Supply chain carbon transparency to consumers via blockchain: does the truth hurt?

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Abstract

Purpose – The purpose of this study is to determine if blockchain-supported carbon offset information provision and shipping options with different cost and environmental footprint implications impact consumer perceptions toward retailers and logistics service providers. Blockchain and carbon neutrality, each can be expensive to adopt and complex to manage, thus getting the "truth" on decarbonization may require additional costs for consumers.

Design/methodology/approach – Experimental modeling is used to address these critical and emergent issues that influence practices across a set of supply chain actors. Three hypotheses relating to the relationship between blockchain-supported carbon offset information and consumer perceptions and intentions associated with the product and supply chain actors are investigated.

Findings – The results show that consumer confidence increases when supply chain carbon offset information has greater reliability, transparency and traceability as supported by blockchain technology. The authors also find that consumers who are provided visibility into various shipping options and the product's journey carbon emissions and offset – from a blockchain-supported system – they are more willing to pay a premium for both the product and shipping options. Blockchain-supported decarbonization information disclosure in the supply chain can lead to organizational legitimacy and financial gains in return.

Originality/value – Understanding consumer action and sustainable consumption is critical for organizations seeking carbon neutrality. Currently, the literature on this understanding from a consumer information provision is not well understood, especially with respect to blockchain-supported information transparency, visibility and reliability. Much of the blockchain literature focuses on the upstream. This study focuses more on consumer-level and downstream supply chain blockchain implications for organizations. The study provides a practical roadmap for considering levels of blockchain information activity and consumer interaction.

Keywords Carbon neutrality, Decarbonization, Blockchain technology, Consumer perceptions, Behavioral experiment

Paper type Research paper

1. Introduction

The pursuit of a low-carbon or decarbonized economy, characterized by reduced greenhouse gas (GHG) emissions, has emerged as a crucial global mission (Lugo-Morin, 2021). From manufacturing to transportation and distribution, anthropocentric activities are the primary contributors to climate change, threatening irreversible consequences on our relationship with nature and broader ecosystems (Boisvenue and Running, 2006; Santiago Fink, 2016). Countries worldwide are responding by implementing regulations to guide organizations and supply chains towards a low-carbon or carbon-neutral economy. Among these strategies is the implementation of carbon taxes, charging producers for GHG emissions from production

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and consumption processes. One notable example is the European Commission's Carbon Border Adjustment Mechanism (CBAM), a part of the European Green Deal that targets global supply chains, transportation and logistics. Although the initiative has raised concerns within the transportation and logistics sectors, it represents a significant stride towards industry-wide emission reduction (Zhang *et al.*, 2016; Trushkina, 2022).

Recently, the concept of carbon neutrality or net-zero has gained traction as an organizational strategy for emissions management (Zhang *et al.*, 2022a). Central to these efforts is carbon offsetting, where organizations fund emission-savings projects to balance out excess carbon emissions under a capped scheme. Carbon offsetting programs often involve reforestation, landfill gas destruction, wastewater treatment and methane destruction initiatives (Campbell *et al.*, 2018; Bai *et al.*, 2022). The benefits of these programs are measured in carbon savings, calculated based on the reduction of GHGs compared to a scenario where the carbon saving project doesn't exist. These programs, which offer an initial step towards global carbon reduction, are particularly feasible for industries with high emission levels. Therefore, firms aiming for carbon neutrality often resort to carbon offsets as part of their strategy.

Amid escalating pressures for GHG reduction, organizations are transforming traditional supply chain management practices, driven by *a diverse group of stakeholders*, including governmental regulators, supply chain actors, NGOs and, increasingly, consumers. While organizational carbon mitigation environmental performance has been in focus since the 19th century (Murthy *et al.*, 1997), the broadening concept of supply chain has shifted this focus towards the network of supply chain actors, range from retailers, logistics service providers and, ultimately, consumers. For instance, the globalized and industrialized marketplace has escalated these expectations, requiring organizations to monitor and manage carbon-intensive activities, such as those within logistics processes—a major source of GHG emissions (Miklautsch and Woschank, 2022). This heightened responsibility is apparent in initiatives like the CBAM (Lu *et al.*, 2021), demonstrating the growing importance of comprehensive and collective carbon-offsetting strategies in the modern supply chain landscape. Further, given the expansion from Scope 1 and Scope 2 to Scope 3 emission concerns, supply chain actors are expected to collaborate and coordinate (Li *et al.*, 2019). One manifestation of such collaboration is retailers partnering with logistics service providers who offer carbon-neutral shipping options [1]. Such collaborations allow cost-sharing among multiple supply chain actors, for carbon-saving projects throughout a product or service lifecycle (Liu *et al.*, 2022).

Existing literature on sustainable supply chain management proposes two main approaches for supply chains to achieve GHG reduction. One stream considers developing and managing functional and operational processes for supply chain carbon reduction, such as supplier selection based on carbon performance evaluations (Govindan *et al.*, 2015). The second stream focuses on conceptualizing and measuring carbon footprints within various supply chain activities, such as introducing tools like life cycle analysis to track product carbon footprints (Weidema *et al.*, 2008). Prior research in carbon reduction predominantly focuses on internal firm operations and immediate supply chain partners—who are typically upstream. Broader influence of downstream (consumer) stakeholders on supply chain carbon emissions management is lacking. Sustainable consumption, rather than production, has not been addressed as frequently in the supply chain and logistics literature (Govindan, 2018). Sustainable consumption drives much of what occurs in production supply chains requiring more nuanced and direct study. Sustainable consumption also means that consumers are increasingly scrutinizing firm carbon reduction and neutrality efforts, especially carbon-offsetting programs. They are also basing their purchasing decisions on these assessments (Kim *et al.*, 2014; Nikseresht *et al.*, 2023). To this end, our study shifts from an inward-looking perspective to a perspective that includes consumer actions and perceptions to align with a consumer-centric sustainable supply chain (Esper *et al.*, 2020). The study contributes knowledge and understanding of consumer perception dynamics influencing the transition towards low-carbon and carbon-neutral supply chains. The results inform managerial strategies to better cater to consumer preferences, potentially driving market differentiation and competitive advantage.

Increasing consumer involvement in supply chain sustainability-related carbon-reduction initiatives is likely to occur by promoting supply chain transparency through information disclosure (Bray *et al.*, 2011; Osburg *et al.*, 2020). For example, retailers can influence consumer perception and potentially their purchasing behavior by showcasing firm or supply chain carbon-reduction efforts in their annual sustainability reports. While recent marketing studies have explored the link between a firm's transparency on sustainability and consumer perceptions (Chwialkowska *et al.*, 2020; Creazza *et al.*, 2022), research and understanding remain limited when considering the effects of supply chain transparency on firm carbon-offsetting initiatives. One area of understanding relates to consumer trust in the legitimacy of supply chain carbon neutrality efforts—ultimately affecting purchasing decision-making processes.

An effective solution for firm and supply chain carbon neutrality can be found through digitalization for carbon emissions information disclosure to consumers. Digitalization, especially through multi-stakeholder technology such as blockchain technology—offers a platform for accurate, secure and reliable information tracking (Sarkis *et al.*, 2021). Blockchain technology has been proposed as a valuable tool for carbon offset management within logistics (Fernando *et al.*, 2021). Blockchain technology reshapes the information disclosure paradigm, embedding trust rather than merely promising it (Dubey *et al.*, 2020; Collier and Sarkis, 2021). This shift, fostered by blockchain's transparency, traceability and verifiability capabilities, diminishes trust reliance in supply chains and let consumers confidently evaluate firm carbon-neutrality efforts via immutable ledgers (Wong *et al.*, 2020). Consequently, consumer trust shifts from companies to the blockchain platform, creating a "trustless" environment with confidence in the embedded data.

Using carbon reduction and consumer-centric supply chain transparency study and understanding, we examine the value of a supply chain carbon transparency across multiple supply chain actors—manufacturers, logistics service providers, retailers and consumers. We employ a consumer-based behavioral experiment to investigate how consumers perceive the value of supply chain carbon transparency, specifically in response to blockchain technology use for logistics and supply chain partner environments. Our results inform organizations and managers of the value of blockchain technology platforms for carbon-neutral (especially carbon-offsetting) systems. Specifically, we seek to answer the following research questions:

RQ1. Can blockchain-supported carbon data impact consumer perceptions of retailers and logistics service providers?

RQ2. Will consumers pay a premium for carbon-neutral shipping for blockchain-supported carbon offset information?

RQ3. Will consumers bear even higher costs for carbon-neutral shipping with enhanced interactive blockchain capabilities?

The answers to these research questions not only contribute to understanding information disclosure in carbon-neutral supply chain settings, but also serve as the foundation for a potential roadmap for organizations seeking to adopt blockchain technology for carbon-neutrality information. The remainder of this paper is structured as follows: a comprehensive literature review is conducted using relevant literature streams for theoretical underpinning, including carbon neutrality or offsetting, supply chain transparency and blockchain technology. Section 3 introduces our hypotheses. Section 4 provides methodological information on participants, experiment procedure, measures and manipulation checks. Section 5 discusses the findings and implications. Section 6 is a post hoc analysis to further investigate consumer perception change towards retailers and logistics service providers who are given different pre- and post-information cost disclosure. Section 7 summarizes the theoretical and managerial implications of this study. Section 8 concludes this study with key contributions, limitations and future research directions.

2. Background

This section provides the theoretical and practical underpinnings of this study. The focus will be on the need for carbon neutrality and how transparency within the supply chain can support these organizational and supply chain efforts.

2.1 Carbon neutrality

Carbon neutrality refers to offsetting the generated GHG through carbon capture, storage and conversion for the purpose of *net-zero emissions*. Early concept implementation occurred in Samsø Island, Denmark in 1997. The concept has been adopted and introduced to many industries and locations with the emergence of sustainable development goals, sustainability and carbon reduction and trading schemes. Broadly, for example, on December 11, 2019, the European Union (EU) Green Deal proposed a climate neutral continent by 2050—resulting in a cleaner environment, more affordable energy, smarter transport, new jobs and an overall better quality of life.

For various reasons, firms play critical roles in supporting carbon neutrality. Various studies have investigated low-carbon production and consumption systems (Jabbour *et al.*, 2019). However, *low-carbon*—achieving decarbonization through carbon reduction—and *carbon neutral*—achieving decarbonization through carbon offsets—may require different strategic planning and tactical supply chain actions. Research on emergent the carbon-neutrality concept is still in its infancy.

Existing carbon-neutrality studies mainly investigate macro-level initiatives and programs. An example includes examining triggers for policy-making and technological effectiveness for implementing national and regional carbon-neutral programs (Zhang *et al.*, 2021; Chen *et al.*, 2022). Current studies also view carbon-neutral initiatives as proactive environmental strategies at the organizational level (e.g. Roy *et al.*, 2001; Jansson *et al.*, 2017). Existing research has completed initial exploration of organizational motivations for committing to carbon neutrality and the implications of such a commitment for firm performance and supply chain management. Table 1 provides a comprehensive but not exhaustive literature review on carbon-neutral supply chain management. The table includes dimensions of decarbonization theme, level of analysis, supply chain scope and stakeholder involvement.

From Table 1, we can conclude that a significant portion of existing decarbonization studies have been conducted at the macro level of analysis. Studies typically investigate carbon-reduction policy and regulatory impact on individual supply chain subsystems—such as energy and transportation concerns. A majority of the limited studies examining the supply chain level of analysis focus on the upstream supply chain—vendor and supply management. Examples include how firms incorporate GHG-related performance measures in supplier selection for aggregated carbon reduction and neutrality (Bai *et al.*, 2022).

Although some studies evaluate carbon neutrality from a supply chain perspective, consumers are usually left out of this evaluation (see Table 1). Additionally, these studies are primarily conceptual or theoretical analytical models using illustrative data. Few empirical

Table 1. Carbon-neutral supply chain management literature review

Paper	Level of analysis	Supply chain systems	Decarbonization theme	Stakeholder involvement: Manufacturers	Retailers	Distributors	Customers
Hickman *et al.* (2010)	Macro	Transportation	Carbon reduction			√	
Strachan and Kannan (2008)	Macro	Energy systems	Carbon reduction	√			
Teng *et al.* (2012)	Meso	Energy systems	Carbon reduction	√			
Huisingh *et al.* (2015)	Macro	Energy systems	Carbon reduction	√	√		
Chen (2016)	Micro	Downstream supply chain	Carbon reduction				√
Du *et al.* (2017)	Organizational	Upstream supply chain	Carbon reduction	√	√		
Brandenburg (2015)	Organizational	Upstream supply chain	Carbon reduction	√			
Shaw *et al.* (2012)	Organizational	Upstream supply chain	Carbon reduction	√			
Caro *et al.* (2013)	Supply Chain	Upstream supply chain	Carbon neutrality	√			
Rosa *et al.* (2022)	Supply Chain	Energy systems	Carbon neutrality	√			
Kilian *et al.* (2012)	Supply Chain	Upstream supply chain	Carbon neutrality	√	√		√
McKinnon (2010)	Organizational	Upstream supply chain	Carbon reduction	√			
Bai *et al.* (2022)	Supply Chain	Upstream supply chain	Carbon neutrality	√			
Halldórsson *et al.* (2009)	Supply Chain	Entire supply chain	Carbon neutrality	√	√	√	
Zhang *et al.* (2021)	Macro	Energy systems	Carbon neutrality	√			
Zhang *et al.* (2022b)	Macro	Energy systems	Carbon neutrality	√			
Cheng *et al.* (2021)	Macro	Energy systems	Carbon neutrality	√			
Reiche (2010)	Macro	Energy systems	Carbon neutrality	√			
Lam and Dai (2015)	Supply Chain	Downstream supply chain	Carbon reduction			√	
von der Gracht and Darkow (2016)	Supply Chain	Downstream supply chain	Carbon reduction			√	
This paper	*Supply Chain*	*Supply chain that includes upstream and downstream actors*	*Carbon neutrality*	√	√	√	√

Source(s): Authors' own work

studies have been completed. This study addresses some of these limitations and oversights by exploring how supply chain collaborative efforts including manufacturers, retailers, logistics distributors and consumers, help advance and achieve carbon neutrality, using multi-step behavioral experiments as an empirical methodology.

2.2 Transparency in consumer-centric supply chains

More firms are adopting a consumer-centric mindset as consumer issues are vital for a focal firm and its upstream supply chain management (Esper *et al.*, 2020). Firms are increasingly disclosing supply chain-related information to foster consumer trust and cultivate a more favorable corporate image (Sodhi and Tang, 2019). Traditional approaches for firms to disclose supply chain-related information include annual financial reports, sustainability reports, press releases or via third-party websites. Legitimacy theory posits that firms will practice information disclosure for improved reputational outcomes (Peters and Romi, 2014). This theoretical perspective also applies to operational information transparency offered by firms. Traditional information disclosure literature has focused on sustainability reporting and disclosure—typically as part of a strategic effort by organizations—which can enhance legitimacy of organizations (Kouhizadeh *et al.*, 2021).

However, it is costly, complicated and time-consuming for companies to collect, sort, validate, disclose and manage such information while its benefits are not clear—further preventing firms to support transparency. Though there are recent studies that examine the important relationship between information disclosure and consumer perceptions in the context of the supply chain. These studies mainly focus on information disclosure, including environmental and social sustainability (Longoni and Cagliano, 2018; Duan *et al.*, 2021; Mollenkopf *et al.*, 2022) and logistics related service expectations (Peinkofer *et al.*, 2022). Whether this general sustainability focus applies to specific carbon-neutrality information disclosure and trust from a consumer perspective remains an open and important question.

Understanding multiple supply chain tiers including product manufacturing and last-mile logistics delivery service with a consumer-centric supply chain research framework is lacking and important for carbon-neutral supply chain strategic planning (Esper *et al.*, 2020). Thus, this research investigates consumer perceptions and logistics delivery decisions, as well as their willingness to pay a premium for a focal firm's product. Our study delves into the effect of informing consumers on carbon transparency—emissions and offsets—ramifications linked to their choices. The findings will enrich our understanding of consumer psychology, particularly within the purview of sustainable supply chain management (Groening *et al.*, 2018).

Disclosing supply chain-related information from firms to external stakeholders is inextricably linked with the concept of *supply chain transparency*. This notion differs somewhat from *supply chain visibility* and *traceability*. Supply chain *visibility* focuses on internal informational flows and refers to the accessibility of essential operational information by supply chain actors (Barratt and Barratt, 2011). *Traceability*, however, is a firm's ability to identify and verify each component's origin within its supply chain for quality control and regulatory compliance (Somapa *et al.*, 2018). Supply chain transparency, unlike visibility and traceability, focuses on internal processes and involves disclosing supply chain information to a wider range of stakeholders, including external ones like consumers. Research has examined the influence of sustainability-related disclosures on supply chain transparency and consumers (Hoffjan *et al.*, 2011; Wilhelm *et al.*, 2016; Villena and Dhanorkar, 2020). However, few have studied the effects of combined supply chain and logistics environmental sustainability disclosures on consumers.

Carbon transparency is a type of sustainable supply chain transparency of current importance to supply chain actors. Many firms are encouraged to report carbon emissions along their supply chains—not only their internal operations (e.g. Scope 3 emissions). The reporting of carbon emissions is also needed for their supply chain partners (Theißen *et al.*, 2014). Firms are motivated to disclose carbon emissions for operational, strategic and regulatory reasons (Villena and Dhanorkar, 2020). Current studies widely report that *supplier carbon transparency*—the availability of high-quality, supplier-specific carbon emission information to stakeholders—contribute greatly to supply chain carbon transparency (Hsu *et al.*, 2013; Dou *et al.*, 2015; Villena and Dhanorkar, 2020). Few studies have explored the value of *distributor carbon transparency*—which we define as the availability of high-quality, logistics partner-specific carbon emission information to stakeholders.

Disclosing distributor carbon transparency to consumers also relates to political consumerism, also known as ethical or conscientious consumerism. For this perspective of consumer behavior individuals consider the political and social implications of their purchasing choices (den Hond and Bakker, 2007). It involves making purchase decisions based on organizational ethical practices, environmental responsibility, treatment of workers, support for social causes and adherence to fair trade principal factors, for example. Carbon transparency influences the behavior of politically conscious consumers, especially those who are pro-environmental and socially conscious. When consumers have access to detailed information about a company's carbon reduction and offsetting practices, they can make more informed decisions aligning with their ethical values. Transparent disclosure of a company's supply chain activities enables consumers to understand the impacts of their purchases along all product logistics journey, allowing them to purchase and select shipping options that align with their social and environmental values.

2.3 Transparency in consumer-centric supply chains

Achieving *supply chain transparency,* yet important, is not easy and has many hurdles. First, it is practically difficult and costly since it requires engagement and collaboration amongst multiple supply chain actors with activities such as information gathering, validating, tracing and processing. Additionally, companies at different positions within supply chain networks have varying motivations for information disclosure, and thus, it will be difficult to reach a consensus on information sharing across the supply chain. Second, potential risks exist for disclosing supply chain information as companies can be questioned on their commitments by stakeholders. For example, if a company claims to be a sustainable producer, consumers or advocacy group may then trace all possible information and evaluate if the disclosure is complete and accurate. Any negative information about the supplier or distributor puts the focal company at a reputational risk of *guilt by omission* with accusations of greenwashing. Third, disclosing supply chain information may not be well-perceived by consumers, as consumers may perceive companies as *cherry-picking* selected information or disclosing fraudulent information.

One potential solution for the focal firm is to incorporate blockchain technology into its supply chain carbon transparency effort (Bai and Sarkis, 2020). Blockchain, a decentralized (distributed ledger) information management technology that was popularized by Bitcoin cryptocurrency (Narayanan *et al.*, 2016), has quickly expanded to various contexts including the supply chain field (Gurtu and Johny, 2019; Saberi *et al.*, 2019). The primary reason for the growing interest in blockchain is its unique attributes that provide information security, anonymity and data integrity without third parties in control of the transactions. Blockchain capabilities include and support supply chain transparency, traceability, security, immutability and smart execution, especially addressing some information management challenges in multi-tier supply chains.

Specifically, blockchains use decentralized databases and ledgers for maintaining and tracking secure and tamper-proof transactions and records (Nakamoto, 2009; Swan, 2015) and store information as a chain of blocks where each block has multiple copies in a network of computers with cryptographic structure that ensures the security of the system and prevent information from tampering and falsification. Blockchain ledgers can only be updated with valid information that has passed a predefined network verification algorithm; this feature ensures the validity of the information entry (Tapscott and Tapscott, 2017; Tönnissen and Teuteberg, 2020).

While blockchain technology shows promise in supply chain management in terms of information sharing, traceability and provenance, there are still some gaps and challenges, particularly in logistics and carbon information disclosure understanding. *Supply chain carbon transparency* requires information flows from multiple supply chain actors—making information difficult to gather, track and manage (Datta and Christopher, 2011; Maheshwari *et al.*, 2021). Blockchain technology provides a platform where supply chain actors can update, review and cross-validate information, even when trust and commitment relationships do not exist. Consumers, as supply chain downstream actors, can also review blockchain-based information given appropriate levels (permission) of access.

For instance, information about the materials and products, their carbon footprints from manufactures to retailers, to logistic partners, to end-consumers, product journey and related carbon emission information can be synchronized using blockchain ledger (Kamble *et al.*, 2019). Simultaneously, when firms claim carbon-offsetting programs, they can stipulate specific carbon-offsetting or carbon-neutral programs. This type of information may be activated along a product journey, how much carbon emissions have been offset at each product processing activity. In final product fulfillment, the system can provide information on whether a carbon surplus or neutrality exists for the product. Because of the inherent blockchain *trustless* mechanisms, consumers can be confident that blockchain information is reliable and reflects reality (Kshetri, 2018; Bai and Sarkis, 2020). Hence, given these capabilities of blockchain and consumer perceptions or knowledge of blockchain, we hypothesize that:

H1. Blockchain-supported carbon offset information will result in more positive consumer perceptions toward (a) retailers and (b) logistics service providers.

Drawing from the theory of planned behavior by Ajzen (1991) as the foundational framework for understanding ethical consumption, recent studies have elucidated the influence of individual consumer characteristics. These characteristics encompass environmental involvement (Vermeir and Verbeke, 2006), ethical ideologies and concerns (Schniederjans and Starkey, 2014; Hosta and Zabkar, 2021), cultural orientation (Chwialkowska *et al.*, 2020; Creazza *et al.*, 2022), as well as information attributes such as framing (Duan *et al.*, 2022) and external assurance (Misiuda and Lachmann, 2022). Together, these factors shape ethical consumption in response to firm information disclosures—each through the theory of planned behavior lens. Relatedly, building trust via information disclosure is one of the important drivers for firms to influence consumer ethical (sustainable) consumption (Alsayegh *et al.*, 2020; Fu *et al.*, 2023). For instance, Alsayegh *et al.* (2020) show that firms disclosing their environmental, social and governance (ESG) practices in a comprehensive manner will result in increased accountability, transparency and stakeholder trust. Similarly, Fu *et al.* (2023) find that the focal firm can increase information transparency to stimulate consumer trust, resulting in higher purchasing behavior, in the context of green agricultural products.

While the long-held belief that information disclosure increases consumer trust remains unchallenged—blockchain technology subtly redefines this relationship, fostering a new paradigm where trust is built-in, not just promised. Specifically, blockchain transparency and information verifiability tend to decrease the need for trust among supply chain partners (a *trustless* environment characterization)—not only trust among supply chain business actors but also between consumers and product manufacturers and distributors (Dubey *et al.*, 2020; Collier and Sarkis, 2021). Consumers can review and assess carbon-neutrality efforts and performance using distributed, immutable blockchain ledgers (Wong *et al.*, 2020). This capability is convenient—if well developed—and consumers can have greater confidence in the carbon offset information provided. That is, consumers do not necessarily need to trust the company for a purchase; instead consumers may trust the blockchain platform and the information embedded.

Additionally, via convention information disclosures, consumers may not be confident about information validity—stories in popular news on carbon offset scandals cause confidence deterioration (Greenfield, 2023), reducing confidence and may prevent consumers from engaging in carbon-neutral initiatives. Given blockchain technology is a trust-free technology—with reliable, accurate and transparent information—will make them more confident that their contribution and engagement to carbon neutrality will promote a cleaner and greener supply chain. Hence, consumers are theoretically willing to engage in collaborative carbon-neutrality efforts. Therefore, we hypothesize that:

H2. The blockchain-supported provision of supply chain carbon offset information will positively impact consumer decisions to support carbon-neutral initiatives.

The relationship between carbon offsetting initiatives and consumer behavior has been addressed in several studies (e.g. Gössling *et al.*, 2007; Segerstedt and Grote, 2016). The airline industry was one of the first industries to adopt carbon-neutrality programs to consumers, allowing consumers to voluntarily offset their journey by paying an extra fee (Gössling *et al.*, 2007; MacKerron *et al.*, 2009). Such programs include the protection of forest areas, the installation of solar panels in public buildings, with reputable certificates showing the program effectiveness (Wehner *et al.*, 2021). Studies indicate that the number of airline passengers willing to pay for such collaborative carbon-neutrality programs is low, ranging from 1% to 10% of air travelers (Schwirplies *et al.*, 2019). A majority of prior studies examine consumer willingness to pay for airline carbon-offsetting initiatives have focused on the impact of various individual consumer characteristics such as materialism and consumer health concerns (Dang *et al.*, 2021), subjective and moral norms (Tao *et al.*, 2021) and socio-demographics (Blasch and Farsi, 2014). Consumer knowledge insufficiency and perceived lack of transparency are further identified as deterrents for engaging in carbon-offsetting activities (Babakhani *et al.*, 2017). Recent studies have identified firm lack of transparency as one of the primary barriers to raising capital for further engagement in carbon-offsetting activities (Kaplan *et al.*, 2023).

Differently, in blockchain-aided supply chain systems, carbon offset information will be gathered, monitored and validated in a real-time manner, with no possibility for manual manipulation and falsification. Further, consumers can track the carbon-offsetting processes for the supply chain processes—from sourcing to last-mile logistics fulfillment. Consequently, the implementation of blockchain technology should significantly mitigate and address consumers' previous reservations and concerns about possible greenwashing, which have been largely due to perceived deficiencies in transparency and trustworthiness related to carbon-offsetting initiatives. Thus, consistent with Hypothesis 2, we argue that when blockchain-supported carbon offset information is provided, consumer involvement may go beyond general support to more specific and support of carbon-neutrality efforts with the company, especially paying for carbon-neutral shipping. Therefore, we hypothesize that,

H3. Blockchain-supported carbon offset information transparency with advanced blockchain consumer interaction will increase the likelihood for consumers to pay a price premium for carbon-neutral shipping.

A framework summarizing the relationships between the constructs and hypotheses appears in Figure 1.

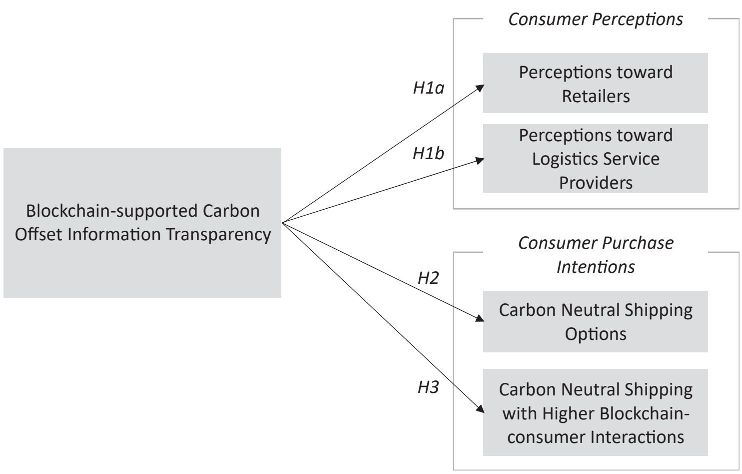
3. Methodology

To examine our hypotheses regarding consumer perceptions and reactions toward retailer carbon offset strategies, we conducted a vignette-based and role-play experiment. This approach is particularly appropriate for studies that are interested in studying perceptions (Rungtusanatham *et al.*, 2011; Ried *et al.*, 2022). The experiment features a 2 (Blockchain-supported carbon offset information provision: with vs without) × 3 (Shipping options: free vs carbon-neutral shipping without blockchain-supported tracking vs carbon-neutral shipping with blockchain-supported tracking) × 2 (Time: pre- (T1) vs post-shipping options (T2)) mixed design. Specifically, the blockchain-supported carbon offset information provision is the between-subject factorial while the shipping options and time are the within-subject factorials in this study.

3.1 Participants

Participants were recruited by using the Amazon Mechanic Turk (M-Turk), an online crowdsourcing platform used in numerous business disciplines (e.g. Mollenkopf *et al.*, 2022). Admittedly, there are concerns related to the sample characteristics, reliability and applicability of using M-Turk as a primary source for data collection, we implemented a series of approaches to ensure those concerns would not impact the validity and applicability of our results. See Table 2 for a summary of our approach.

We recruited 200 participants from M-Turk. We excluded those who failed the attention check (Abbey and Meloy, 2017) and showed an obvious tendency to straight lining (Kim *et al.*, 2019). Our final sample includes 189 participants. On average, each participant spent 13 min and 49 s on the study and received a payment of $0.70. Among the 189 participants, approximately 60% were male, 75% reported receiving at least some college education and 58% were Caucasian. See Table 3 demographic information of the participants.



Source(s): Authors' own work

Figure 1.
Conceptual framework of this study

Potential concerns	Description of concern	Our approaches
Representation of the population	M-Turk participants tend to be more diverse in culture, occupation, education and age (Kees *et al.*, 2017)	• Only allow USA residents to participate in the study by specifying geographic locations during the data collection • We conducted an additional post-hoc comparison of demographics between our sample and the USA population and did not notice significant differences
Character misrepresentation	Character misrepresentation occurs when respondents deceitfully claim an identity, ownership, or behavior to qualify and be paid for completing a survey or behavioral research study (Sharpe Wessling *et al.*, 2017, p. 211)	• No demographic restrictions were imposed during the data collection processes (Sharpe Wessling *et al.*, 2017)
Non-naïve participants	Participants behave differently in studies due to prior exposure to experimental materials (Chandler *et al.*, 2014)	• The between-subject design and subtle manipulation prevent participants from guessing the research purpose
Selective attrition	Participants self-select to opt out of an experiment for reasons related to the condition to which they were assigned (Zhou and Fishbach, 2016)	• Participants are required to formally "accept" the consent before accessing the study (Peer *et al.*, 2014; Goodman and Paolacci, 2017)
Self-selection bias	Participants are free to select the tasks in which they participate (Goodman and Paolacci, 2017)	• Adopted a generic study description: "Blockchain study." • In the study description, we did not provide any detailed information except asking participants to finish a short survey about blockchain (Goodman and Paolacci, 2017)
Inattentive respondents	Respondents do not pay close attention to the experiment's instructions (Peer *et al.*, 2014)	• Included attention check questions to screen out inattentive respondents (Peer *et al.*, 2014) • Included a quality filter and only recruited workers with an approval rating above 95% approval rate (Peer *et al.*, 2014)
High attrition rates	The percentage of participants "quitting a study before completing it and getting paid" is higher in the online experiments than in the lab environment (Aguinis *et al.*, 2021)	• We are able to capture all responses, including both the incomplete and completed ones. Among the 200 responses we collected, there were 8 participants who dropped out during the experiment, resulting in an attrition rate of 8%. Compared with online experimental studies, this attrition rate is relatively trivial (Zhou and Fishbach, 2016). Thus, we do not consider the high attrition rate to be a significant factor that biased our conclusion
Inconsistent English language fluency	Participants "from countries where English is not the primary language displays only configural invariance with data collected from undergraduates and organizational employees from countries where English is the primary language (Aguinis *et al.*, 2021, p. 826)."	• To avoid potential confound, we only recruit consumers from the USA for our study. The IP addresses further confirm that all participants are from the USA. Thus, English fluency should not be an issue for our study given all participants are from the USA

(*continued*)

Table 2. Approaches to minimize M-Turk concerns

Potential concerns	Description of concern	Our approaches
Vulnerability to web robots (or "bots")	Malicious software programs, rather than human beings, are used to participate in online studies to receive compensation (Aguinis *et al.*, 2021)	• Required all participants to complete an informed consent form prior to study • Our study includes the attention check that requires a specific, counter-intuitive answer that can be achieved only after finish reading • Additionally, we have multiple qualitative open-ended questions, and the study will not be able to proceed without providing a reasonable written answer • Avoiding using scales that have only "end" points labeled, instead, labeled every point for every scale. (Aguinis *et al.*, 2021)
Perceived researcher Unfairness	Participants are concerned about fairness of the researcher in the areas of the compensation decisions, lack of a communication process, unavailability of disability access features and inaccurately stated time requirements (Aguinis *et al.*, 2021)	• Participants were provided with an email in the informed consent to reach the researcher directly • Each participant was paid 24–48 h upon completing the study • Participants were clearly informed in the informed consent regarding the criteria for successful payment and for those who were declined payment, a detailed explanation was provided (Aguinis *et al.*, 2021)

Table 2.

Source(s): Authors' own work

Final sample size		189	
		N	%
Gender	Female	76	40
	Male	112	59
	Prefer not to say	1	1
Race	White	109	58
	African American	15	8
	Hispanic	1	1
	Asian	62	33
	Other	2	1
Education	Less than college	22	12
	Some college	22	12
	Two-year college	17	9
	Four-year college	111	59
	Graduate level and above	17	9
Income	Under 30,000	48	25
	30,000–60,000	71	38
	60,001–90,000	38	20
	90,001–120,000	17	9
	More than 120,001	15	8

Source(s): Authors' own work

Table 3.
Demographic information of participants

3.2 Procedure

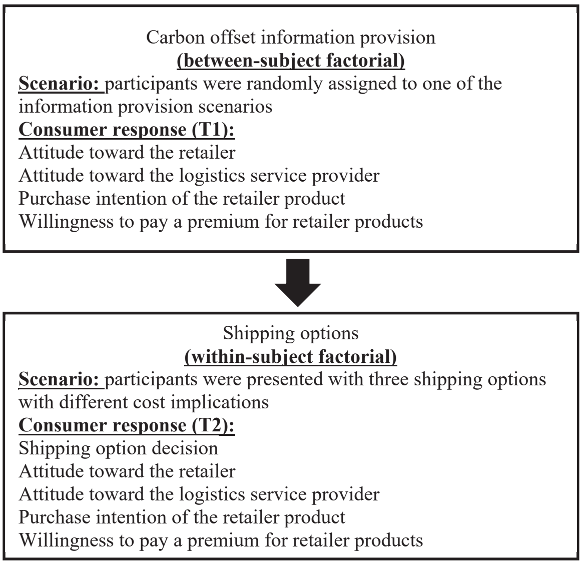
Figure 2 summarizes the experimental procedure with a mixed design. Upon formally agreeing to participate in the study, participants in each scenario were informed to imagine a shopping scenario and shown the webpage of a hypothetical e-commerce company (i.e. Apparel 360). Each participant was provided the same contextual information (common cue module) from the webpage (Rungtusanatham *et al.*, 2011):

> You are going to purchase clothes for the holiday season for a friend who lives in Boston, MA. You come across a clothing retailer during your shopping: Apparel 360. The retailer provides the following information on its webpage.

Following the common cue module, each participant was randomly assigned to one of the two scenarios manipulating the blockchain-supported carbon offset information provision: *with* vs *without*. The blockchain-supported carbon offset information provision scenario included basic brand and retailer (Apparel 360) carbon-neutral initiatives (in collaboration with ProShip), which set the foundation. Participants were also provided detailed information on the collaborative and interaction effort for carbon-neutral initiatives across logistics and supply chain actors. This interaction—through information provision—between supply chain actors included the stages from manufacturer to retailer and from retailer to consumer each which is supported by the logistics service provider information provision.

A web-based geospatial platform simulator was included in the experimental manipulation. The interactive map incorporated information on the retailer's carbon footprint from part of the inbound (upstream) logistics—from the manufacturer's warehouse to the retailer's warehouse. Each participant was asked to interact with the map. A Supplementary file displays an example of the interactive map created for the participants (consumer view).

Differently, in the without carbon-neutral information provision scenario, participants were only provided with basic brand information (i.e. brand name, mission statement) and a brief introduction toward Apparel 360s collaboration with its logistics service provider,



Source(s): Authors' own work

Figure 2. Experimental procedure for the mixed design

ProShip, to achieve carbon-neutrality vis providing carbon-neutral shipping options. No web-based geospatial platform simulator was provided. Upon finishing the vignette, participants were prompted to answer questions about their perceptions towards the retailer and the logistics service provider (T1).

After the between-subject factorial (carbon offset information provision) and the perception measure, a within-subject factorial was presented to each participant. Each participant was informed that the multiple products bought for the friend in Boston would be sent from multiple retailer warehouses. The total cost of the multiple items was $70, satisfying the retailer's free shipping threshold ($50) and was presented with the within-subject factorial of three shipping options (i.e. free vs carbon-neutral shipping of $2.99 vs carbon-neutral shipping with blockchain traceability of $4.99).

Participants who opt for the $4.99 carbon-neutral shipping with blockchain traceability are provided with another interactive map with the geospatial feature. This feature shows them the retailer's carbon footprint for portions of the outbound (downstream) logistics activities—specifically from the retailer's warehouse to the eventual consumer's home address.

Table 4 displays some of the language used in the vignette. After participants chose their preferred shipping option, we again asked about their perceptions towards the retailer and logistics service provider (T2). Lastly, participants were directed to answer questions regarding their demographics and personal traits, including environmental involvement (Savitz and Weber, 2006) and blockchain knowledge (Kelting *et al.*, 2017).

Between-subject factorial	
Blockchain-supported carbon offset information provision	
With	We believe every day should feel as exceptional as the start of a long weekend. Comfortable, confident, stress-free—together
	We think about all the impacts of creating fashion to the environment. We track the carbon footprint of our products and their logistics processes. We make sure that our products are sustainably made during their life cycle and share information about what impact each garment has on the environment
	We aim to achieve climate neutrality* for our supply chain. Specifically, we offer carbon-neutral shipping* options through our shipping partner–ProShip Logistics*
	*Climate neutrality refers to the idea of achieving a world where global emissions are in balance with what is naturally absorbed in "sinks" such as forests and oceans
	*ProShip's carbon-neutral shipping option supports projects that offset the emissions of the shipment's transport. ProShip has supported projects that include reforestation, landfill gas destruction, wastewater treatment and methane destruction
Without	We believe every day should feel as exceptional as the start of a long weekend. Comfortable, confident, stress-free—together
	We aim to achieve climate neutrality* for our supply chain. Specifically, we offer carbon-neutral shipping options through our shipping partner–ProShip Logistics
Within-subject factorial	
Shipping options	
Option 1	Free
Option 2	Carbon-neutral shipping $2.99
	By collaborating with our shipping partner, ProShip Logistics, we make sure that our apparel is 100% carbon neutral
Option 3	Carbon-neutral shipping with blockchain traceability $4.99
	By collaborating with our shipping partner, ProShip Logistics, we make sure that our apparel is 100% carbon neutral
	Further, we adopt blockchain technology to provide detailed information on the carbon offset process of your shipment. After checkout, you will be provided with the interactive map for the carbon offset information along the entire product logistics journey

Source(s): Authors' own work

Table 4.
Manipulation in study 1

Upon finishing the display interaction in the experiment, participants were asked about their perceptions of the retailer and the logistics service provider. After the perception measure (T1), the same within-subject factorial was presented to each participant. Each participant was presented with the identical within-subject factorial of three shipping options with different cost implications (i.e. free vs carbon-neutral shipping of \$2.99 vs carbon-neutral shipping with blockchain traceability of \$4.99). Those who opt for the \$4.99 carbon-neutral shipping with blockchain traceability are provided with another interactive map with the blockchain supported geospatial feature. This blockchain supported geospatial feature shows the retailer's carbon footprint for downstream logistics—from the retailer's warehouse to the end consumer's home address.

Lastly, we asked study participants about their perceptions towards the retailer and logistics service provider again (T2). Participants were also directed to answer questions regarding their demographics and personal traits and experiences—including environmental involvement and blockchain knowledge. See examples of the vignettes used in the study in Figures A1 and A2.

3.3 Measures

The study has two primary independent variables. The first is whether carbon offset information provision exists, and it is captured by a categorical variable (0 = without, 1 = with). The second independent variable is a categorical variable of the three shipping options—represented in Table 4—with (−1 = Option 1, 0 = Option 2, 1 = Option 3). The dependent variables in this study include effects of supply chain transparency on consumer attitude, purchase intention and willingness to pay a premium for shipping and products. These three different perception measures are well supported in prior studies. For example, attitude towards the retailer and logistics service provider (Burton *et al.*, 2000), purchase intention for the retailer products (Kozup *et al.*, 2003) and willingness to pay a premium (Netemeyer *et al.*, 2004) are well supported in the literature. Scales and measurements are reported in Table A1. These measures have been widely used in prior literature to capture consumer perceptions (Andrews *et al.*, 2000; Becker-Olsen *et al.*, 2006). We also recognize that in prior consumer literature there are also consumer individual characteristics (e.g. skepticism, knowledge, demographic and cultural background, sustainability involvement) and disclosed information characteristics (e.g. availability, volume, communication platforms) may play a role in various consumer perceptions (Bray *et al.*, 2011; Osburg *et al.*, 2020; Chwialkowska *et al.*, 2020; Creazza *et al.*, 2022). To maintain model parsimony, we leave these additional considerations and variables for future research.

Prior to behavioral experiment testing, we conducted a confirmatory factor analysis (CFA) to assess and establish the convergent and discriminant validity of the dependent variables. Cronbach's alpha (see Table A1) was used to assess the reliability of the dependent variables by means of composite reliability statistics. The values of Cronbach's alpha for this experimental study exceed conventional thresholds and are comparable to and consistent with prior studies conducted in a similar context (Burton *et al.*, 2000; Kozup *et al.*, 2003). Additionally, we measure participant shipping option preference by a categorical variable (0 = free, 1 = carbon-neutral shipping, 2 = carbon-neutral shipping with blockchain traceability).

3.4 Manipulation check

To evaluate the efficacy of information provision manipulation, we included one manipulation check question in the study. Using a 7-point Likert scale (1 = Strongly disagree, 7 = Strongly agree), we asked participants to evaluate to what extent they agreed that Apparel 360 allows them to see detailed and comprehensive carbon footprint information about the product's logistics journey.

The results of a one-way ANOVA test provide support for the information provision manipulation: the agreement ratings for participants assigned to the *with* carbon offset information provision scenario are significantly higher than participants assigned to the *without* provision scenario (M_{with} = 6.34, standard deviation (SD) = 0.67, $M_{without}$ = 4.58, SD = 1.66, F = 89.14, $p < 0.001$). Additionally, to avoid potential confounding effects from the sample difference between scenarios, we examined whether participants in different scenarios tend to differ significantly in environmental involvement and blockchain knowledge. We failed to identify any significant difference between participants in both scenarios supporting the contention that random assignments did occur.

4. Results and discussion

Table 5 summarizes the descriptive statistics for each variable in this study. Recall that in Hypothesis 1, we argue that Blockchain-supported carbon offset information will result in more positive consumer perceptions toward retailers (H_{1a}) and logistics service providers (H_{1b}). The results of a one-way MANCOVA and one-way ANOVA provide support for H_{1a} and H_{1b}. Using supply chain carbon information provision as the independent variable and consumer perception measures captured in T1 (i.e. attitude towards the retailer, attitude towards the logistics service provider, purchase intention and willingness to pay a premium) as the dependent variables, while controlling for consumer demographics, environmental involvement and blockchain knowledge, we find that providing carbon offset information will significantly impact consumer perception toward the logistics service providers ($M_{without}$ = 5.57, SD = 1.42, M_{with} = 6.04, SD = 1.05, F = 13.56, $p < 0.001$) and retailers (Wilks' Λ = 0.94, F [3, 179] = 3.60, $p < 0.05$) [2].

Specifically, we find support that carbon offset information provision results in a significantly greater positive attitude toward the retailers ($M_{without}$ = 5.56, SD = 1.44, M_{with} = 6.03, SD = 1.15, F = 12.93, $p < 0.01$) and marginally higher purchase intention from the retailers ($M_{without}$ = 5.31, SD = 1.19, M_{with} = 5.44, SD = 1.32, F = 3.30, $p < 0.10$).

In sum, we find support for H_{1a} and partial support for H_{1b}. We also asked participants whether they will pay a premium for the products that provide carbon offset information for the product journey. We do not find significant support that carbon offset information will result in significantly higher willingness to pay a premium for the retailer products. The positive attitude toward the retailers and logistic providers will spill over to greater purchase intention but not to pay higher price for the products.

In Hypothesis 2, we argue that the provision of supply chain carbon offset information will result in consumers being more favorable toward carbon-neutral *shipping* initiatives. To examine this hypothesis, we focus on how carbon offset information provision will impact subsequent consumer decisions for free shipping with a small incremental cost with carbon-neutral shipping ($2.99). Thus, as a baseline, to examine Hypothesis 2, we only include participants that chose free or $2.99 carbon-neutral shipping in our analysis and exclude those who opt for $4.99 carbon-neutral shipping with blockchain (N = 165).

We use carbon offset information provision as the primary independent variable and the binary variable of consumer shipping choice as the dependent variable—while controlling for participant demographics, environmental involvement and previous knowledge about blockchain. Results of a one-way ANOVA fail to provide support for Hypothesis 2. We do not find significant evidence that carbon offset information provision will result in consumers preferring the carbon-neutral shipping option over the free option ($M_{without}$ = 1.56, SD = 0.50, M_{with} = 1.57, SD = 0.50, F = 0.842, p = 0.360). Thus, Hypothesis 2 is not supported.

We further examine Hypothesis 3, which explores whether blockchain supported carbon offset information provision will motivate consumers to pay a higher premium for carbon-neutral shipping options with a traceability feature. Specifically, we only include participants

		Mean	SD	1	2	3	4	5	6	7	8	9	10	11
1	Attitude toward retailer (T1)	5.79	1.33	1	0.75**	0.82**	0.49**	0.64**	0.66**	0.50**	0.51**	0.52**	0.02	0.34**
2	Attitude toward retailer (T2)	5.85	1.26		1	0.75**	0.69**	0.75**	0.84**	0.62**	0.67**	0.57**	0.06	0.40**
3	Attitude toward logistics service provider (T1)	5.80	1.27			1	0.53**	0.61**	0.62**	0.47**	0.47**	0.51**	0.09	0.27**
4	Attitude toward logistics service provider (T2)	6.39	1.85				1	0.61**	0.62**	0.47**	0.47**	0.51**	0.09	0.28**
5	Purchase intention (T1)	5.37	1.25					1	0.88**	0.74**	0.69**	0.72**	0.19**	0.38**
6	Purchase intention (T2)	5.34	1.30						1	0.73**	0.76**	0.68**	0.14	0.44**
7	Willingness to pay a premium (T1)	4.00	1.55							1	0.82**	0.63**	0.33**	0.41**
8	Willingness to pay a premium (T2)	4.03	1.64								1	0.60**	0.30**	0.47**
9	Environmental involvement	5.67	1.15									1	0.10	0.31**
10	Previous blockchain knowledge	4.22	1.53										1	−0.02
11	Shipping decision	1.75	0.67											1

Source(s): Authors' own work

Table 5.
Descriptive statistics for each variable in this study

that chose the \$2.99 carbon-neutral shipping option or the \$4.99 carbon-neutral shipping with blockchain-traceability option in our analysis. In this part of the analysis, we exclude participants who opt for free shipping (N = 117).

Among those who opt for carbon-neutral shipping, we find evidence that carbon offset information provision with blockchain indeed significantly impacts their subsequent decision in shipping options ($M_{without} = 2.12$, $SD = 0.33$, $M_{with} = 2.29$, $SD = 0.46$, $F = 5.07$, $p < 0.05$). Hence, we find strong evidence for Hypothesis 3.

The results from both Hypotheses 2 and 3 indicate that providing carbon offset information upfront can motivate consumers to choose carbon-neutral shipping options, even when these options have a significantly higher shipping premium. However, announcing that the retailer is engaging in carbon-neutral initiatives without indicating that much information is supported by blockchain will not be effective in altering consumer shipping decisions. Consumers will be willing to engage and contribute to carbon neutral shipping options when carbon offset information is supported and provided by blockchain technology.

5. Post hoc analysis

One underlying confounding variable for consumer perception change is the cost associated with shipping options. Some consumers may be price sensitive regardless of whether blockchain and carbon offset transparency exist. To examine the nuances of cost confounding effects, we further investigate how shipping option cost implications relate to consumer perceptions. Given that each participant's perceptions are measured twice (pre- and post-shipping option presentation), we can study the perception change of the same individual.

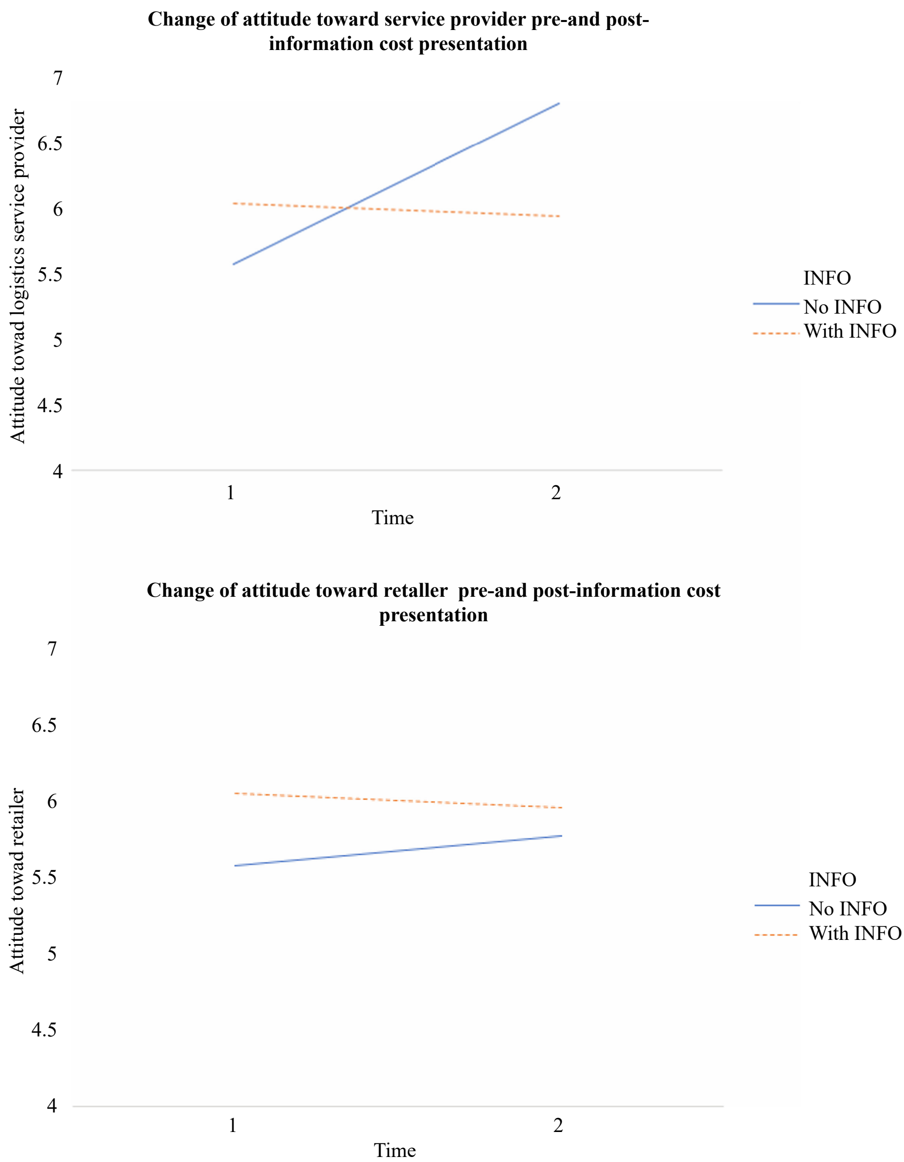
Conducting a repeated measure generalized linear model, with the carbon offset information provision as the independent variable and consumer perception measures for both T1 and T2 as the dependent variables, we find that some of the consumer perceptions indeed change significantly after exposure to the information cost—where carbon-neutral shipping will result in a premium cost. Specifically, both consumer attitudes toward the logistics service provider ($M_{service\ provider\_T1} = 5.80$, $M_{service\ provider\_T2} = 6.39$, $F = 39.56$, $p < 0.001$) and retailer ($M_{retailer\_T1} = 5.79$, $M_{retailer\_T2} = 5.85$, $F = 4.65$, $p < 0.05$) are significantly influenced by the presentation of the information cost. Interestingly, the exposure to the cost of information impact consumer perceptions toward the retailer and the logistics service provider differs. See Figure 3 for the plots regarding the different effects of information cost on consumer perceptions towards different supply chain actors.

With respect to the logistics service provider, informing consumers that there is a cost associated with the information will result in a significant increase in attitude (positive perception) toward the service provider. This result is only true for those participants who were not previously provided access to detailed information. For those participants who were exposed to detailed information before, informing them that there will be an associated cost with the information tended to result in a slight, but not significant, negative perception toward the logistics service provider.

For the retailer, while there is a positive main effect of information disclosure (they were shown detailed information initially), consumer perceptions toward the retailer do not seem to change significantly when compared to the pre- and post-knowing that there will be a cost associated with the information.

6. Implications

Our study provides a number of theoretical and managerial implications. Recent literature has highlighted the important roles of consumers' individual characteristics (Vermeir and



Source(s): Authors' own work

Figure 3. Changes of attitude towards service providers and retailer pre- and post-information cost presentation

Verbeke, 2006; Schniederjans and Starkey, 2014; Chwialkowska *et al.*, 2020; Hosta and Zabkar, 2021; Creazza *et al.*, 2022) and various information attributes (Misiuda and Lachmann, 2022) as drivers for consumers' ethical consumption decisions. However, in line with the evolving supply chain landscape characterized by technology adoption opportunities and consumer-centric mindsets (Esper *et al.*, 2020), researchers must revisit the question of information disclosures and their influence on consumer perceptions, duly incorporating these recent shifts. In this research, we aim to investigate consumer perceptions and logistics delivery decisions, as well as their willingness to pay a premium for a focal firm's product as the focal firm discloses carbon-offsetting information throughout the transportation of cargo with blockchain adoption.

Specifically, for the first research question—will blockchain-supported carbon offset information (when such information is free) positively alter consumer perception toward retailers and the logistics service providers? The findings show a significant positive relationship between blockchain-supported carbon offset information provision and consumer favorability of supply chain actors who practice this information provision—including the product retailer and logistics service providers. The ultimate result shows a further positive effect on their purchase intention. Hence, we extend the current literature on consumer attitude toward *carbon transparency* along two dimensions.

First, the majority of the current supply chain carbon transparency literature has been focused on the upstream supply chain actors and activities—supplier carbon transparency. This study contributes to the understanding of the business value of disclosing downstream carbon transparency. We found that disclosing downstream carbon offset information will enhance customer relationships. Providing visibility along the supply chain carbon offset information can significantly impact consumer perceptions—even more so than just upstream visibility alone (based on the focal firm perspective—in this case the retailer). Transparency and visibility of the logistics journey will likely be of importance for end-consumers.

Second, the current supply chain transparency literature contains contradicting consumer perspectives about full supply chain visibility. Some studies have argued of adverse consumer perception outcomes (Mollenkopf *et al.*, 2022). An underlying reason is the trust between consumers and companies; that is, consumers may perceive companies of cherry-picking information to disclose or disclosing faulty information (Sodhi and Tang, 2019). With the support of blockchain technology—a trust-free technology—our study has confirmed the positive perceptions of consumers toward greater supply chain transparency, especially carbon transparency.

Legitimacy theory posits that firms will practice information disclosure to provide improved reputational outcomes (Peters and Romi, 2014). This theoretical perspective is supported in this study from operational information transparency offered by firms. Traditional information disclosure literature has focused on sustainability reporting and disclosure—typically as part of a strategic effort by organizations. Our evidence shows that operational and almost real-time (depending on how quickly information is provided) disclosure of events and visibility can enhance legitimacy of organizations. Expanding disclosure from a general aggregated reporting (as in annual sustainability reports) to operational information disclosure to consumers can expand the perspective of legitimacy theory to operational logistics and supply chain activities. The implication is that a blockchain trustless operational environment broadly contributes to organizational and supply chain reputation.

Our research also provides important practical implications:

First there is value in adopting blockchain technology. The question that practically arises is whether this value is greater than the cost of the blockchain technology implementation. Firms integrating blockchain technology into their operations should make a concerted effort to communicate this development to their consumers. The adoption of such advanced technology should not be limited to internal supply chain processes, but should also be leveraged externally, especially as an informative tool in marketing efforts. Furthermore, businesses should acknowledge the opportunity to impose a premium for this adoption. Empirical evidence from our study suggests consumer willingness to incur an additional cost for enhanced transparency and trustworthiness afforded by blockchain technology.

Further, the results do not provide significant evidence that carbon offset information provision will result in consumers favoring carbon-neutral shipping option (without blockchain) over the free option—which is the second research question of our study.

However, we found strong evidence that providing carbon offset information can motivate consumers to choose carbon-neutral shipping options with the support of blockchain technology, even if such an option is associated with a significantly higher shipping premium. This latter finding answers the third research question in the affirmative. These two joint findings further indicate that retailers engaging in carbon-neutral initiatives without providing much information will not be effective in altering consumer shipping decisions. Also, consumers will likely not pay for carbon-neutral shipping without trusted information disclosure—especially in the blockchain technology case. Taken together, these insights lead to two crucial practical recommendations for businesses. First, retailers undertaking carbon-neutral initiatives should enhance their information disclosure practices, especially through credible platforms like blockchain, to impact consumer shipping decisions effectively. Second, without the backing of trusted disclosures—particularly through blockchain—consumers may remain reluctant to pay for carbon-neutral shipping. Hence, incorporating blockchain technology in environmental disclosures could be a game-changer in persuading consumers to embrace carbon-neutral choices, despite higher costs.

The literature has documented the benefits of the business value of supply chain visibility and carbon transparency to stakeholder benefits (Caridi *et al.*, 2014). Existing studies show organizational value creation when the information is complete and true (e.g. Somapa *et al.*, 2018). Consumers purchase intention is likely to increase for products and services from companies they trust. Blockchain technology—as a trustless decentralized technology—offers consumers a vehicle to trust supply chain actors—retailers, manufacturers and logistics shipping partners. This trust-free support can resolve trust concerns in supply chain strategic development—such as sustainability, circular economy, decarbonization—where consumers and even supply chain actors, will be more willing to engage in collaborative sustainability efforts if they are confident that the results will occur and they are reliable.

Carbon neutrality involves multiple supply chain actors and the initial cost of investing in full supply chain transparency can be high. Blockchain technology capabilities give consumers more confidence that sustainable results can be monitored and shown to occur. This confidence means they will be more willing to share the cost with the focal firm and its supply chain actors (i.e. by paying a premium price). With this cost-sharing motivation and intention, focal firms may find it viable to initiate carbon-neutral projects, fostering a collaborative effort towards supply chain decarbonization across different actors along the supply chain. Thus, it is possible to foster collaboration throughout the supply chain to for collective carbon-neutrality efforts.

Another observation is that carbon transparency is more valuable to supply chain actors when the information sharing and disclosure is enabled and supported by blockchain. A holistic approach that integrates blockchain technology with carbon neutrality can generate synergistic benefits for supply chain actors. Companies should consider adopting blockchain technology not only for operational efficiency but also as a strategic tool for environmental and social good. The synergistic effect of combining these strategies can yield greater benefits, enhancing the company's reputation and stakeholder value.

In this study, we found that for consumers who have seen upstream carbon offset information (from manufacturer to retailer) are more likely to pay a higher premium to view downstream carbon offset information from a product's journey from the retailer to the consumer household. Hence, managerial implications mean that organizations should carefully investigate the adoption of blockchain incorporating both upstream and downstream information—where most of the current visibility research focuses on upstream transparency, more complete transparency downstream of a focal firm can be just as important. This situation expands the roles of stakeholders who would be active in the planning and design, development, implementation and operation of blockchain technology. Blockchain technology operations means that captured, traced and managed information and their access should be available to manufacturers, logistics partners and consumers—each of whom will likely find value in the adoption of blockchain technology for carbon-offsetting for logistics and supply chain product delivery.

This study result suggests a strategic roadmap for firms considering the adoption of blockchain technology to bolster carbon neutrality within their supply chains. The roadmap commences with an initial assessment of whether they should even consider carbon-neutral information provisions or offering. Supply chain actors will have to gauge their existing commitment to carbon neutrality, laying a foundation for later strategies. A tactical supply chain recommendation we consider in this study is the introduction of a blockchain to support a carbon-neutrality strategy. The first tactic for an organization is to offer passive blockchain information support, enabling monitoring of carbon emissions and offsets usage within the supply chain. Just providing this information would not require active consumer participation. The next stage of the study explores advanced consumer-centric extensions of blockchain technology—resulting in more proactive participation with the blockchain technology. Overall, we show that organizations and supply chain actors will benefit from these stages because consumers have a more favorable attitude, be more willing to purchase and are willing to pay premiums for products and logistics shipping services. A major concern in this roadmap of integrating carbon-neutral strategy into supply chain activities using blockchain is whether the resources needed to move along the current roadmap are worth the benefits associated with the next stage.

One interesting step in this road map for managerial and organizational decision-making is a stage we did not explicitly consider but is implied from the results. It seems that some consumers are willing to pay an even greater premium in some cases when they start to more fully appreciate blockchain capabilities in scenarios with interactive mapping. The implication is that consumers are willing to even go beyond offsetting the carbon emitted during the supply chain activities. This willingness to go beyond paying just for carbon emitted (carbon neutrality) means purchasing offsets beyond their own emissions (carbon negative). Further study and practice in further developing an extended roadmap going beyond carbon neutrality will be even more important.

7. Conclusion

This study investigates the true value of supply chain carbon transparency—when such transparency is supported by blockchain technology. Overall, we found consumer perceptions of logistics service providers and organizations in the supply chain are positively enhanced when carbon transparency increases. However, consumers will more likely be willing to pay for the carbon-neutral initiative when the carbon offset information is disclosed by a blockchain platform. The findings provide motivations for blockchain adoption for full value realization on carbon-neutrality strategic planning.

Limitations in this study exist—but these limitations provide fertile ground for future study. First, this research focuses on capturing consumer perception, an important antecedent of behavior (Ajzen, 1991). However, there is evidence from prior literature that demonstrates the existence of the intention-behavior gap, especially in the context of ethical consumption (Hassan *et al.*, 2016). Though the primary focus of this research is not capturing consumer actual behavior, future research can further extend the research by capturing both perceptions and behaviors via incentives experiment or field experiments.

Another limitation associated with individual level behavioral experiments is the lack of generalizability and external validity due to the nature of behavioral experiments (Stevens, 2011). For instance, we primarily recruited participants from the USA. This approach, while providing a depth of insight within this demographic, does not capture the potential moderating impacts of nationality, cultural background, or socio-economic status on ethical consumption decisions. These elements, as demonstrated by prior research (Chwialkowska *et al.*, 2020; Creazza *et al.*, 2022), play a pivotal role in shaping consumers' decision-making processes, and their exclusion in our study denotes a limitation that future research should address. Cultural influences can have profound effects on consumption decisions, as they shape individual values, norms and behaviors. Similarly, socio-economic status can impact access to, preferences for and perceptions of ethically produced goods. Given these nuances, future research in this domain could significantly benefit from a more expansive and diverse participant base. By incorporating these moderating factors, future studies can help to uncover a richer and more complex understanding of ethical consumption. Not only could this provide more holistic insights, but it could also contribute to the development of more effective strategies for promoting ethical consumption across different sociocultural contexts.

Overall, decarbonization efforts need support from various supply chain actors. Contributing to decarbonization should involve multiple stakeholders who need to not only provide appropriate practices or utilize carbon offsets but need to invest in these efforts. Consumer involvement and the willingness-to-pay as well as improvement of reputation for organizations that seek to make the extra effort of transparency can bode well for decarbonization of logistics. This research builds on this contention, an important concern as anthropogenic contribution of climate change needs to be bridled and reduced.

Notes

1. Some examples include the collaboration between H&M and Maersk ECO Delivery (https://www.maersk.com/news/articles/2020/02/28/h-m-group-reduces-carbon-footprint-with-maersk-eco-delivery), and Walmart and Canoo(https://corporate.walmart.com/newsroom/2022/07/12/walmart-to-purchase-4-500-canoo-electric-delivery-vehicles-to-be-used-for-last-mile-deliveries-in-support-of-its-growing-ecommerce-business#:~:text=BENTONVILLE%2C%20Ark.%2C%20July%2012,purchase%20up%20to%2010%2C000%20units).
2. We use one-way MANCOVA to examine consumers' perceptions toward the retailer given the multiple perception measures and one-way ANOVA to examine consumers' perceptions toward the logistics service provider given the single attitude measure.

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Supplementary file

The supplementary material for this article can be found online.

Appendix

Table A1. Measurements used in the study

Measure	Adapted from	Item description	Anchors	α
Attitude towards the firm	Burton *et al.* (2000)	What is your overall attitude toward Apparel 360?	1 = Very Unfavorable 7 = Very Favorable 1 = Bad, 7 = Good 1 = Negative 7 = Positive	0.97
Willingness-to pay a premium	Netemeyer *et al.* (2004)	WTPP1: The price of clothes from Apparel 360 would have to go up quite a bit before I would switch to another company WTPP2: I am willing to pay a higher price for clothes from Apparel 360 than for other retailers	1 = Strongly Disagree 7 = Strongly Agree	0.86
		WTPP3: I am willing to pay______ more for clothes from Apparel 360 over other brands	1 = 0% 7 = more than 25%	
Purchase intention	Kozup *et al.* (2003)	PI1: Assuming you were going to buy clothes, would you be more likely or less likely to purchase this product? PI2: How probable is it that you would consider a purchase from Apparel 360, if you were going to buy the clothes? PI3: How likely would you be to purchase the clothes, given the information shown on the website of Apparel 360?	1 = Strongly Disagree 7 = Strongly Agree	0.94
Consumer blockchain knowledge	Kelting *et al.*, 2017	How familiar are you with blockchain?	1 = Not at all familiar 7 = Extremely familiar	0.88
		How much do you know about blockchain?	1 = Very little 7 = A lot	
		How clear is your understanding of characteristics of tracking systems?	1 = Not at all clear 7 = Extremely clear	
		How would you rate your knowledge about blockchain relative to the rest of the population?	1 = One of the least knowledgeable 7 = One of the most knowledgeable	
Model fit indices	Comparative fit index (CFI) = 0.989, normed-fit index (NFI) = 0.99, root mean square error of approximation (RMSEA) = 0.04, root mean square residual (RMR) = 0.022, and goodness-of-fit index (GFI) = 0.98. All measures are above the recommended cutoffs			
Construct reliability and validity	Convergent validity was established by calculating the average variance extracted (AVE). The AVE values for all three dependent variables exceed the recommended threshold of 0.5 (Fornell and Larcker, 1981) Discriminant validity was established by comparing the phi-square correlation ($\phi 2$) of each factor pair with their respective AVE. For each pair of factors, AVE exceeded $\phi 2$ (Fornell and Larcker, 1981)			

Source(s): Authors’ own work

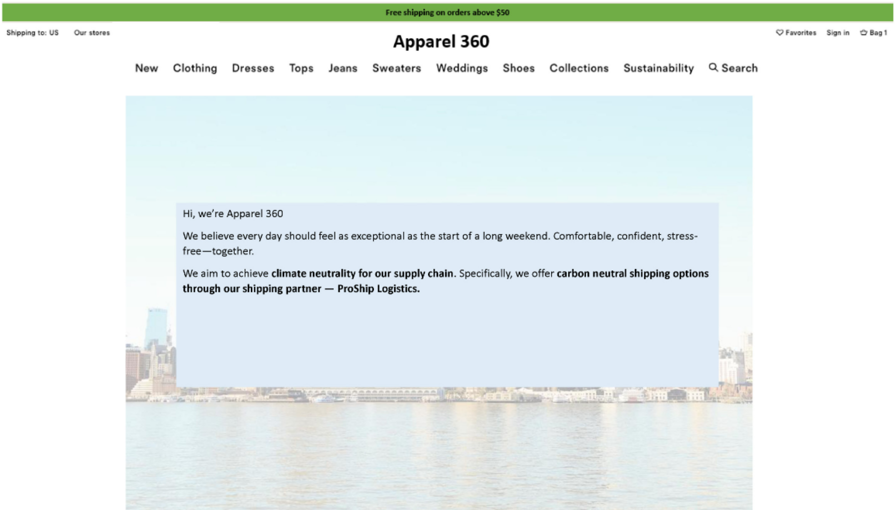


Figure A1. Examples of the experimental vignette (without carbon-neutral shipping provision)

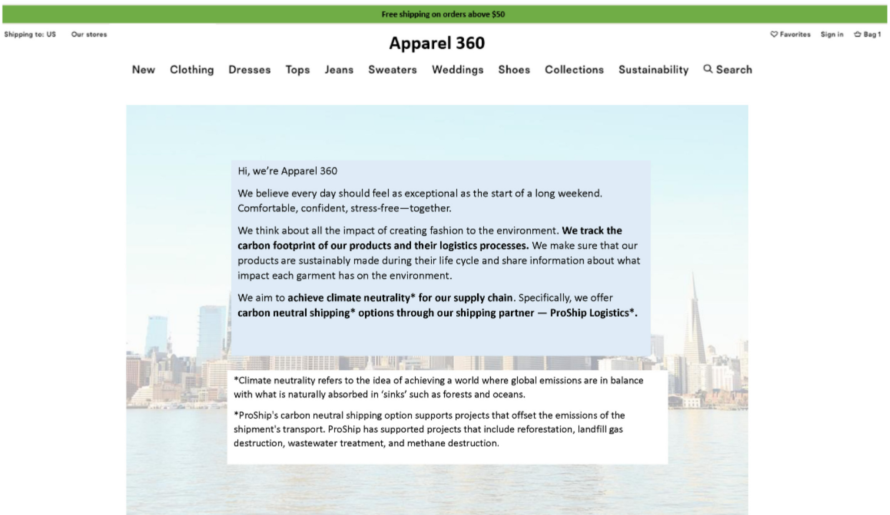
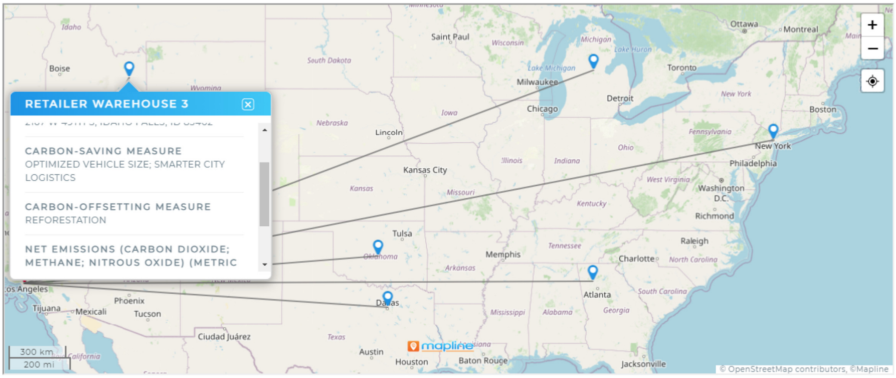


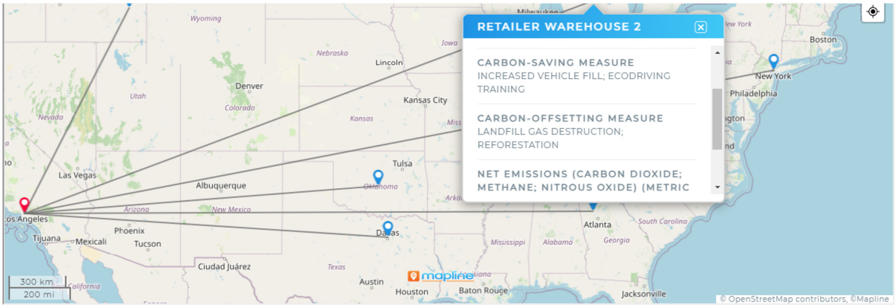
Figure A2. Examples of the experimental vignette (with carbon-neutral shipping provision)

(*continued*)

Feel free to zoom in/out of the map, click the pin on the map for details regarding how we save and/or offset the greenhouse gas emissions during the product journey from the manufacturer warehouse to our warehouses; click the line on the map for information about the geographic distance covered.



Mapping by Mapline



Mapping by Mapline

Role	Location	Distance from the manufacturer warehouse (miles)	Carbon saving measure	Carbon offsetting measure	Total emissions*	Emissions after offset*
Manufacturer warehouse	Cota Ave, Long Beach, CA 90813					
Retailer warehouse 1	1389 Hwy 92 Ste 102, Acworth, GA 30102	2,215	Switch to biofuel; Modal shift	Wastewater treatment; Methane destruction	9.9	0
Retailer warehouse 2	393 W Webster St, Coleman, MI 48618	2,290	Increased vehicle fill; Eco-driving training	Landfill gas destruction; Reforestation	6.4	-0.5
Retailer warehouse 3	2167 W 49th S, Idaho Falls, ID 83402	909	Optimized vehicle size; Smarter city logistics	Reforestation	0.4	0

Figure A2.

Source(s): Authors' own work

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