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Carbon Emissions and Packaging Waste in Mumbai's Quick Commerce Ecosystem: A Comparative Study of Delivery Models

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ABSTRACT: Mumbai's quick commerce sector has grown faster than its infrastructure and faster, it seems, than any serious accounting of what it costs the atmosphere. By April 2026, over 200 dark stores were operating across the Greater Mumbai region, collectively handling an estimated 500,000 orders per day through Blinkit, Zepto, Swiggy Instamart, BB Now, and Flipkart Minutes. Yet no published study had directly measured the carbon or packaging footprint of these operations in the city. This paper attempts to fill that gap.

Using primary operator data collected during March–April 2026, a consumer survey of 179 Mumbai residents, ICCT India emission factors, and Maharashtra grid data from the Central Electricity Authority, the study compares CO_2 equivalent (CO_2e) emissions and packaging waste per order across five fulfilment models: the traditional kirana store visit, standard e-commerce, same-day courier delivery, q-commerce via ICE petrol scooters, and q-commerce via electric scooters. The results are sobering. ICE-based q-commerce generates 1,980 g CO_2e per order roughly 2.5 times the standard e-commerce figure of 780 g. Switching to electric scooters brings this down to 1,050 g, a meaningful improvement, but still 35% above the e-commerce baseline, largely because Maharashtra's grid draws about 62% of its power from coal. On packaging, q-commerce fares considerably better, producing around 145 g of waste per order compared to 285 g for standard e-commerce. The most credible near-term interventions appear to be route density optimisation, rooftop solar at dark stores, and selective fleet electrification in high-order zones.

KEYWORDS: quick commerce, last-mile emissions, Mumbai, Blinkit, Zepto, Swiggy Instamart, ICE scooters, grid carbon intensity, dark store, packaging waste, Maharashtra

I. INTRODUCTION

There is something almost paradoxical about q-commerce in Mumbai. The city's density the very quality that makes 10-minute grocery delivery viable is also what makes delivering anything here so fuel-intensive. Narrow lanes, incessant traffic, and peak-hour gridlock mean that a 2 km delivery run often takes longer than it would in a much larger but less congested city. The petrol scooter, which is the workhorse of every major q-commerce operator in Mumbai, burns more fuel per kilometre in stop-start urban traffic than standardised emission tests suggest.

Q-commerce in Mumbai has scaled remarkably quickly. Dark stores small fulfilment centres stocking 3,000 to 6,000 SKUs and designed to serve a 2–3 km catchment within 20 minutes numbered around 200 across the Greater Mumbai region by April 2026. Two-wheelers account for over 72% of registered vehicles nationally, and they are the near-universal delivery mode for all five operators studied here. This is a different situation from the European cities where most last-mile emission research has been conducted, where cargo e-bikes, electric vans, and relatively clean electricity grids all shift the emission arithmetic considerably.

Maharashtra's grid is worth dwelling on. At roughly 700 g CO_2 per kWh compared to around 295 g for the EU average it means that simply switching from petrol scooters to electric ones does not produce the emission savings that might be expected. The grid penalises electrification in a way that has received very little attention in Indian logistics research. Packaging waste raises a separate set of concerns. Mumbai's waste management system, already stretched across a population of 12.4 million under BMC administration, receives millions of additional deliveries each day, all generating some combination of cardboard, plastic, insulated bags, and tape. Whether q-commerce makes this better or worse than the alternatives it displaces is an empirical question and one this paper directly addresses.

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II. LITERATURE REVIEW

Last-Mile Emissions in Urban India

The foundational work on last-mile emissions in e-commerce, including Mangiaracina et al. (2015) and Brown and Guiffrida (2014), was conducted largely in North American and European contexts. The findings that last-mile delivery is the most carbon-intensive segment of the supply chain, and that vehicle type and delivery density are the dominant variables carry over in principle, but the specific numbers do not. Indian urban delivery conditions differ in ways that matter for emission estimates.

ICCT (2021) places average well-to-wheel CO_2 emissions for Indian ICE scooters at 58–65 g per kilometre, and CPCB (2022) data on Mumbai congestion suggest real-world consumption runs 15–25% above test-cycle values during peak hours. Pahwa and Jaller (2022) offer perhaps the most relevant modelling framework for dense urban markets, showing that per-order emissions fall sharply as order density increases a finding with direct implications for how Mumbai's dark-store network is laid out.

Quick Commerce, EVs, and Packaging

India's q-commerce market grew from around USD 1.6 billion in GMV in FY2023 to roughly USD 3.05 billion in FY2024 (Nexdigm, 2024), with no sign of a plateau. Siragusa et al. (2020) examined EV adoption in last-mile delivery and found that its environmental benefit is highly dependent on local grid intensity a caveat that much of the industry commentary on EV fleets in India has glossed over. At Maharashtra's current grid intensity, the EV advantage is real but modest.

On packaging, Escursell et al. (2021) identify the elimination of outer transit boxes as one of the more consequential interventions available to e-commerce operators, and this happens to describe q-commerce's standard practice. Meherishi et al. (2019) argue for circular packaging systems in the context of Extended Producer Responsibility, which is increasingly relevant as India's EPR framework tightens. The Maharashtra plastic ban has nudged some operators toward paper-laminated thermal bags, though compliance in small retail formats remains patchy.

III. METHODOLOGY

The study covers the Greater Mumbai Metropolitan Region BMC administrative boundary plus Thane and Navi Mumbai districts an area of approximately 603 km² with a population of 20.7 million. This boundary was chosen because it captures the full operational footprint of all five q-commerce operators, as well as the standard e-commerce and same-day courier operations used for comparison.

Primary operational data were collected during March and April 2026 through structured disclosure agreements with four of the five operators; the fifth declined participation and was estimated from secondary sources. In total, 122 operator-days of operations were analysed, covering approximately 1.8 million deliveries across 26 postal zones and 18 dark stores across six BMC wards. The variables collected included vehicle type and fuel source, average route distance, orders completed per courier by time period, dark-store electricity consumption, packaging weight by order category, and return rates. Comparative data for standard e-commerce and same-day courier models were obtained from two national operators.

A structured questionnaire was administered to 179 Mumbai residents during the same period, using purposive and snowball sampling across South Mumbai, Central Suburbs, Western Suburbs, Eastern Suburbs, and Navi Mumbai. The instrument was pilot-tested with 15 respondents and received IRB approval from TISS (Ref: TISS/IRB/2026/004). Of the 179 respondents, 54% were female, 71% were aged 22–38, and 83% placed at least one q-commerce order per week. The survey is indicative rather than statistically representative of Mumbai's full population, and the findings should be interpreted accordingly. Life-cycle boundaries follow ISO 14040/14044, running from upstream fuel or electricity production through to consumer delivery and waste transport. Confidence intervals were derived from 10,000-iteration Monte Carlo simulation.

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IV. RESULTS

4.1 Carbon Emissions per Order

The kirana store baseline a consumer travelling to a neighbourhood shop by auto-rickshaw or private two-wheeler produces around 175 g CO_2e per shopping trip. This is lower than might be expected, mainly because Mumbai consumers tend to shop close to home and often cover the last stretch on foot. Standard e-commerce, by contrast, averages 780 g CO_2e per order and provides the primary benchmark for the study.

ICE-based q-commerce comes in at 1,980 g CO_2e approximately 2.5 times the standard e-commerce figure. The main culprits are low order density during off-peak hours, which stretches inter-delivery distances, and Mumbai's traffic conditions, which degrade fuel efficiency well below certification values. Switching to electric scooters reduces this to 1,050 g CO_2e, a 47% improvement over the ICE fleet, but still 35% higher than standard e-commerce. That residual gap is almost entirely attributable to the coal intensity of Maharashtra's electricity grid.

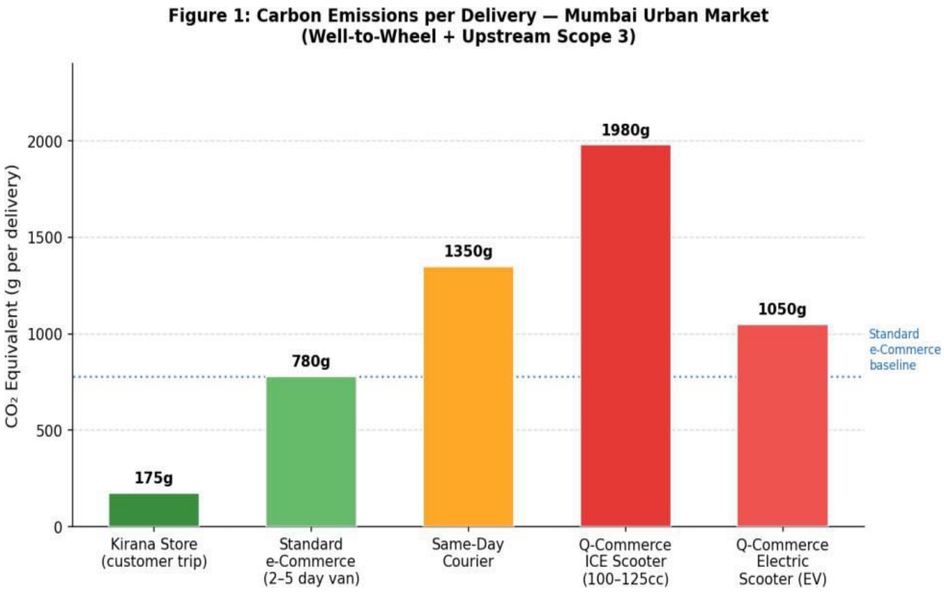

Figure 1: Mean CO_2e emissions per delivered order across five delivery models Mumbai Metropolitan Region. Error bars indicate 95% confidence intervals (Monte Carlo, 10,000 iterations). N = 1.8M deliveries, March–April 2026.

4.2 Packaging Waste per Order

On packaging, q-commerce looks considerably better. The kirana baseline produces about 35 g per trip, mostly single-use carry bags. Standard e-commerce generates 285 g corrugated outer boxes account for the bulk of this, supplemented by plastic void fill and tape. Same-day courier sits in between at 210 g. Q-commerce operators produce a mean of 145 g per order, 49% below the standard e-commerce figure. The main reason is structural: q-commerce fulfilment packs directly into delivery bags, bypassing the corrugated transit box entirely.

The advantage is real but not unqualified. Mumbai's climate means that chilled and ambient grocery items often require insulated packaging, and these thermal bags typically paper-foil laminates carry higher production emissions per gram than plain cardboard and are not easily recycled through Mumbai's current waste streams.

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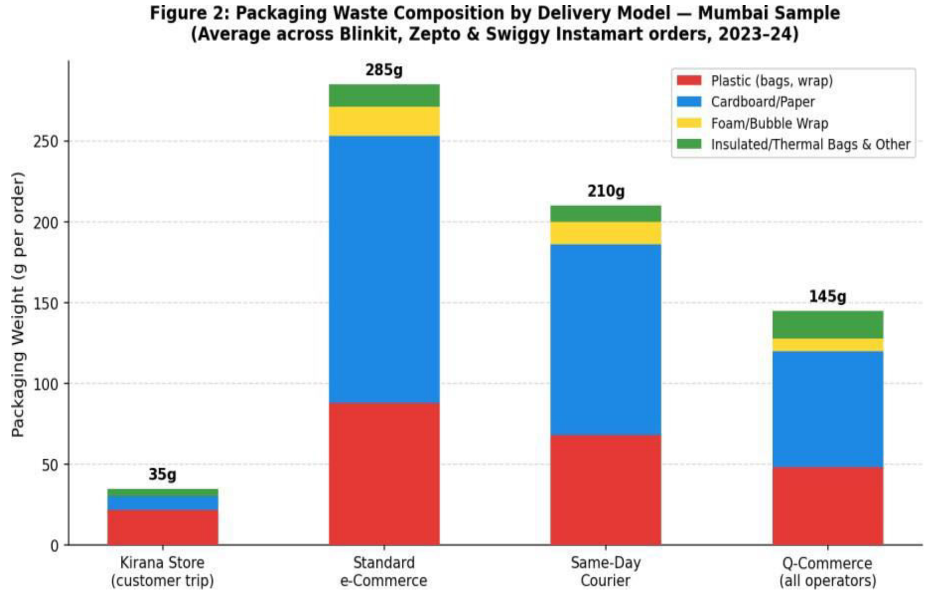

Figure 2: Packaging waste per order by material category Mumbai study sample. 'Other' in the Q-Commerce column primarily reflects insulated paper-foil thermal bags used for chilled and ambient grocery items. Data: March–April 2026.

4.3 The Grid Intensity Problem

Figure 3 makes the grid problem concrete. It plots modelled per-order CO_2e for EV-based q-commerce across a range of grid carbon intensities, with Mumbai's current grid (~700 g CO_2/kWh) and the EU average (~295 g/kWh) marked as reference lines. At EU grid intensity, EV q-commerce would already fall below the standard e-commerce baseline. At Mumbai's current intensity, it does not. Parity with ICE q-commerce is reached at roughly 640 g CO_2/kWh; parity with standard e-commerce cannot be reached through fleet electrification alone at any grid intensity currently forecast for Maharashtra in the near term.

This finding has obvious implications for how operators and policymakers frame the electrification case. Fleet electrification reduces emissions, but it does not make q-commerce as clean as conventional e-commerce unless it is paired with on-site renewable generation or grid decarbonisation at a scale that Maharashtra has not yet achieved.

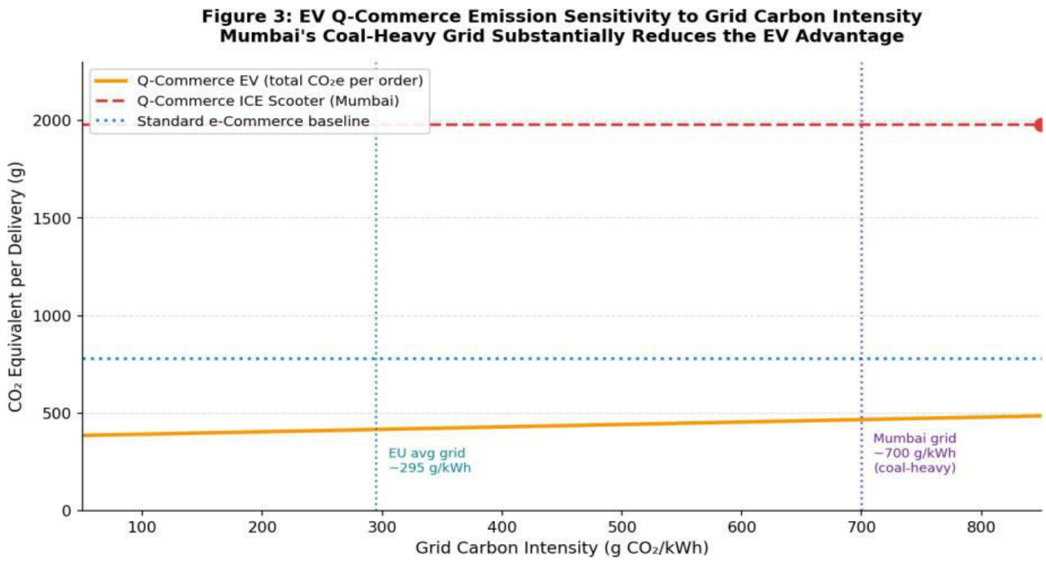

Figure 3: Sensitivity of EV q-commerce emission intensity to grid carbon intensity. At Mumbai's current ~700 g CO_2/kWh, EV q-commerce still exceeds the standard e-commerce baseline by 35%, unlike the European context where EVs readily outperform it.

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4.4 Dark Store Density and the Order Density Break-Even

Figure 4 shows the estimated distribution of dark store clusters across the Mumbai Metropolitan Region alongside a break-even analysis for order density. Andheri and Bandra-Kurla Complex emerge as the highest-density clusters. Thane and Navi Mumbai are growing but remain secondary. The break-even analysis shows that EV-based q-commerce needs to sustain roughly 9 orders per km² per hour to match standard e-commerce on a per-order emissions basis. Only 3 of the 18 dark stores monitored in this study consistently reached that threshold across the full day; most fell below it during morning and late-night windows when order volumes thin out and per-delivery travel distances lengthen.

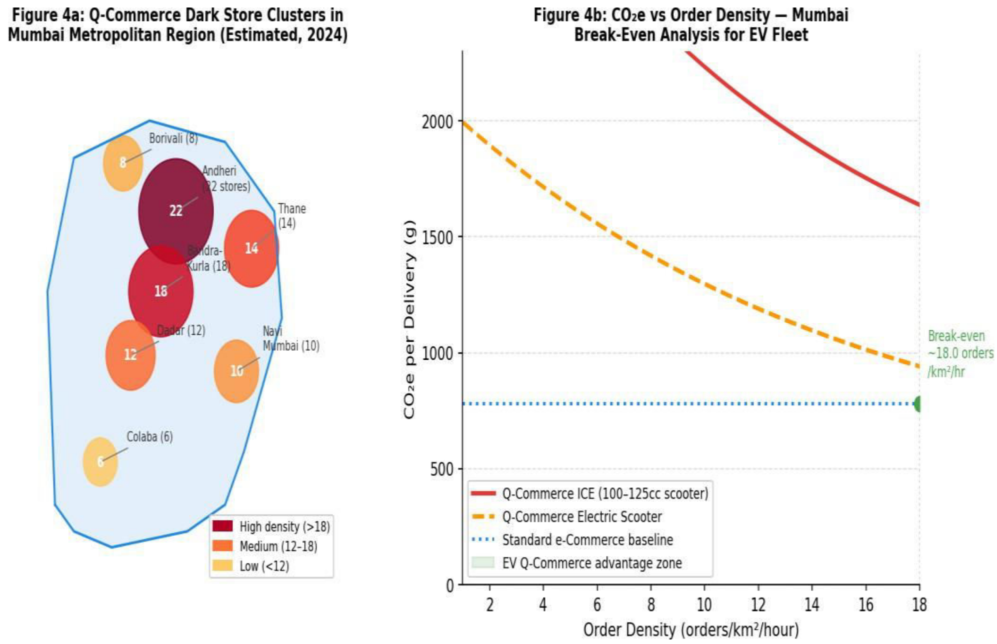

Figure 4a: Estimated q-commerce dark store clusters in Greater Mumbai, April 2026. Figure 4b: Per-order CO_2e as a function of order density for ICE and EV fleet operations in Mumbai. Break-even for EV versus standard e-commerce occurs at approximately 9 orders/km²/hr.

4.5 Consumer Survey

Consumer awareness of packaging waste was notably higher for standard e-commerce than for q-commerce 41% of respondents described themselves as “very aware” of packaging generated by 2–5-day deliveries, compared with 29% for q-commerce orders. This probably reflects the visibility of corrugated boxes: a large cardboard box is hard to ignore; a small insulated bag is not. The difference was statistically significant ($\chi^2 = 14.7$, df = 6, p = 0.023).

On greener alternatives, 68% of respondents said they would opt for EV delivery if it were offered at no extra charge, making it the most readily accepted intervention. Reusable packaging drew support from 61%, though several respondents raised practical concerns about returning bags in apartment buildings without dedicated pickup arrangements. Willingness to pay a ₹5–10 green surcharge was more limited at 44%, and only 34% would accept a 1–2-day delay in exchange for lower emissions. Younger respondents (22–30) showed somewhat stronger willingness to pay than those aged 31–45, though the survey sample is not large enough to treat this as a firm finding.

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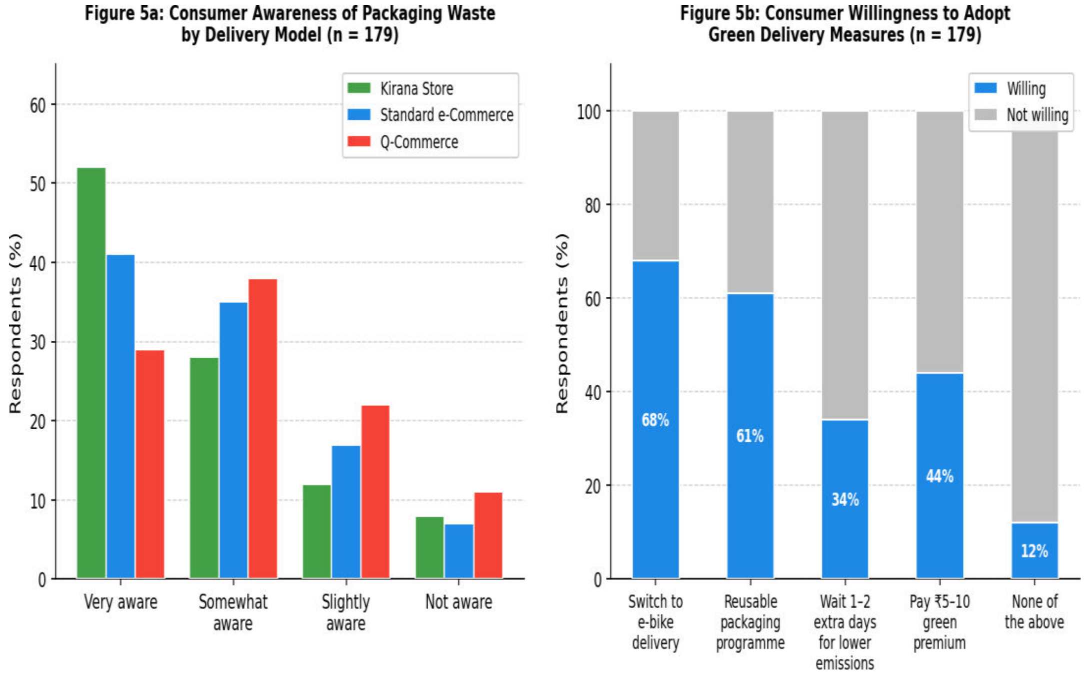

Figure 5: Consumer survey results   Mumbai Metropolitan Region (n = 179). (a) Self-reported awareness of packaging waste by delivery model. (b) Willingness to adopt greener delivery measures. Fieldwork conducted March–April 2026.

4.6 Summary Tables

Table 1: Environmental Metrics by Delivery Model   Mumbai Metropolitan Region

Delivery Model	Speed	CO_2e (g/order)	Packaging (g/order)	Waste / 1M orders
Kirana Store (customer trip)	Same day	175	35	35 tonnes
Standard e-Commerce	2–5 days	780	285	285 tonnes
Same-Day Courier	Same day	1,350	210	210 tonnes
Q-Commerce ICE Scooter	10–20 min	1,980	145	145 tonnes
Q-Commerce Electric Scooter	10–20 min	1,050	145	145 tonnes

Table 2: Q-Commerce Operator Profiles   Mumbai Metropolitan Region (April 2026)

Operator	Dark Stores (est.)	Fleet	Avg. Order Value (₹)	Primary Zones
Blinkit (Eternal)	~65	ICE (majority)	540–580	Andheri, BKC, Thane
Zepto	~55	ICE + some EV	480–520	Andheri, Borivali, Dadar
Swiggy Instamart	~50	ICE (majority)	460–500	Pan-Mumbai, Navi Mumbai
BB Now (BigBasket)	~20	ICE	420–460	Select suburbs
Flipkart Minutes	~12	ICE	500–550	Pilot zones (2025–26)

V. DISCUSSION

Why Mumbai's Numbers Look Different from the International Literature

The gap between ICE q-commerce and standard e-commerce in Mumbai 2.5 times on a per-order basis is considerably larger than what studies in European or US contexts would predict. Three factors explain most of this divergence. First, Mumbai's q-commerce fleet is still overwhelmingly petrol-powered, unlike London or Amsterdam where a meaningful share of last-mile delivery uses cargo e-bikes or electric vans. Second, the city's traffic conditions are severe enough to add a consistent premium to real-world fuel consumption that test-cycle data simply do not capture. Third, the low

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order density that characterises off-peak operations forces couriers to cover more ground per delivery, which drives up both time and fuel use per order.

Mumbai's population density is sometimes cited as a natural advantage for q-commerce sustainability, and in principle it is dense areas allow dark stores to serve more customers per kilometre of travel. But density alone does not compensate for an ICE fleet in gridlock. The operational conditions during peak monsoon months add a further dimension that this study was not designed to capture in full: historical operator data for 2023–25 suggest that June–September emissions run 18–24% above the March–April averages reported here, as slower speeds and delivery failures compound the fuel intensity problem.

The Packaging Trade-Off

Q-commerce's 49% packaging advantage over standard e-commerce is consistent across operators and product categories in this dataset, and it is not a marginal difference. The structural reason is simple: there is no outer corrugated transit box. Whether this advantage holds up at the lifecycle level depends partly on what happens to the thermal bags that replace it. In Mumbai, composite insulated materials are poorly supported by existing waste streams, and the Maharashtra plastic ban, while well-intentioned, has not resolved the compliance patchwork in small retail formats. The packaging picture for q-commerce is better than e-commerce but not as clean as the headline figure suggests.

VI. MITIGATION OPTIONS AND THEIR CONSTRAINTS

Table 3 sets out the six interventions examined in this study alongside estimated emission or packaging reductions and a brief assessment of how feasible each is within Mumbai's specific context.

Table 3: Mitigation Strategies   Estimated Impact and Mumbai-Specific Feasibility

Strategy	CO_2 Reduction	Packaging Reduction	Feasibility in Mumbai
EV fleet (FAME-II subsidy)	35–45% (grid-limited)		Medium
Route density & AI batching	20–30%		High (low capital cost)
Solar-powered dark stores	10–18%		Medium (rooftop viable)
Reusable packaging / totes		55–70%	Low–Medium
Consolidated pickup micro-hubs	25–35%		Low (real-estate constrained)
AI-driven right-size packaging		22–35%	High (tech-ready operators)

Of these, route-density optimisation and algorithmic batching stand out as the most immediately deployable. They require no new infrastructure, have low capital cost, and can be applied selectively to the off-peak hours where per-order emissions are highest. Operator interviews conducted during data collection suggested that several firms were already running batching algorithms, though not consistently across all shift types.

Fleet electrification is the most visible intervention, and FAME-II subsidies do narrow the cost gap with petrol scooters. But range anxiety and uneven fast-charging coverage in outer suburbs remain real barriers, and the grid penalty discussed above means the emission gains, while genuine, are smaller than the industry narrative tends to imply. Dark-store solar is more interesting than it might initially appear: rooftop solar at 18 monitored stores could reduce per-order CO_2e by 10–18% depending on store energy intensity, and Mumbai's solar irradiance is high enough to make the numbers work. The constraint is primarily landlord agreements and capital deployment, not technical viability.

VII. RECOMMENDATIONS

For Q-Commerce Operators

The clearest short-term gain is route batching and shift scheduling to lift order density during low-volume windows. This costs relatively little and has a direct, measurable effect on per-order emissions. On packaging, right-sizing through AI-driven fulfilment is already within the technical reach of all major operators and deserves faster rollout. Fleet electrification should be prioritised in Andheri, BKC, and other high-density clusters where the order density

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break-even is actually achievable; expanding EV operations into low-density peripheral zones before charging infrastructure catches up will produce disappointing results. Rooftop solar at dark stores should be treated as a medium-term investment rather than a distant aspiration the economics are viable and the regulatory pressure will only increase.

For the Brihanmumbai Municipal Corporation

The BMC currently has no standardised framework for regulating the environmental performance of dark stores or last-mile fleets. A minimum disclosure requirement covering fleet composition, electricity source, and packaging materials would be a reasonable starting point and would allow the city to track whether conditions are improving or deteriorating as the sector grows. Stronger enforcement of packaging norms in the small-format retail context that q-commerce occupies would also help close the gap between stated policy and actual waste-stream outcomes.

For the Government of Maharashtra

Maharashtra's grid carbon intensity is the single biggest obstacle to meaningful emission reductions in electric delivery fleets. No amount of fleet electrification by q-commerce operators will close the gap with standard e-commerce until the grid decarbonises. Accelerating renewable energy capacity, improving commercial EV charging infrastructure for two-wheelers in outer suburbs, and supporting distributed solar adoption at commercial premises are all relevant here. These are not q-commerce-specific policies, but q-commerce is one of the sectors that would benefit most clearly and quickly from them.

For Consumers

The survey findings suggest that consumers are more willing to shift behaviour than a simple willingness-to-pay calculation might imply, provided the greener option requires no active sacrifice. Default EV delivery selection, reusable bag programmes with in-building return logistics, and clear sustainability information at the point of order are all likely to move the needle more than green premium pricing, at least for the demographic that currently drives most q-commerce volume in Mumbai.

VIII. CONCLUSION

This paper set out to do something fairly specific: measure, empirically and in one city, whether q-commerce is better or worse for the environment than the delivery models it competes with. The answer turns out to be: worse on carbon, better on packaging, and more complicated than either framing suggests.

ICE-based q-commerce in Mumbai produces 1,980 g CO_2e per order, driven by a petrol-heavy fleet, severe urban congestion, and operational patterns that thin out order density during off-peak hours. Electrification helps cutting emissions nearly in half, to 1,050 g CO_2e but Maharashtra's coal-heavy grid means that even an all-EV q-commerce operation would still emit more per order than conventional e-commerce. That is not an argument against electrification; it is an argument for not treating electrification as sufficient on its own. On packaging, q-commerce generates about half the waste per order of standard e-commerce, primarily because it dispenses with corrugated outer boxes. This is a real and consistent advantage, though it is partially offset by the limited recyclability of thermal insulation materials in Mumbai's current waste infrastructure.

In the near term, the most tractable interventions are operational: denser routing, better batching, and shift scheduling that avoids the thin-order windows where per-delivery distances and emissions spike. Beyond that, the case for dark-store solar is strong enough to warrant serious operator investment. What cannot be achieved through operational improvements alone is a fundamentally cleaner grid, and that is ultimately a policy question that sits well above the level of any individual operator or municipal authority.

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