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Consumer Responses to Carbon-Aware Delivery Options

Dr. Daniel Cooper

Professor, Macquarie University, Australia

Abstract

The environmental implications of online retail increasingly depend not only on what consumers purchase but also on how orders are fulfilled and delivered. Checkout interfaces traditionally emphasize delivery speed, price, and convenience while providing limited information about the environmental consequences associated with alternative fulfillment arrangements. Carbon-aware delivery options attempt to address this information gap by communicating estimated emissions, identifying comparatively lower-carbon alternatives, enabling shipment consolidation, or allowing customers to accept longer delivery windows when operational flexibility may support more efficient logistics. This study examines consumer responses to such options through a simulation-based analytical framework. A synthetic sample of 480 observations was distributed equally across four hypothetical checkout conditions: speed-focused delivery without carbon information, a basic carbon label, comparative carbon-impact information, and carbon information combined with a consolidated lower-impact delivery option. Sustainable delivery choice intention represents the primary outcome, while environmental decision confidence, perceived sacrifice, information trust, and checkout satisfaction are examined as associated constructs.

Simulated sustainable delivery choice intention increases from 2.62 in the speed-focused condition to 4.12 when emissions information is combined with a consolidated delivery alternative. The analysis also indicates that transparent comparative information may improve environmental decision confidence while excessive time or price sacrifices could constrain adoption. The study argues that effective carbon-aware delivery design should make environmental consequences understandable without implying that slower delivery is automatically environmentally superior in every logistics context. All numerical findings are synthetic and are presented for methodological demonstration rather than as evidence collected from actual consumers.

***Keywords*:** carbon-aware delivery; sustainable delivery; consumer behavior; e-commerce; last-mile logistics; carbon information; sustainable consumption

1. Introduction

Electronic commerce has increased consumers' ability to purchase goods without traveling to conventional stores, but the environmental consequences of online retail remain highly dependent on fulfillment configuration, transportation efficiency, delivery density, failed delivery rates, packaging, returns, consumer travel, and the characteristics of the underlying logistics network. Comparative

carbon-footprint research has demonstrated that no simple assumption that online or physical retail is always environmentally superior is defensible because outcomes vary substantially according to fulfillment and consumer behavior. Shahmohammadi and colleagues, for example, showed that retail-channel greenhouse-gas comparisons are sensitive to the specific configuration of the shopping and delivery system.

The last mile represents a particularly visible component of this system because consumers directly select or experience delivery speed, location, and convenience. Conventional checkout pages often frame these decisions primarily through service attributes such as same-day, next-day, standard, free, home, or pickup delivery. Yet operational research has identified a wide range of last-mile configurations, including home delivery, collection points, parcel lockers, alternative routing arrangements, and other models with different cost, service, and environmental implications. The environmental consequence of a specific delivery option therefore depends on actual logistics conditions rather than on a simple label such as “standard” or “express.”

Carbon-aware delivery extends consumer choice by making environmental consequences part of the checkout decision. Instead of presenting delivery alternatives only through price and arrival date, retailers may communicate estimated carbon emissions, relative emission reductions, shipment-consolidation opportunities, alternative reception locations, or longer delivery windows. Evidence available by 2020 already indicated that consumers' preferred last-mile choices can change when environmental and social sustainability information is explicitly provided. Ignat and Chankov found that displaying sustainability impacts made e-commerce customers generally more likely to select a more sustainable last-mile option, while also acknowledging the familiar limitation that stated intentions may differ from real behavior.

However, carbon-aware delivery introduces several behavioral and informational complications. Consumers may value environmental protection but simultaneously prioritize urgency, convenience, price, reliability, or delivery certainty. A lower-carbon option may therefore be acceptable for a routine household item but unattractive when a purchase is urgently required. Moreover, carbon estimates can appear technically authoritative despite depending on assumptions concerning route density, vehicle technology, warehouse location, packaging, consolidation, failed delivery probability, and consumer travel. Sustainable checkout design should consequently avoid presenting carbon values as more precise or universally comparable than the underlying calculation permits. Comparative footprint research emphasizes precisely this context dependence.

2. Objectives of the Study

2.1 Evaluating Consumer Response to Carbon Information

The primary objective is to examine whether sustainable delivery choice intention differs according to the way carbon information is presented at checkout. Four informational environments are distinguished: no carbon information, a basic carbon label, comparative carbon-impact information, and comparative information accompanied by a consolidated lower-impact delivery option. This progression enables investigation of whether environmental information becomes more behaviorally useful when consumers can connect it directly with a concrete delivery decision.

The objective does not assume that consumers will always select the option with the lowest estimated carbon impact. Delivery decisions involve competing considerations, including urgency, reliability, convenience, and cost. The study instead assesses whether carbon information becomes sufficiently salient and understandable to enter the consumer's decision process alongside these conventional attributes.

2.2 Examining Environmental Confidence and Perceived Sacrifice

The second objective is to assess how carbon-aware options may influence environmental decision confidence and perceived sacrifice. Environmental confidence concerns whether consumers believe they possess enough credible information to distinguish relatively lower-impact delivery options. Perceived sacrifice captures the extent to which sustainable selection appears to require unacceptable additional waiting, inconvenience, cost, or uncertainty.

This distinction is theoretically important because a consumer may understand that one delivery option is environmentally preferable while still rejecting it because the personal sacrifice is considered excessive. Sustainable delivery adoption therefore depends not only on awareness but on the perceived balance between environmental benefit and service consequences.

2.3 Assessing Trust and Checkout Experience

The third objective is to evaluate whether credible carbon information can strengthen trust in the delivery-choice process without reducing checkout satisfaction. Consumers may respond positively when environmental information appears specific, comparable, and relevant, but vague claims such as “eco-friendly shipping” may generate uncertainty if the basis of the claim is unclear.

The study accordingly treats transparency as central to responsible carbon-aware delivery. Retailers should communicate what a carbon comparison represents, avoid unsupported environmental superiority claims, and distinguish estimated impacts from guaranteed reductions. Such transparency may allow sustainability information to enhance rather than complicate consumer choice.

3. Review of Literature

3.1 Sustainable Consumption and Environmental Choice

Consumer sustainability research consistently demonstrates that positive environmental attitudes do not automatically translate into purchasing behavior. Peattie emphasized that green consumption involves contextual and behavioral complexities that make simplistic attitude-to-action models inadequate. Vermeir and Verbeke similarly documented the gap between favorable attitudes toward sustainable products and actual purchase intentions, emphasizing availability, perceived consumer effectiveness, involvement, and social factors.

Ajzen's theory of planned behavior offers a useful explanation for this gap. Behavioral intention depends not only on attitude but also on subjective norms and perceived behavioral control. Carbon-aware delivery information can potentially influence attitudes by making environmental consequences visible while also increasing perceived control by showing that the consumer can make a delivery-related environmental choice within the transaction itself.

White, Habib, and Hardisty's SHIFT framework further suggests that sustainable behavior becomes more likely when interventions draw on social influence, habit formation, individual identity, feelings and cognition, and tangibility. Carbon information can contribute particularly to tangibility by translating an otherwise largely invisible logistics externality into a visible checkout attribute. However, the information must remain comprehensible and relevant rather than becoming a technically complex metric that consumers cannot interpret.

3.2 Last-Mile Delivery and Environmental Information

Last-mile logistics has become an important research area because consumer requirements concerning delivery speed, convenience, and location interact with routing efficiency, vehicle utilization, failed deliveries, and urban transport conditions. Alternative e-commerce delivery-policy research has therefore examined several approaches to organizing the last mile rather than assuming that attended home delivery is the only viable model.

The environmental effect of e-commerce delivery is similarly conditional. Shahmohammadi and colleagues' 2020 greenhouse-gas footprint comparison demonstrated that retail-channel impacts depend on fulfillment structure and consumer behavior, reinforcing the need for careful interpretation of delivery-related environmental claims.

Consumer-facing evidence is especially relevant to the present paper. Ignat and Chankov's 2020 stated-preference research specifically examined whether e-commerce customers modify last-mile preferences after receiving environmental and social sustainability information. Their results showed that additional sustainability information can change consumer preferences toward more sustainable options. Importantly, the authors also identified potential discrepancies between stated intentions and real-world behavior, which supports the need for field validation of checkout interventions.

3.3 Carbon Communication, Nudging, and Choice Architecture

Carbon-aware delivery can also be understood through the concept of choice architecture. Thaler and Sunstein argued that decision environments can influence behavior without eliminating choice, while earlier social-psychological research demonstrated that appropriately framed contextual cues can encourage pro-environmental action. In an e-commerce context, the ordering, wording, visual prominence, default status, and comparability of delivery alternatives can therefore influence which attributes consumers attend to.

The ethical distinction lies between making relevant environmental information easier to use and manipulating consumers through misleading presentation. A lower-carbon option should not be described as environmentally superior unless the claim is supported by a defensible calculation. Equally, a delivery option should not automatically be portrayed as green merely because it is slower. Actual emissions can depend on route consolidation, vehicle utilization, failed delivery likelihood, pickup travel, and other operational conditions. Existing carbon-footprint research supports this context-sensitive interpretation.

Well-designed carbon information may therefore work best as decision support rather than moral pressure. Consumers can be shown the relative environmental consequences of available alternatives and allowed to decide whether the difference justifies additional waiting or inconvenience. Ignat and

Chankov's findings provide early empirical support for the proposition that transparent sustainability information can alter last-mile preferences without requiring consumers to be denied conventional delivery choices.

4. Research Methodology

4.1 Research Design and Simulation Conditions

The study employs a simulation-based between-condition design. No actual e-commerce customers were recruited, and no completed transactions were analyzed. Synthetic data were produced solely to demonstrate how alternative checkout configurations could be examined in a future experiment.

A total of 480 simulated observations were distributed equally across four carbon-information conditions. The first condition represents a speed-focused checkout containing conventional delivery dates and prices but no environmental information. The second introduces a basic carbon label. The third provides an estimated carbon value accompanied by a relative comparison. The fourth combines comparative carbon information with a consolidated delivery option designed to represent operational flexibility for a potentially lower-impact fulfillment process.

Table 1: Simulation Design and Measurement Framework

Research Element	Operational Specification
Research approach	Simulation-based comparative study
Synthetic analytical sample	480 observations
Observations per condition	120
Condition 1	Speed-focused delivery with no carbon information
Condition 2	Basic carbon label
Condition 3	Carbon estimate with relative comparison
Condition 4	Carbon comparison with consolidated delivery option
Primary outcome	Sustainable delivery choice intention
Additional constructs	Environmental decision confidence, perceived sacrifice, information trust, checkout satisfaction
Measurement format	Illustrative five-point scales

Note: All observations, means, and statistical results are synthetic. They must not be reported as responses obtained from actual consumers.

4.2 Construct Measurement and Experimental Logic

Sustainable delivery choice intention is conceptualized as the consumer's willingness to select a delivery arrangement identified as having a comparatively lower estimated environmental impact. A future empirical experiment could measure likelihood of selection, preference between delivery alternatives, and actual checkout choice where behavioral testing is feasible.

Environmental decision confidence reflects the consumer's certainty that the information provided is sufficient to make an environmentally informed delivery decision. Carbon-information trust represents confidence that the environmental comparison is credible, adequately explained, and not merely promotional language. These constructs should remain distinct because consumers may understand a comparison while doubting the reliability of its calculation.

Perceived sacrifice captures additional waiting time, inconvenience, reduced flexibility, or monetary cost associated with selecting the lower-impact alternative. Future experiments should manipulate these trade-offs separately. A sustainable option requiring one additional day may produce a different response from one requiring a week-long delay or an additional fee.

4.3 Statistical Analysis and Ethical Position

Synthetic observations were generated around theoretically specified condition means with individual variation within each group. Sustainable delivery choice intention was compared across the four experimental conditions using descriptive statistics and a one-way analysis of variance.

Using the synthetic dataset constructed for the study, the illustrative ANOVA yielded $F(3, 476) = 207.25$, $p < .001$. Because the simulation was intentionally parameterized around progressively differentiated condition means, statistical significance is an internal feature of the model rather than evidence of an empirically established population effect.

No human participants, account records, delivery addresses, transaction histories, or personally identifiable information were involved. Consequently, no institutional ethics approval or informed consent is claimed. Future behavioral experiments should obtain appropriate ethical review where applicable and should ensure that carbon information presented to participants is based on transparent assumptions rather than fictitious environmental claims presented as factual.

5. Analysis

5.1 Consumer Response Across Carbon-Aware Conditions

The simulated analysis indicates that sustainable delivery choice intention increases as environmental information becomes more specific and actionable. The speed-focused condition without carbon information produces the lowest mean score at 2.62. Introducing a basic carbon label increases the simulated mean to 3.28, indicating that environmental salience alone may affect consideration.

The strongest response occurs when comparative information is accompanied by a consolidated lower-impact delivery alternative, with a simulated mean intention of 4. The pattern illustrates the proposition that consumers may respond more strongly when carbon information is translated into a specific action rather than presented as an isolated environmental metric.

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Table 2: Simulated Consumer Responses to Carbon-Aware Delivery Options

Checkout Delivery Condition	Sustainable Delivery Choice	Environmental Decision Confidence	Carbon-Information Trust	Perceived Sacrifice	Checkout Satisfaction
Speed-focused, no carbon information	2.62	2.51	2.76	2.14	3.89
Carbon label only	3.28	3.18	3.21	2.42	3.84
Carbon estimate + comparison	3.79	3.86	3.73	2.69	3.91
Carbon estimate + consolidated option	4.12	4.19	4.03	3.08	3.82

Scale: 1 = low; 5 = high. Source: Author-generated synthetic dataset.

The table also illustrates a useful trade-off. Perceived sacrifice increases as the sustainable option becomes more behaviorally meaningful, yet checkout satisfaction remains comparatively stable. This simulated pattern suggests that consumers may tolerate a moderate sacrifice when the environmental benefit is understandable and the alternative remains practically acceptable.

5.2 Environmental Confidence, Trust, and Delivery Trade-Offs

The improvement in environmental decision confidence between the basic label and comparative-information conditions is theoretically important. A simple carbon symbol tells consumers that sustainability is relevant but may provide insufficient information for distinguishing among alternatives. Comparative information offers a reference point through which the consumer can interpret the environmental consequence of the choice.

This interpretation is consistent with Ignat and Chankov's empirical finding that customers can change preferred last-mile delivery after receiving sustainability-impact information. Their study directly supports the proposition that environmental information can become behaviorally relevant when incorporated into delivery selection.

However, carbon-aware checkout design should not obscure operational complexity. Comparative research on retail greenhouse-gas footprints demonstrates that emissions vary according to channel configuration and behavior. Carbon values should therefore be described as estimates where appropriate and should state the relevant scope or comparison basis rather than implying universal environmental certainty.

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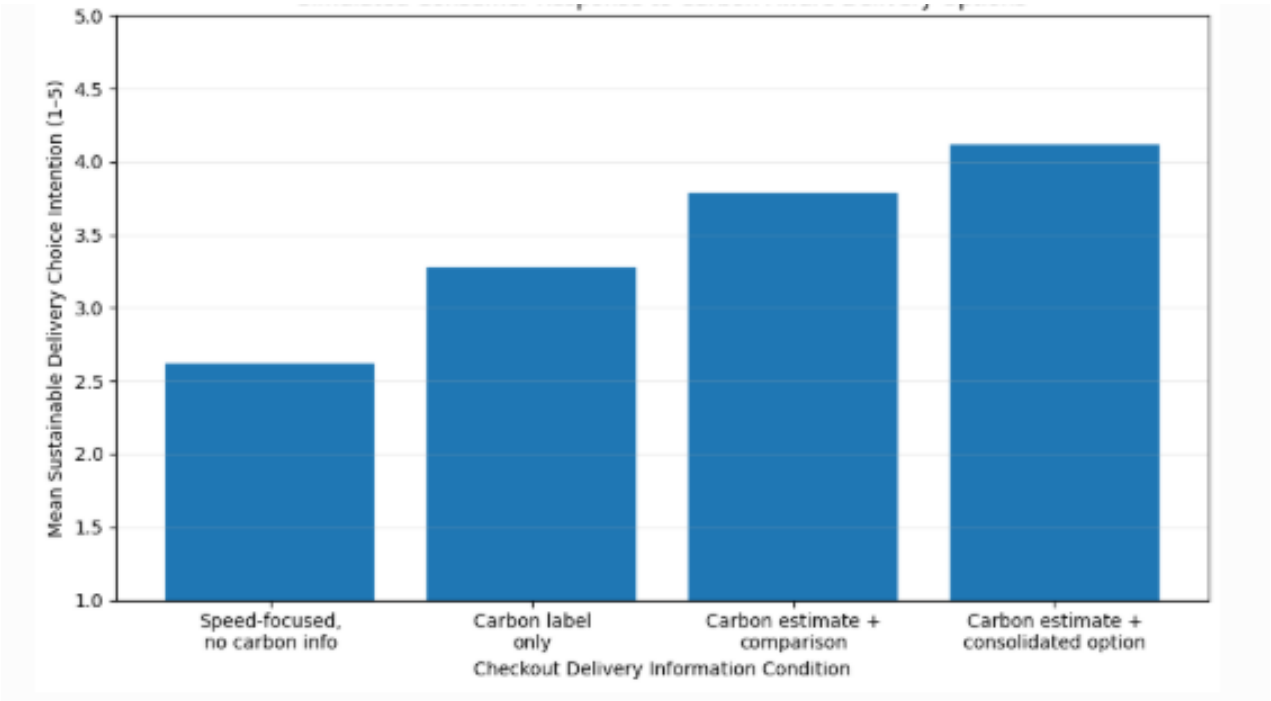
5.3 Graphical Interpretation

Graph 1: Simulated Consumer Response to Carbon-Aware Delivery Options



Supporting Means: Speed-focused/no carbon information = 2.62; carbon label = 3.28; carbon estimate with comparison = 3.79; carbon estimate with consolidated option = 4.12.

Key Finding: Sustainable delivery choice intention increases as carbon information becomes more interpretable and is connected to a specific lower-impact delivery action.

The graphical pattern should not be interpreted as evidence that carbon information inevitably changes real purchasing behavior. Ignat and Chankov themselves identify stated-versus-actual behavior as an important limitation in consumer delivery research.

The Graph instead illustrates a testable hypothesis for future checkout experiments. Actual response is likely to depend on urgency, price, delivery delay, environmental concern, product type, previous sustainable behavior, perceived credibility, and whether the advertised emissions difference is large enough to justify the required sacrifice.

6. Discussion

6.1 Making an Invisible Logistics Consequence Decision-Relevant

The simulation supports the argument that carbon-aware delivery may become more influential when environmental consequences are made visible at the exact moment a consumer chooses among fulfillment alternatives. Without such information, consumers may compare delivery choices solely according to speed and price even if they hold strong environmental preferences.

This does not imply that consumers are responsible for solving the environmental problems of logistics systems. Retailers, carriers, policymakers, vehicle technologies, warehouse configurations, and route-planning systems remain central determinants of actual emissions. Consumer-facing information is

better understood as one component of a wider decarbonization strategy rather than as a substitute for operational improvement. The diversity of last-mile configurations identified in logistics research reinforces this systems perspective.

Carbon-aware checkout systems can nevertheless provide consumers with agency when genuine operational alternatives exist. The value of the intervention lies not simply in displaying an environmental symbol but in connecting verified differences in logistics impact with a clear behavioral choice.

6.2 The Importance of Sacrifice, Convenience, and Context

A major implication concerns the trade-off between environmental benefit and consumer sacrifice. Consumers may accept additional delivery time when a purchase is nonurgent, but willingness to wait is unlikely to be uniform across situations. Medicine, replacement equipment, gifts required by a fixed date, and routine household purchases all create different urgency profiles.

Retailers should consequently avoid treating carbon-aware delivery as a moral test. A consumer selecting faster delivery may possess a legitimate service requirement rather than weak environmental concern. Choice architecture should provide relevant environmental information without stigmatizing conventional options.

The actual environmental consequence must also remain contextual. A longer delivery window can create operational flexibility, but slower service should not automatically be labeled lower carbon unless the logistics system can use that flexibility to consolidate routes, increase vehicle utilization, alter transportation mode, or otherwise reduce emissions. Carbon-footprint studies demonstrate why fulfillment assumptions matter to environmental comparisons.

6.3 Implications for Responsible E-Commerce Design

For retailers, the most useful carbon-aware checkout is likely to combine simplicity with methodological transparency. Consumers generally should not need to understand detailed life-cycle models during checkout, but they should be able to understand what the comparison means. A statement such as “estimated delivery emissions are lower because your order can be consolidated with scheduled deliveries” provides more decision context than an unexplained green icon.

Comparative framing may also be more useful than isolated carbon quantities. Many consumers have limited intuitive understanding of whether a particular number of grams or kilograms of carbon dioxide equivalent represents a large or small impact. Showing the relative difference among available delivery options can improve interpretability, provided that the same accounting boundaries and assumptions are used consistently.

Retailers should additionally protect against greenwashing. Carbon-aware delivery claims should be based on actual logistics differences and should not distract from more material environmental impacts elsewhere in the product lifecycle. Shahmohammadi and colleagues' comparative analysis demonstrates that the environmental performance of retail systems arises from multiple interacting stages rather than delivery alone.

7. Conclusion

Carbon-aware delivery options introduce environmental information into a checkout decision traditionally organized around speed, price, and convenience. Their potential importance lies in making an otherwise largely invisible logistics consequence available when consumers can still act on it. Existing research provides evidence that sustainability information can influence preferred last-mile choices, while broader environmental assessments demonstrate that the actual carbon consequences of online fulfillment remain highly context dependent.

The simulation developed in this paper demonstrates a theoretically consistent progression. Mean sustainable delivery choice intention increases from 2.62 when checkout contains no carbon information to 3.28 with a basic label, 3.79 when carbon estimates are comparatively framed, and 4.12 when the comparison is accompanied by an actionable consolidated delivery alternative. Environmental decision confidence and information trust also improve across these conditions, although perceived consumer sacrifice becomes more noticeable as sustainable alternatives involve meaningful delivery trade-offs. These numerical values are synthetic and must not be represented as empirical findings.

The results suggest that the quality of carbon communication is likely to matter as much as its mere presence. Retailers should avoid assuming that slower delivery is inherently greener or that an unexplained environmental badge constitutes adequate sustainability disclosure. Carbon estimates should be based on consistent calculation boundaries, presented as estimates where uncertainty exists, and connected to actual differences in fulfillment practice.

Future research should validate the framework through randomized checkout experiments and real transaction data. Particularly valuable designs would examine willingness to accept one-, two-, or three-day delays; free versus paid sustainable options; carbon quantities versus percentage comparisons; default versus actively selected delivery options; consolidated home delivery versus pickup points; and differences between urgent and nonurgent products. Field evidence should also test whether environmental information changes actual delivery selection rather than stated intentions alone. Such research could help transform carbon-aware delivery from a promotional sustainability feature into a credible mechanism for aligning consumer choice with operational decarbonization.

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