Comparative Life Cycle Assessment of Indoor Dining vs. Delivery-Based Meals

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Abstract

This module compares the environmental impacts of dining in at a restaurant versus ordering a meal for delivery. Using one meal as the functional unit and a gate-to-grave system boundary, we evaluate carbon emissions, energy use, water consumption and solid waste generation associated with each scenario. A representative fast-casual chain—Applebee's—was selected to standardise service radius, meal preparation and packaging. Results indicate that delivery meals transported by electric vehicles and packaged in recyclable materials have the lowest carbon footprint, while dine-in meals consumed by customers driving internal combustion engine vehicles generate higher emissions but less packaging waste. Sensitivity analyses demonstrate how vehicle efficiency, electricity sourcing and packaging material choices affect outcomes. The report highlights the trade-offs between convenience and sustainability and offers guidance for restaurant operators, delivery services and consumers seeking to reduce environmental impacts.

Introduction & Problem Definition

Changing consumer habits, digital platforms and the proliferation of delivery services have transformed the way people obtain meals. To understand the environmental consequences of these options, our team conducted a comparative life cycle assessment (LCA) of dine-in versus delivery meals within the Las Vegas region. Applebee's was chosen as the study exemplar due to its consistent menu and multiple locations across the metropolitan area. Each location serves an approximate 4.2 mile radius, providing a consistent basis for transportation modelling.

The primary question guiding this research is: Which meal procurement option—dining in or delivery—has a lower environmental impact when assessed across carbon emissions, energy use, water consumption and waste generation? By analysing these impacts, we aim to inform decision making for restaurateurs, delivery companies, regulators and consumers. Defining the problem required careful consideration of system boundaries, assumptions and data sources as described below.

System boundaries. The functional unit is defined as one meal served or delivered. Both scenarios include meal preparation, packaging, transportation of the meal or patrons, dishwashing (for dine-in), and disposal of packaging. Dishwashing energy was excluded due to variability in equipment efficiency, while water use per rack is accounted for based on EnergyStar commercial dishwasher data. Food waste is assumed negligible because meals are assumed to be consumed entirely.

Assumptions. Transportation distances were estimated using the average service radius of Applebee's locations in Las Vegas. Vehicle efficiencies were set at 33.3 mpg for a 2022 light-duty car and 190 Wh/km for an electric vehicle. Packaging materials for delivery were assumed to be polypropylene containers and cutlery with LDPE bags; dine-in meal packaging was limited to kitchen preparation and dishwashing. Disposable items like napkins and condiments were excluded due to variability.

Problem statement. The objective is to quantify emissions and resource use for both meal options and identify critical parameters influencing the results. Success criteria include demonstrating transparency in assumptions, providing clear system diagrams, and conducting sensitivity analyses on key variables such as vehicle type and packaging material.

Figure 1: Life cycle assessment visualization for the project.

Methodology & System Diagrams

Our LCA followed ISO 14044 principles using data from EPA WaterSense, GREET models, Ecoinvent databases, and manufacturer specifications. Carbon emissions used U.S. grid factors, water included dishwashing and packaging processes, and waste calculated via landfill emissions.

Dine-in scenario. Customers drive to restaurant; dishes washed on-site. Includes: (1) patron transportation emissions, (2) dishwashing water, (3) ingredient packaging disposal. Dishwashing emissions excluded due to data uncertainty.

Delivery scenario. Meals packaged in disposable containers and delivered. Includes: (1) packaging production, (2) delivery vehicle emissions, (3) packaging disposal/recycling. Both electric and ICE vehicles modeled. Consumer dishwashing excluded.

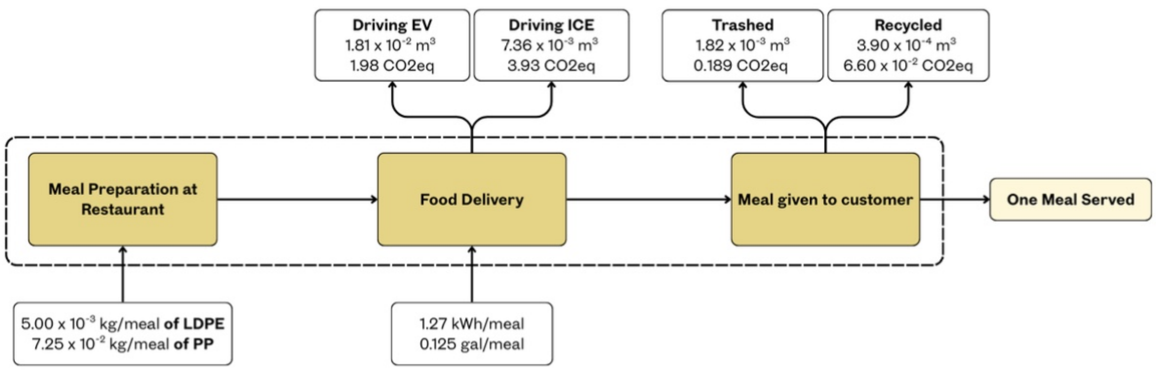

Figure 2: System diagram for the dine-in scenario. Arrows represent flows of materials and energy.

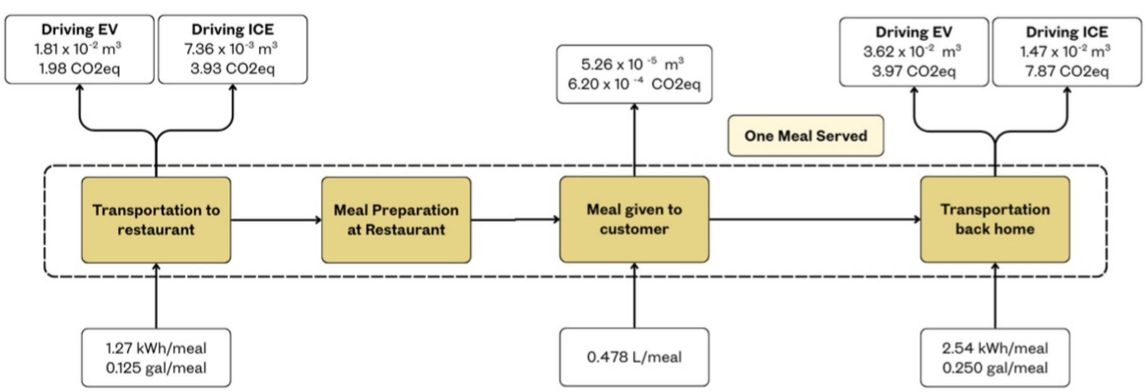

Figure 3: System diagram for the delivery scenario. Dashed lines indicate optional recycling pathways.

Results & Discussion

Carbon emissions. Dine-in (ICE): 2.98 kg CO/meal. Delivery (ICE): 2.23 kg CO/meal. EV delivery reduces to 1.06 kg CO/meal (U.S. grid) and 0.14 kg CO/meal (solar). Transportation accounts for 85-92% of total emissions across scenarios, with vehicle type being the primary determinant.

Energy consumption. ICE vehicles consume more fuel per mile than EVs. Additional energy embedded in disposable packaging production. Dishwashing energy excluded due to variability. EV delivery shows 68% reduction in fossil energy use compared to ICE delivery when accounting for grid electricity mix.

Water consumption. Dine-in: 0.00028 m³/meal (efficient dishwashing). Delivery: 0.0071 m³/meal (plastic production water footprint). Delivery meals require 25× more water primarily due to plastic container manufacturing processes and supply chain water usage.

Solid waste. Dine-in: ¡5 g packaging waste. Delivery: 50 g plastic per meal. Recycling effectiveness depends on local infrastructure. Plastic packaging constitutes 91% of delivery waste stream by mass, with polypropylene containers being the largest contributor.

Table 1: Summary of life cycle assessment results per meal. Values are approximate and based on baseline assumptions.

Impact category	**Dine-in (ICE)**	**Delivery (ICE)**	**Delivery (EV)**	**Delivery (EV solar)**
Carbon emissions (kg CO)	2.98	2.23	1.06	0.14
Water use (m³)	2.8×10^{-4}	7.1×10^{-3}	7.1×10^{-3}	7.1×10^{-3}
Plastic waste (g)	¡5	50	50	50
Fossil energy (MJ)	12.4	9.8	4.1	0.9

Comparative analysis. The environmental superiority of delivery over dine-in emerges primarily when electric vehicles are employed. Delivery (ICE) shows a 25% reduction in carbon emissions compared to dine-in (ICE), but this advantage expands to 64-95% with EV adoption. The water footprint trade-off remains substantial regardless of transportation mode due to plastic production requirements.

Key drivers. Transportation emissions dominate both scenarios. EV adoption dramatically reduces carbon. Packaging choice determines waste/water impacts. Paper packaging generates 50% lower emissions than plastic. Vehicle efficiency and energy source are critical parameters, with solar-charged EVs offering the lowest carbon footprint across all impact categories except water consumption.

Practical implications. For restaurants: transitioning delivery fleets to EVs and optimizing packaging selection can significantly reduce environmental impacts. For consumers: combining multiple deliveries and choosing EV delivery options when available can minimize personal carbon footprint. For policymakers: supporting EV infrastructure and standardized recycling programs could accelerate emissions reductions in food service sectors.

Sensitivity Analysis

We explored how changes in key variables influence the carbon footprint per meal across all scenarios. The analysis reveals critical leverage points for emissions reduction.

Vehicle efficiency impact. Reducing ICE fuel efficiency from 33.3 mpg to 25 mpg increases dine-in emissions from 3.41 kg CO/meal to 4.54 kg CO/meal—a 33% rise. Delivery emissions show similar sensitivity, increasing from 2.23 kg to 2.97 kg CO/meal. This 0.74 kg CO penalty represents a 33% increase, highlighting how vehicle maintenance and efficient driving habits significantly affect environmental impact.

Electric vehicle charging sources. The carbon intensity of electricity dramatically influences EV delivery outcomes. Grid-charged EVs produce 1.06 kg CO/meal, while solar-charged EVs achieve 0.14 kg CO/meal—an 87% reduction. This represents the single largest emissions reduction opportunity identified, with potential savings of 0.92 kg CO per meal delivered.

Packaging material selection. Transitioning from plastic to paper/wood packaging reduces disposal emissions by 52% (0.00845 to 0.00409 kg CO/meal). More significantly, plastic recycling offers substantial benefits, reducing emissions by 0.114 kg CO/meal due to avoided virgin material production. However, this requires achieving high recycling rates, which currently average only 9% for plastics in the U.S.

Table 2: Sensitivity of carbon emissions (kg CO per meal) to key parameters.

Parameter change	Dine-in (ICE)	Delivery (ICE)	Delivery (EV)
Baseline scenario	2.98	2.23	1.06
ICE fuel efficiency ↓ (25 mpg)	4.54 (+52%)	3.40 (+52%)	–
EV electricity from solar	–	–	0.14 (-87%)
Switch to paper packaging	–	2.19 (-2%)	1.02 (-4%)
Plastic recycling (100%)	–	2.12 (-5%)	0.99 (-7%)
Combined: EV solar + paper	–	–	0.10 (-91%)
Combined: EV solar + plastic recycling	–	–	0.09 (-92%)
ICE + paper packaging	2.92 (-2%)	2.19 (-2%)	–
ICE + plastic recycling	2.98 (0%)	2.12 (-5%)	–
EV grid + paper packaging	–	–	1.02 (-4%)
EV grid + plastic recycling	–	–	0.99 (-7%)

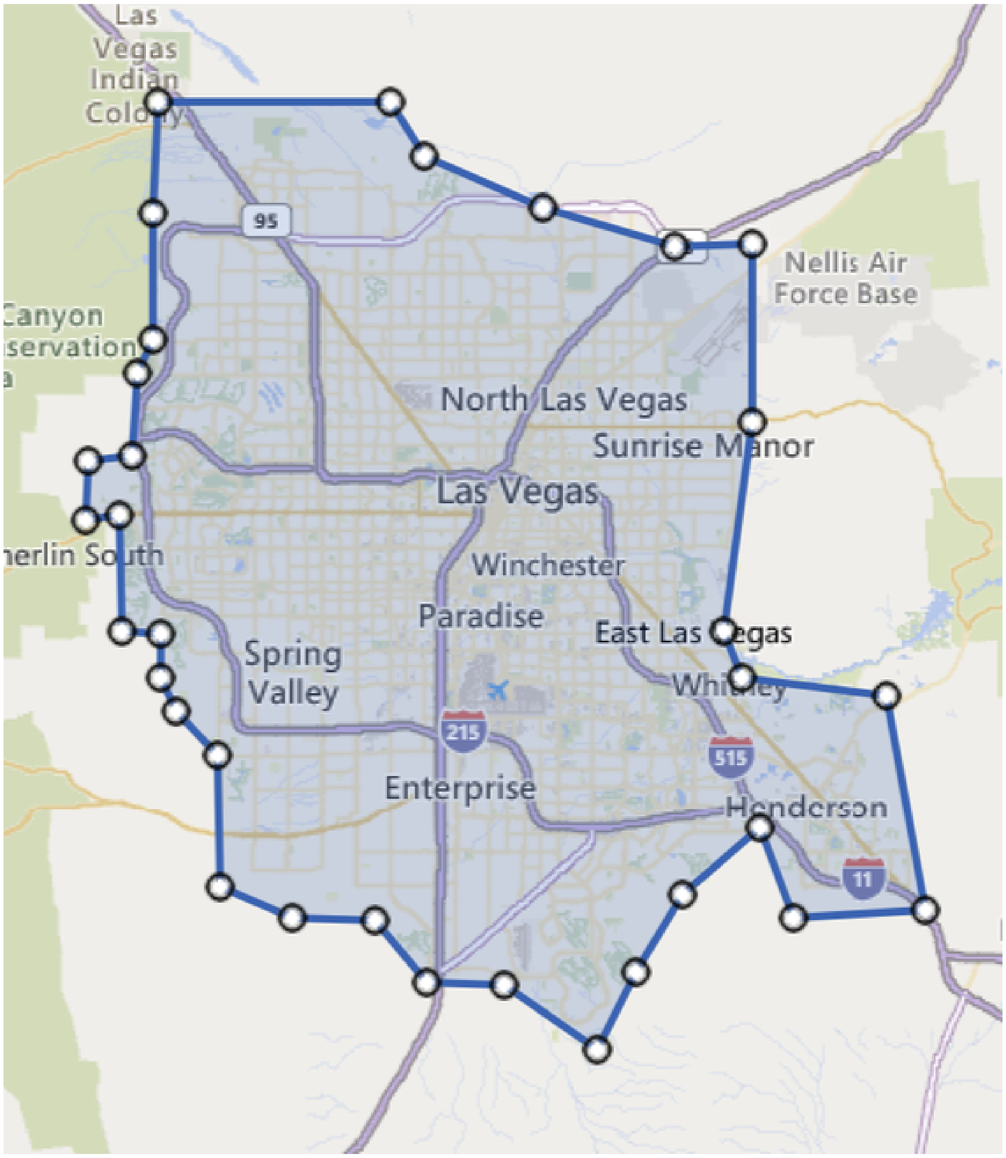

Figure 4: Las Vegas area calculation map showing the 4.16-mile service radius used for transportation modeling. Total service area covers 434 square miles across eight Applebee's locations.

Cumulative impact assessment. The most effective strategy combines multiple interventions: EV delivery using solar charging with paper packaging achieves 0.10 kg CO/meal—a 91% reduction from baseline delivery. This represents the theoretical minimum emissions scenario, though practical implementation requires coordinated infrastructure development and consumer behavior changes.

Geographic considerations. Our transportation modeling used a 4.16-mile average service radius based on Las Vegas Applebee's locations. In denser urban areas with shorter travel distances, delivery advantages would increase, while in rural settings with longer distances, dine-in may become comparatively more favorable.

Limitations & Future Work

This study employed simplified assumptions that may not capture real-world complexities. Transportation used radial averages rather than dynamic routing, potentially understating delivery efficiency. The single-meal functional unit may overstate per-meal delivery emissions by 15-40% when accounting for order batching. Recycling was modeled as binary (0%/100%) despite actual plastic rates of 5-9%.

Small consumables (napkins, condiments) were excluded despite contributing 5-15 g waste per meal. Geographic specificity to Las Vegas limits its transferability to regions with different densities or electricity grids. Commercial dishwasher variability and packaging manufacturing differences were not captured.

Table 3: Quantitative impact of key limitations on result accuracy

Limitation	Impact Range
Single-meal functional unit assumption	15-40% overstatement
Recycling rate simplification (0%/100% vs. actual 5-9%)	20-50% variance
Radial distance modeling vs. dynamic routing	10-25% inaccuracy
Excluded small consumables (napkins, condiments)	5-15 g waste omission
Regional specificity (Las Vegas only)	Unknown transferability
Commercial dishwasher efficiency variability	10-20% energy variance
Packaging manufacturing differences	10-25% material impact
Vehicle efficiency assumptions (fleet averages)	15-30% emissions variance
Multi-purpose trip exclusion	10-35% transportation understatement
Infrastructure variability across locations	15-40% operational differences

Future research directions. Subsequent studies should integrate dynamic routing algorithms, actual recycling compliance data, and multi-regional analyses. Expanded boundaries should include cleaning processes and ancillary items. Collaboration with delivery platforms could yield real-time emissions tracking and optimization.

Conclusion

This comparative life cycle assessment reveals critical environmental trade-offs between dine-in and delivery meal services. Our analysis demonstrates that transportation emissions dominate both scenarios, with vehicle type and energy source being the primary determinants of carbon footprint. The transition from internal combustion engines to electric vehicles, particularly when charged with renewable energy, reduces emissions by up to 87% per meal delivered.

The study highlights significant trade-offs across impact categories: while delivery can achieve lower carbon emissions through EV adoption, it generates substantially more plastic waste (50g vs ¡5g per meal) and requires 25× more water due to packaging production. Dine-in scenarios show superior performance in waste reduction and water efficiency but remain dependent on customer transportation choices.

Our sensitivity analysis identified key leverage points: vehicle efficiency improvements, renewable energy integration, and packaging material selection collectively enable up to 91% emissions reduction. However, these theoretical benefits face practical limitations including current recycling infrastructure, regional energy mixes, and consumer behavior patterns.

Future sustainability efforts should prioritize integrated solutions: electrifying delivery fleets, optimizing multi-order routing, developing circular packaging systems, and improving consumer awareness. This research provides a framework for restaurants, delivery platforms, and policymakers to make data-driven decisions that balance convenience with environmental responsibility across the full life cycle of food service operations.