively online [40]. This suggest that customers might use multiple channels to meet their grocery needs. Another factor to consider is that while shopping frequency is known to be different between rural and urban areas, there are likely to be other factors that influence the overall shopping frequency as well, such as gender, household income and education level[41], [42] .

Future research could expand on the findings of this study by exploring the potential benefits of reduced food waste and loss in rural e-commerce services as compared to traditional grocery shopping alternatives, as well as actual changes in shopping behavior that are observed with e-commerce. Food waste and loss could result in higher emissions in rural areas that pertain national supply chain, with less developed infrastructure and longer transportation distances [43].

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Appendix

Table. 1 Functional Unit of this study is based on USDA Nutritional List

USDA Nutritional List	Recommended Intake (grams/week)	Food Type	Purchase Input (kg)	Sources
Dark-Green Vegetables (cup eq/wk)	540	Lettuce Leaf, USA	0.71	Venkat, K., Comparison of Twelve Organic and Conventional Farming Systems: A Life Cycle Greenhouse Gas Emissions Perspective. Journal of Sustainable Agriculture 2012, 36 (6), 620-649.
Red and Orange Vegetables (cup eq/wk)	2494	Orange, USA	3.20	Gonzalez, A. D., Frostell, B. and Carlsson-Kanyama, A., Protein efficiency per unit energy and per unit greenhouse gas emissions: Potential contribution of diet choices to climate change mitigation.
Beans, Peas, Lentils (cup eq/wk)	616.5	Dry Bean, USA	0.75	Blonk Consultants. Agri-Footprint 2.0. 2015 [cited 2015] Available from: http://www.agrifootprint.
Starchy Vegetables (cup eq/wk)	2100	Sweet Corn, USA	2.76	Swiss Center for Life Cycle Inventories, Ecoinvent Database version 3.3. 2016.
Other Vegetables (cup eq/wk)	2300	Tomato, USA	3.03	Jones, C. D., Fraisse, C. W. and Ozores-Hampton, M., Quantification of greenhouse gas emissions from open field-grown Florida tomato production. Agricultural Systems 2012, 113, 64-72.
Fruits (cup eq/day)	4340	Apple, USA	5.79	Venkat, K., Comparison of Twelve Organic and Conventional Farming Systems: A Life Cycle Greenhouse Gas Emissions Perspective. Journal of Sustainable Agriculture 2012, 36 (6), 620-649.
Grains (ounce eq/day)	3373.6	Wheat Grain, USA	4.16	Sanders, K. T. and Webber, M. E., A comparative analysis of the greenhouse gas emissions intensity of wheat and beef in the United States. Environmental Research Letters 2014, 9 (4), 044011.

Dairy (cup eq/day)	13608	Milk, USA	17.01	Thoma, G., Popp, J., Nutter, D., Shonnard, D., Ulrich, R., Matlock, M., Kim, D. S., Neiderman, Z., Kemper, N., East, C. and Adom, F., Greenhouse gas emissions from milk production and consumption in the United States: A cradle-to-grave life cycle assessment circa 2008. International Dairy Journal 2013, 31 (1), S3-S14.
Meats, Poultry, Eggs (ounce eq/wk)	1871.1	Chicken, USA, #31 Midwest	2.28	Pelletier, N., Ibarburu, M. and Xin, H., A carbon footprint analysis of egg production and processing supply chains in the Midwestern United States. Journal of Cleaner Production 2013, 54, 108-114.
Seafood (ounce eq/wk)	595.34	Fish, Alaska, #522	0.86	Fulton, S., Fish and Fuel: Life Cycle Greenhouse Gas Emissions Associated with Icelandic Cod, Alaskan Pollock, and Alaskan Pink Salmon Fillets Delivered to the United Kingdom. Master thesis, Dalhousie
Nuts, Seeds, Soy Products (ounce eq/wk)	340.19	soybean seed, USA #945	0.37	Blonk Consultants. Agri-Footprint 2.0. 2015 [cited 2015] Available from: http://www.agrifootprint.
Oils (grams/day)	511	soybean oil, USA, #948	0.62	Blonk Consultants. Agri-Footprint 2.0. 2015 [cited 2015] Available from: http://www.agrifootprint.

Table. 2 Food Weight Across all Supply Chain Stages on National Average Baseline

Data Parameter	Subtype	Agricultural Production Food Weight (kg)	Handling and Processing weight (kg)	Pre-distribution center weight (kg)	Pre-retail food weight (kg)	purchased weight (kg)	End consumption weight (kg)	Source
Food Input	Lettuce Leaf, USA	0.94	0.78	0.75	0.74	0.67	0.54	U.S. Department of Agriculture and U.S. Department of Health and Human Services. Dietary Guidelines for Americans, 2020-2025. 9th Edition. December 2020. Available at DietaryGuidelines.gov.
	Orange, USA	4.04	3.37	3.30	3.29	3.04	2.49	
	Dry Bean, USA	0.98	0.96	0.93	0.77	0.73	0.62	
	Sweet Corn, USA	3.65	3.04	2.92	2.86	2.60	2.10	
	Tomato, USA	3.99	3.33	3.20	3.14	2.85	2.30	
	Apple, USA	7.73	6.45	6.20	6.08	5.43	4.34	
	Wheat Grain, USA	4.45	4.36	4.28	4.26	4.01	3.37	
	Milk, USA	18.74	18.10	18.01	17.80	16.33	13.61	
	Chicken, USA	2.52	2.44	2.41	2.30	2.21	1.87	
	Fish, Alaska	1.00	0.90	0.89	0.84	0.78	0.60	

	soybean seed, USA	0.46	0.41	0.41	0.39	0.37	0.34	
	soybean oil, USA	0.85	0.76	0.76	0.72	0.60	0.51	
	Total Sum	**49.36**	**44.89**	**44.06**	**43.18**	**39.62**	**32.69**	

Table 3. Estimated and Assumed Food Loss and Waste Rate Across Supply Chain

Data Parameter	**Subtype**	**Agricultural Production Food Loss**	**Handling & Storage%**	**Transportation & Distribution Food Loss%**	**Retail Food Loss %**	**Consumer Food Loss and Waste%**	**Sources**
Food Input	Lettuce Leaf, USA	20%	4%	2%	10%	24%	[1]FAO. 2011. Global food losses and food waste – Extent, causes and prevention. Rome
	Orange, USA	20%	2%	1%	8%	22%	
	Dry Bean, USA	2%	0.04	0.2	6%	18%	[2] Buzby, Jean C., Hodan F. Wells, and Jeffrey Hyman. The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States, EIB-121, U.S. Department of Agriculture, Economic Research Service, February 2014.
	Sweet Corn, USA	20%	4%	2%	10%	24%	
	Tomato, USA	20%	4%	2%	10%	24%	
	Apple, USA	20%	4%	2%	12%	25%	
	Wheat Grain, USA	2%	2%	0.50%	6%	19%	

	Milk, USA	3.50%	0.50%	1.20%	9%	20%	
	Chicken, USA	3.50%	1%	5%	4%	18%	
	Fish, Alaska	12%	0.50%	6%	8%	31%	
	Soybean Seed, USA	12%	0%	5%	6%	9%	
	Soybean Oil, USA	12%	0%	5%	21%	17%	

Table. 4 Regional Distribution Center

Data Parameter		Subtype	Value Input	Unit	Source
Upstream Energy	Transportation	Vehicle Type	53' freight truck		
		Vehicle Fuel Economy	6.78	mpg	GREET 2021
			9.70	mpg	
		Route Distance	134.00	mile	
		Number of Stops	1.00		
		items delivered per stops	22500.00	pieces/stop	Harrison, A. Meijer Supply Chain Strategy and Services. Grand Rapids, MI. Personal 141 communication, July, 2021
		Total fuel cycle emissions factor (grams/CO_2e/mile)	7.81	g CO_2e per item	
		Total fuel cycle emissions factor (grams/ CO_2e /mile)	5.46	g CO_2e per item	

	Regional Distribution Center	Annual Electricity	60.00	kWh/sqft	ACEE 2002
		Store Size& Area	25600.00	sqft	ACEE 2002
		Total Annual Electricity	1536000.00	kWh	
		Store Size& Area	2378.00	m^2	
		Energy Consumption	645.92	kWh/ m^2	
		Electricity emission factor	0.54	kg CO_2/kWh of electricity	EIA 2021

Table.5 Store Feature

Data Parameter		Subtype	Value Input	Unit	Source	Note
Retail	Store Feature	Annual Electricity	50.00	kWh/sqft	Energy Star	
		Annual Natural Gas	50.00	cube feet/sqft	Energy Star	
		Store Size& Area	50000.00	sqft	Energy Star	
		Total Annual Electricity	2500000.00	kWh	Calculation from Energy Star	
		Total Annual Natural Gas	2500000.00	cube feet	Calculation from Energy Star	

Table. 6

Data Parameter		Subtype	Percentage	Value Input	Unit	Source
Retail	Electricity Breakdown	HVAC	0.15	375000.00	kWh	Industry Report 2012
		Lighting	0.23	575000.00	kWh	
		Refrigeration	0.57	1425000.00	kWh	
		Other (eg: cooking)	0.05	125000.00	kWh	

	Natural Gas Breakdown	Heating	0.69	1725000.00	cube feet	
		Cooking	0.22	550000.00	cube feet	
		other	0.09	225000.00	cube feet	

Table7. Retail Power Consumption Breakdown

Data Parameter		Subtype	Value Input	Unit	Source	Note
Retail Emission Factor	HVAC	Ventilation in electricity	375000.00	kWh	From calculation above	
		Space Conditioning in Gas	350000.00	kWh	EIA	
		Store Size& Area	4645.15	m^2	Energy Star	
		Ventilation energy consumption	80.73	kWh/ m^2	From calculation above	
		Space conditioning energy consumption	75.35	kWh/ m^2	From calculation above	
		Natural gas emission factor	0.41	kg CO2/kWh of gas	EIA 2021	
		Electricity emission factor	0.54	kg CO2/kWh of electricity	EIA 2021	
		ratio of cabinet display to sale area	4.00		Defra	
	Lighting	Lighting electricity	575000.00	kWh	From calculation above	
		Store Size& Area	4645.15	m^2	Energy Star	
		Lighting electrical energy use	123.79	kWh/ m^2	From calculation above	
		Electricity emission factor	0.54	kg CO2/kWh of electricity	EIA 2021	
		ratio of cabinet display to sale area	4.00		Defra	

	Walk-in Cooler	Walk-in cooler energy consumption	25.20	kWh/h	Defra	U.S Department of Energy 1996
		Walk-in freezer energy consumption	29.90	kWh/h	Defra	U.S Department of Energy 1996
		Walk-in cooler size	200.00	m^2	Defra	Area & size refer to walk-on cooler area, based on assumption
		Walk-in cooler energy consumption	0.13	kWh/ m^2-h	Defra	
		Walk-in freezer energy consumption	0.15	kWh/ m^2-h	Defra	
		GHG emission factor for electricity	0.54	kg CO_2/kWh		
	Cabinet Display	Cabinet Display for Packed Fresh Meat PVC2	13.40	kWh/ m^2-day		
		cabinet display 2		kWh/h		
		cabinet display 3...		kWh/h		

Table 8. Last Mile Transportation

Data Parameter		Subtype	Value Input	Unit	Source	Note
Last Mile	Fuel Economy	New Light-Duty Vehicles	25.70	MPG	EPA 2020	Gasoline

	Distance	Last Mile Travel	3.79	Miles	USDA 2015	FoodAPS National Household Food Acquisition and Purchase Survey in 2021
	Trip Chaining	Numbers of stops per trip	3.20	times/trip	NHTS 2017	
	Consumer Behavior	Shopping Frequency Per Week	2.50	times/week	Food Marketing Institute 2019	New Report released in 2022
	Calculation	Last mile GHG emission	2.05	Kg CO_2e/week		