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S.I. : DESIGN AND MANAGEMENT OF HUMANITARIAN SUPPLY CHAINS

Reducing carbon emissions in humanitarian supply chain: the role of decision making and coordination

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Abstract

In this study, we investigate the role of decision-making and coordination related to carbon reduction within humanitarian supply chain. Accordingly, a two-stage supply chain consisting of a single manufacturer and a single retailer has been designed, within which three strategies for carbon emission reduction have been considered, namely direct procurement of carbon emission right, investment in fixed carbon reduction targets, and investment in reducing carbon emissions per unit product. The game model under decentralized decision-making, centralized decision-making, and coordinative status has been established. The influences of both consumer carbon sensitivity coefficient and carbon trading price on investment decision based on carbon emission reduction within supply chains, as well as the optimal decision of supply chain operations, are all discussed in this paper. Our study shows that the choice of supply chain carbon reduction strategies depends on carbon trading price and fixed emission reduction target, both the wholesale price and selling price of products are positively correlated with carbon trading price, and both optimal production volume of supply chain and optimal expected profit of supply chain operations are negatively correlated with consumer carbon sensitivity coefficient. The price discount contract may realize coordination within a supply chain, but the value of discount price depends on respective negotiation ability.

Keywords Carbon reduction · Investment decision making · Price discount contract · Humanitarian supply chain operations

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1 Introduction

The increase of carbon dioxide emissions into the atmosphere represents one of the main causes of global warming (Gleick et al. 2010), which has led to costly and rising effects on economies all over the world (Wu et al. 2019). In recent years, low carbon consumption awareness has gradually grown in consumers' eyes (Sharma and Foropon 2019). Nowadays, on top of being concerned with product quality, more and more consumers pay attention to both environment-friendly performance and social value of supply chains behind products (Islam et al. 2020; Nouria et al. 2016; Wang et al. 2017). The extant literature has shown that low-carbon-sensitive consumers consider environment-friendly performance as an important influence factor for procurement, and such consumers are willing to pay higher price for low-carbon products. Indeed, even if brands with low-carbon products are not the first consumers' choices, roughly 67% of consumers prefer low-carbon products and intend to buy products with carbon labels (Vanclay et al. 2011). In addition, products carbon emission reduction degree is positively correlated with product price demanded by consumers (Pang and Li 2011); it has been noted that urban consumers in China are willing to pay higher price for low carbon products (Ying et al. 2012). Concurrently, the field of green supply chain management with the introduction of concepts of sustainability and environmental thinking has grown very significantly (Sheu et al. 2005), and there is also a growing interest regarding process improvement approaches in humanitarian operations (Larson and Foropon 2018).

The growth of low carbon-sensitive consumers has urged companies to lower their own carbon emission as well as carbon emission of their suppliers, given that carbon emission within a supply chain is far higher than carbon emission of the enterprise itself (Balasubramanian and Shukla 2018; Keshin and Plambeck 2011). For instance, Wal-Mart has found that 90% of carbon emission come from supply chain partners rather than itself (Hoffman 2007). Overall, carbon emission is jointly released by upstream and downstream enterprises within a supply chain, and a lack of coordination within any entire supply chain will lead to higher carbon emission (Luo et al. 2017; Song et al. 2015, 2018). Therefore, joint efforts from supply chain operations are required to lower the carbon emission of an entire supply chain (Benjaafar et al. 2013; Chen et al. 2013; Ma and Gao 2013; Wu et al. 2019; Zhao et al. 2012). With this regard, the extant literature has provided encouraging findings. First, Kohn and Brodin (2008)—through an extensive literature review and analyses of case studies—have illustrated a set of circumstances under which it is possible to both decrease carbon dioxide emissions as well as to provide satisfying cost-efficient customer service. Second, supply chains may reach requirements and environmental regulations by directly purchasing carbon emission right or adopting carbon emission reduction investment strategies (Yang and Ji 2013). Therefore, since modern market economy makes any enterprise coexist with upstream and downstream enterprises, meeting consumers' requirements for low carbon products by lowering carbon emission could provide new competitive strength for enterprises and global supply chain systems.

The field of humanitarian supply chain management makes no exception, and the impacts of humanitarian supply chain operations on global warming should be considered. Despite a need for planning and achievement of sustainability performance in humanitarian operations, there is still a lack of decision support systems in this field (Laguna-Salvado et al. 2019). In this regard, Behl and Dutta (2019) have conducted a thematic literature review in the domain of operations and supply chain management, and the authors have shown that humanitarian supply chain properties and resources that are needed for efficient and effective management of humanitarian operations represents one key theme to consider. Hence, our study aims at filling out such research gap by developing a decision-making model integrating the criterion of carbon reduction in the field of humanitarian supply chain management. Indeed, given consumers' low carbon awareness gradually intensifies, the way supply chains lower carbon emission with a view to improve competitiveness becomes an urgent problem to be solved. For that reason, this paper mainly investigates the following issues: (1) influence of carbon-sensitive consumers on decision making of supply chain members; (2) selection of carbon emission investment strategy for a supply chain; (3) design of an effective coordination strategy to maximize benefits of member enterprises and the entire supply chain when meeting environmental regulations, and reach coordinative development between environment and economy.

The remainder of the paper is structured as follows. In Sect. 2, we provide a literature review about decision-making and coordination related to carbon emission reduction within humanitarian supply chain. In Sect. 3, we present both problem description and variable explanation. Next, Sects. 4 and 5 are dedicated to model building and associated analysis. Then, theoretical implications are presented in Sect. 6, followed by managerial implications in Sect. 7. Finally, we conclude in Sect. 8 and discuss further research directions.

2 Literature review

As awareness of low-carbon consumption has been gradually growing over the years, more and more scholars have focused on research studies linked to consumers' carbon sensitivity (Ghosh and Shah 2015; Luo et al. 2017; Nouria et al. 2016; Song et al. 2016; Velazquez et al. 2017; Yao et al. 2019). Low-carbon products may not only meet consumers' production demands, but also meet consumers' social demands, that is consumers keeping in mind an active consumption view (Kotchen 2005). In this regard, Wang and He (2011) have studied psychological attribution for creation mechanisms of low carbon consumption consumers' behaviors with a view to provide theoretical basis for governments to formulate effective guiding approaches. Moreover, Toptal and Cetinkaya (2015) have studied carbon reduction problems under the condition that two-level supply chain members are all restricted by carbon policies and retailing price is fixed regardless the impact of consumer behaviors and emission reduction factors. Hence, aforesaid studies did not consider the impact of carbon sensitive consumers on a supply chain, and our research study aims at filling out this research gap.

In order to realize supply chain carbon emission reduction, academic scholars have investigated the process of decision making on carbon emission reduction within supply chains. First, Zhang et al. (2011) have studied how enterprises relying on carbon emission would balance various emission right acquisition channels and formulate optimal output decision making under definite demands. Second, Chen et al. (2013) have concluded that carbon quota policy could effectively promote enterprise carbon emission reduction after comparatively analyzed influence of carbon policies on enterprise decision making based on EOQ model. Third, Toptal et al. (2014) have carried out comparative analysis on enterprises' investment in emission reduction under carbon quota, carbon tax and carbon trading, and concluded that the carbon trading policy under carbon emission reduction investment could better reduce enterprises' costs and carbon emission. Fourth, Wang and Zhao (2014) have discussed decision making of retailers to confirm optimal order level and of supplier to select carbon reduction level assuming consumers prefer low carbon products and enterprises reduce carbon emission. Later, He et al. (2016) have established a pricing strategy model for enterprises under carbon quota policy, carbon quota and trading policy, and green technology input under carbon quota and trading policy. In addition, Yang and Ji (2013) have established carbon emission investment theoretical model by taking consumer behavior into account and carried out comparative analysis. Yang and Ji (2013) offered supply chain carbon emission reduction strategy, but assumed that carbon trading price is given and market demand is certain; their study also did not reflect influence of carbon sensitivity of consumers. Such identified gap has been addressed in our study. It is worth noting that previous studies did not involve the influence of consumers' preferences on supply chain carbon emission decision-making. Moreover, Brown and Guiffrida (2014) have performed a comprehensive comparison of carbon emissions resulting from conventional shopping involving pickup with trip chaining versus e-commerce-based online retailing involving last mile delivery to customers' homes, and have concluded the breakeven number of customers for carbon emissions equivalence and have analysed the feasibility for last mile delivery at a desired service. More recently, in order to reduce both costs and carbon emission of heavy good vehicles, Velazquez et al. (2017) have developed a robust decision-making framework optimizing vehicle specification for specific duty cycles. Overall, the process of decision-making on carbon emission reduction has been investigated in the area of supply chain management, but the focus on carbon emission reduction in the decision-making process within humanitarian supply operations has not been investigated yet.

Over the last years, the research focus on decision-making in the field of humanitarian supply chain operations has been fruitful. First, Kim et al. (2019) have recently developed and evaluated a hybrid multi-criteria decision-making model for logistics service providers selection in the disaster preparedness stage, but did not take into account carbon reduction criterion in their model. Second, Zhang et al. (2019) have established a reliability integrated optimization model for the humanitarian relief supply chain in order to improve the disaster operations efficiency of the humanitarian relief supply in the crisis state, but did not include any carbon reduction consideration in their model. Third, Mediouni et al. (2019) have proposed a hybrid evaluation methodology to decide about the most competent expert who can properly and adequately develop and implement humanitarian projects, decision-making approach that does not consider carbon reduction. Fourth, Goldschmidt and Kumar (2019) have investigated the extent to which disaster preparation and preparedness reduce the cost of humanitarian disaster response, but did not take into account carbon reduction in their study. Fifth, Flores-Garza et al. (2017) have introduced a multi-vehicle cumulative covering tour problem whose motivation arises from humanitarian logistics, and without carbon reduction consideration. Next, Yang et al. (2016) have proposed a decision-making programme focusing on reserving relief supplies for earthquake. In other words, in the field of humanitarian supply chain operations, academic research has considered a various set of decision criteria in order to optimize emergency relief routing, including equity and priority (Zhu et al. 2019), or delivery amount in the early recovery phase of disaster (Jana et al. 2019), or supply chain partner selection in continuous aid humanitarian supply chains (Venkatesh et al. 2019). In this regard, Anaya-Arenas et al. (2014)'s systematic literature review indicates the absence of carbon emission criterion in the field of relief distribution networks. Overall, to the best of our knowledge, the criterion of carbon emission has not been taken into account yet in the optimization models within the field of humanitarian supply chain operations, and accordingly, this paper focuses on carbon emission criterion in the decision-making and coordination within humanitarian supply chain operations. Our study aims at providing elements of understanding with this regard.

Various studies have put forward supply chain coordination model based on cost sharing contract under carbon emission restrict. First, Ghosh and Shah (2015) have established nation model based on cost sharing contract considering consumer carbon sensitivity, and they have studied the influence of consumer carbon sensitivity and carbon reduction level on supply chain members. Second, Zhou et al. (2015) have established the Stackelberg model based on emission reduction cost sharing contract, and have compared changes in order quantity, profits of supply chain members and overall profits of the supply chain with or without emission reduction cost sharing contracts. Third, Zhi et al. (2017) have developed a theoretically optimal carbon emission strategy; single cost sharing contract could improve the “hitchhike” phenomenon of single wholesale price contract but could not solve the problem of “double marginalization”. Further, Liu et al. (2016) have discussed low carbon supply chain coordination problem that the supplier leads investment emission reduction under consumer low carbon preference and carbon trading system, and they have proposed quantity discount contract that retailers share emission reduction cost. More recently, Yao et al. (2019) have showed that collaboration in city logistics can indeed improve the profit and achieve carbon emissions abatement at the same time. Lastly, benefits sharing contract (Chen et al. 2008; Yang and Luo 2016), price discount contract (Xu and Zhang 2016; Wang and Luo 2014), and combination of different contracts have been found effective supply chain coordination strategies. In the field of humanitarian supply chain operations, coordination between various stakeholders is one of the major challenges (Dubey et al. 2019), and the extant literature has come up with various contributions in this regard, such as modelling the inter-relationship between factors affecting coordination in a humanitarian supply chain (John et al. 2019). Decentralization is a key theme that has been investigated as well. Indeed, effectiveness depends on the critical last mile between beneficiaries and needed supplies and services, and Muggy and Heier Stamm (2020) have proven new bounds on the system performance that results from decentralized beneficiary decisions in comparison to centralized optimal assignments, and have introduced mechanisms for achieving centrally optimal outcomes even in the presence of decentralization. It is worth noting that the extant literature has not studied coordination of carbon reduction within humanitarian supply chain operations, and this paper aims at filling this research gap.

Overall, given previous research gaps identified throughout our literature review, we have addressed two research questions in this study, namely: (RQ1) What is the optimal strategy for carbon emission reduction amongst direct procurement of carbon emission right, investment in fixed carbon reduction targets and investment in reducing carbon emissions per unit product?, and (RQ2) What is the role of decision-making and coordination related to carbon reduction within humanitarian supply chain? Building on the extant literature, in this paper, consumers’ carbon sensitivity and the influence of consumers’ carbon sensitivity on product market demand are considered. The influence of consumer carbon sensitivity coefficient on the decision making of supply chain member enterprises is analyzed, and the selection of carbon emission strategy in supply chain is also studied, and the coordination strategy based on price discount contract is designed as well.

3 Problem description and variable explanation

In this paper, we have considered a two-stage supply chain composed of a single manufacture and a single retailer, where the manufacturer is the leader, and the retailer is the follower. Based on information symmetry, carbon information and market information are both transparent in such two-stage supply chain where most carbon emission comes from manufacturing processes, and consumers could know carbon emission situations of products. Carbon emission reduction will not affect the production cost function of the manufacturer, i.e. the production marginal cost remains unchanged—under the confirmed technical level, the unit product carbon emission is certain. Under environmental regulations, the supply chain could meet carbon requirements by directly purchasing carbon emission right, investing in fixed carbon emission target or investing in unit product carbon emission reduction. When directly purchasing carbon emission right, the supply chain directly purchases additional emission permission from carbon market. The carbon emission of the supply chain $E_B = eQ$; when investing in fixed carbon emission target, the emission reduction target is irrelevant to output quantity. Assuming total fixed emission reduction target is ω and $\omega > eQ - G$, when supply chain reduces carbon emission, the total emission is lower than the upper limit set by emission trading rules. Otherwise, the supply chain will directly purchase carbon emission permission. The investment to realize the target shall be $\alpha\omega^2 (\alpha > 0)$, which reflects the progressive decrease feature of return on investment in fixed emission reduction target. The carbon emission of the supply chain is $E_F = eQ - \omega$; for investment in unit product carbon emission reduction, the unit output emission is reduced mainly by improving technologies and process flows. Assuming the unit product carbon emission reduction target is $e_\Delta \left(e - G/Q < e_\Delta < e\right)$, the carbon emission of the supply chain is $E_V = \left(e - e_\Delta\right)Q$. Referring to assumptions of Subramanian et al. (2007), the function of carbon emission reduction target about unit production cost shall be $c + \varepsilon e_\Delta$, in which, $\varepsilon \in \left(-c/e_\Delta, \infty\right)$ (Table 1).

4 Model building and analysis

4.1 Analysis on behaviors under decentralized decision making

Under decentralized status, the manufacturer and retailer pursue maximum profits. At that time, their relationship becomes non-cooperative game led by the manufacturer. According to the given wholesale price of the manufacturer, the retailer confirms optimal order

Table 1 System parameters and decision-making variable symbols

Parameter/symbol	Description
G	Upper limit of supply chain carbon emission
P	Carbon trading price
E	Supply chain carbon emission, $E > G$
υ	Constant
κ	Consumer carbon sensitive coefficient
p	Product retail price (consumers' willing to pay for products), and $p = \upsilon - \kappa E$
e	Unit product carbon emission
c	Unit product production cost
Q	Retailer order quantity, decision making variable
w	Product wholesale price, decision making variable
ω	Fixed carbon emission reduction target of the supply chain, assuming $\omega > eQ - G$
e_Δ	Unit product carbon emission reduction target of the supply chain
$\prod_M \prod_R \prod_{SC}$	Manufacturer, retailer and supply chain profit function

quantity based on reverse acquisition method to maximize its profits. Under the strategy of direct procurement of carbon emission right, the expected profits of retailer shall be:

$$\prod\nolimits_R^{DB} = (\upsilon - \kappa e Q - w)Q \tag{1}$$

According to first-order optimal conditions, the optimal order quantity of retailer shall be:

$$Q^{DB} = \frac{\upsilon - w}{2\kappa e} \tag{2}$$

The expected profits of the manufacturer shall be:

$$\prod\nolimits_M^{DB} = (w - c)Q - (eQ - G)P \tag{3}$$

Put formula (2) into formula (3), and acquire the optimal wholesale price of the manufacturer according to the first-order optimal conditions:

$$w^{DB^*} = \frac{\upsilon + c + eP}{2} \tag{4}$$

The optimal order quantity of retailer shall be:

$$Q^{DB^*} = \frac{\upsilon - c - eP}{4\kappa e} \tag{5}$$

Put formula (4) and (5) into formula (1) to get the optimal expected profits of the retailer:

$$\prod\nolimits_R^{DB^*} = \frac{(\upsilon - c - eP)^2}{16\kappa e} \tag{6}$$

Put formula (4) and (5) into formula (3) to get the optimal expected profits of the manufacturer:

$$\prod\nolimits_M^{DB^*} = \frac{(\upsilon - c - ep)^2}{8\kappa e} + PG \tag{7}$$

Under the strategy of direct procurement of carbon emission right, and under the decentralized supply chain led by the manufacturer, the optimal expected profits of the supply chain can be acquired by adding up the optimal expected profits of the retailer and the manufacturer:

$$\prod\nolimits_{SC}^{DB^*} = \frac{3(\upsilon - c - ep)^2}{16\kappa e} + PG \tag{8}$$

Similarly, the equilibrium outcomes under decentralized status for strategies of investment in fixed carbon emission target and investment in unit product carbon emission reduction can be acquired. The equilibrium outcomes of the supply chain in non-cooperative game under three strategies are respectively shown in Table 2.

According to Table 2, for the strategy of direct procurement of carbon emission right, $\frac{w^{DB^*}}{\partial P} > 0$, $\frac{\partial Q^{DB^*}}{\partial P} < 0$, $\frac{\partial Q^{DB^*}}{\partial \kappa} < 0$, $\frac{\partial \prod_R^{DB^*}}{\partial \kappa} < 0$ and $\frac{\partial \prod_M^{DB^*}}{\partial \kappa} < 0$; for investment in fixed carbon emission target, $\frac{\partial w^{DF^*}}{\partial P} > 0$, $\frac{\partial w^{DF^*}}{\partial \kappa} > 0$ and $\frac{\partial Q^{DF^*}}{\partial P} < 0$. When $(\upsilon - c - eP)^2 > \kappa^2\omega^2$, $\frac{\partial \prod_R^{DF^*}}{\partial \kappa} < 0$, $\frac{\partial \prod_M^{DF^*}}{\partial \kappa} < 0$; for investment in unit product carbon emission reduction, $\frac{\partial w^{DV^*}}{\partial P} > 0$, $\frac{\partial Q^{DV^*}}{\partial P} < 0$, $\frac{\partial Q^{DV^*}}{\partial \kappa} < 0$, $\frac{\partial \prod_R^{DV^*}}{\partial \kappa} < 0$ and $\frac{\partial \prod_M^{DV^*}}{\partial \kappa} < 0$. The following conclusions can be drawn:

Table 2 Equilibrium outcomes of each strategy in non-cooperative game

	Direct procurement of carbon emission right	Investment in fixed carbon emission target	Investment in unit product carbon emission reduction
w	$w^{DB^*}=\frac{\upsilon+c+eP}{2}$	$w^{DF^*}=\frac{\upsilon+c+eP+\kappa\omega}{2}$	$w^{DV^*}=\frac{\upsilon+c+\varepsilon e_\Delta+(e-e_\Delta)P}{2}$
Q	$Q^{DB^*}=\frac{\upsilon-c-eP}{4\kappa e}$	$Q^{DF^*}=\frac{\upsilon-c-eP+\kappa\omega}{4\kappa e}$	$Q^{DV^*}=\frac{\upsilon-c-\varepsilon e_\Delta-(e-e_\Delta)P}{4\kappa(e-e_\Delta)}$
E	$E^{DB^*}=\frac{\upsilon-c-eP}{4\kappa}$	$E^{DF^*}=\frac{\upsilon-c-eP-3\kappa\omega}{4\kappa}$	$E^{DV^*}=\frac{\upsilon-c-\varepsilon e_\Delta-(e-e_\Delta)P}{4\kappa}$
p	$p^{DB^*}=\frac{3\upsilon+c+eP}{4}$	$p^{DF^*}=\frac{3\upsilon+c+eP+3\kappa\omega}{4}$	$p^{DV^*}=\frac{3\upsilon+c+\varepsilon e_\Delta+(e-e_\Delta)P}{4}$
$\prod_R$	$\prod_R^{DB^*}=\frac{(\upsilon-c-eP)^2}{16\kappa e}$	$\prod_R^{DF^*}=\frac{(\upsilon-c-eP+\kappa\omega)^2}{16\kappa e}$	$\prod_R^{DV^*}=\frac{[\upsilon-c-\varepsilon e_\Delta-(e-e_\Delta)P]^2}{16\kappa(e-e_\Delta)}$
$\prod_M$	$\prod_M^{DB^*}=\frac{(\upsilon-c-eP)^2}{8\kappa e}+PG$	$\prod_M^{DF^*}=\frac{(\upsilon-c-eP+\kappa\omega)^2}{8\kappa e}+P(G+\omega)-\alpha\omega^2$	$\prod_M^{DV^*}=\frac{[\upsilon-c-\varepsilon e_\Delta-(e-e_\Delta)P]^2}{8\kappa(e-e_\Delta)}+PG$
$\prod_{SC}$	$\prod_{SC}^{DB^*}=\frac{3(\upsilon-c-eP)^2}{16\kappa e}+PG$	$\prod_{SC}^{DF^*}=\frac{3(\upsilon-c-eP+\kappa\omega)^2}{16\kappa e}+P(G+\omega)-\alpha\omega^2$	$\prod_{SC}^{DV^*}=\frac{3[\upsilon-c-\varepsilon e_\Delta-(e-e_\Delta)P]^2}{16\kappa(e-e_\Delta)}+PG$

Conclusion 1: The unit product wholesale price w and selling price p are positively related to carbon trading price P.

Conclusion 2: The optimal order quantity of retailer Q is negatively related to carbon trading price P and consumer carbon sensitivity coefficient κ.

Conclusion 3: The optimal expected profit of the retailer is of negative correlation with consumer carbon sensitivity coefficient κ; the optimal expected profit of the manufacturer is of positive correlation with upper carbon emission limit G in environmental regulations, and of negative correlation with consumer carbon sensitivity coefficient κ.

Conclusion 4: For the strategy of investment in fixed carbon emission target, under certain conditions ($(\upsilon-c-eP)^2>\kappa^2\omega^2$), the optimal expected profits of retailer and manufacturer are negatively related to consumer carbon sensitivity coefficient κ.

4.2 Model analysis under centralized decision making

Under centralized decision-making status, the manufacturer and retailer are deemed as a whole, and relevant decisions shall be made from the angle of system optimization. When directly purchasing carbon emission right, the expected profits of the supply chain shall be:

$$\prod_{SC}^{IB}=(\upsilon-\kappa eQ)Q-(eQ-G)P-cQ \tag{9}$$

According to the first-order optimal conditions, under the centralized decision-making status, the optimal output of the supply chain shall be:

$$Q_B^{IB^*}=\frac{\upsilon-c-eP}{2\kappa e} \tag{10}$$

Put formula (10) to formula (9) to get the optimal expected profit of the supply chain:

$$\prod\nolimits_{SC}^{IB^*} = \frac{[\upsilon - (c + eP)]^2}{4\kappa e} + PG \tag{11}$$

Similarly, the optimal decision-making solution of the supply chain can be acquired under centralized decision-making status for investment in fixed carbon emission target and investment in unit product carbon emission reduction, as shown in Table 3.

According to Table 3, under the centralized decision making, the optimal output of the supply chain is negatively related to consumer carbon sensitivity coefficient κ and carbon trading price P; the optimal expected profit of the supply chain is of negative correlation with consumer carbon sensitivity coefficient κ and of positive correlation with upper carbon emission limit G in environmental regulations. When investing in fixed carbon emission reduction, under certain conditions ($(\upsilon - c - eP)^2 > \kappa^2\omega^2$), the optimal expected profit of the supply chain is negatively related to consumer carbon sensitivity coefficient κ.

4.3 Comparative analysis on decentralized decision making and centralized decision making

Under the decentralized decision-making status, both the manufacturer and the retailer pursue respectively maximum profits, while under the centralized decision-making status, the supply chain formulate relevant decisions from the angle of system optimization. When directly purchasing carbon emission right, compare the optional order quantity of retailer under decentralized status with the optimal output of supply chain under the centralized status,

$$Q^{IB^*} > Q^{DB^*} \tag{12}$$

Compare the expected profits of the supply chain under decentralized status with the optimal expected profits under centralized status,

$$\prod\nolimits_{SC}^{IB^*} > \prod\nolimits_{SC}^{DB^*} \tag{13}$$

However, with increase of retailer's order quantity, the carbon emission in the supply chain is added. Compare the carbon emission of the supply chain under decentralized status with carbon emission of supply chain under centralized status,

$$E^{IB^*} > E^{NB^*} \tag{14}$$

Table 3 Optimal solution of supply chain for each strategy under centralized decision making

	Direct procurement of carbon emission right	Investment in fixed carbon emission target	Investment in unit product carbon emission reduction
Q	$Q^{IB^*} = \frac{\upsilon-c-eP}{2\kappa e}$	$Q^{IF^*} = \frac{\upsilon-c-eP+\kappa\omega}{2\kappa e}$	$Q^{IV^*} = \frac{\upsilon-(c+\varepsilon e_\Delta)-(e-e_\Delta)P}{2\kappa(e-e_\Delta)}$
E	$E^{IB^*} = \frac{\upsilon-c-eP}{2\kappa}$	$E^{IF^*} = \frac{\upsilon-c-eP-\kappa\omega}{2\kappa}$	$E^{IV^*} = \frac{\upsilon-(c+\varepsilon e_\Delta)-(e-e_\Delta)P}{2\kappa}$
p	$p^{IB^*} = \frac{\upsilon+c+eP}{2}$	$p^{IF^*} = \frac{\upsilon+c+eP+\kappa\omega}{2}$	$p^{IV^*} = \frac{\upsilon+(c+\varepsilon e_\Delta)+(e-e_\Delta)P}{2}$
$\prod_{SC}$	$\prod_{SC}^{IB^*} = \frac{[\upsilon-(c+eP)]^2}{4\kappa e} + PG$	$\prod_{SC}^{IF^*} = \frac{[(\upsilon+\kappa\omega)-(c+eP)]^2}{4\kappa e} + P(G+\omega) - \alpha\omega^2$	$\prod_{SC}^{IV^*} = \frac{[\upsilon-(e-e_\Delta)P-(c+\varepsilon e_\Delta)]^2}{4\kappa(e-e_\Delta)} + PG$

Similarly, the optimal comparison results of the supply chain under decentralized status and centralized status for investment in fixed carbon emission target and investment in unit product carbon emission reduction. The comparison results for each strategy can be seen in Table 4.

According to Table 4, compared to the decentralized status, the optional output and optional expected profits of the supply chain for each strategy under the centralized decision-making status will increase, but the carbon emission in the supply chain will add accordingly. The centralized decision making is an ideal way to make decisions. At that time, the supply chain becomes an integral whole. Under such status, decisions made are the overall optimal, and they could provide standards and references for coordinative research on decentralized supply chain.

4.4 Analysis on decision-making for investment in supply chain carbon emission

The common strategies meeting requirements of carbon emission regulations are direct procurement of carbon emission right, investment in fixed carbon emission target, and investment in unit product carbon emission reduction. Next, the applicability of various strategies is analyzed. In general, the market demand Q is assumed certain.

Under centralized decision making status, make the optimal expected profits of the supply chain are the same for strategies of direct procurement of carbon emission right and investment in fixed carbon emission target, i.e., $\prod_{SC}^{IB} = \prod_{SC}^{IF}$, then,

$$P_{BF} = \alpha\omega - \kappa Q \tag{15}$$

Similarly, make the optimal profits of the supply chain are the same for strategies of direct procurement of carbon emission right and investment in fixed carbon emission target, and optimal profits for strategies of direct procurement of carbon emission right and investment in unit product carbon emission reduction the same, respectively,

$$P_{BV} = \varepsilon - \kappa Q \tag{16}$$

$$P_{FV} = \frac{\left(\kappa\omega + \varepsilon e_{\Delta}\right)Q - \left(\alpha\omega^2 + \kappa e_{\Delta} Q^2\right)}{e_{\Delta} Q - \omega} \tag{17}$$

The formula $P_{FV} = \left(\kappa\omega + \varepsilon e_{\Delta}\right)Q - \left(\alpha\omega^2 + \kappa e_{\Delta} Q^2\right) / e_{\Delta} Q - \omega$ is available, when $P < P_{FV}$, $\prod_{SC}^{IV} < \prod_{SC}^{IF}$; when $P > P_{FV}$, $\prod_{SC}^{IV} > \prod_{SC}^{IF}$. Compare P_{BF} with P_{BV}, P_{BF} with P_{FV}, P_{BV} with P_{FV} respectively, it can be concluded that: if $\omega > \varepsilon / \alpha$, then $P_{FV} < P_{BV}$; if $\omega < \varepsilon / \alpha$, then $P_{BF} < P_{BV} < P_{FV}$.

Table 4 Contrast table of decentralized decision making and centralized decision making for each strategy

	Comparison results		
	Direct procurement of carbon emission right	Investment in fixed carbon emission target	Investment in unit product carbon emission reduction
Q	$Q^{IB^*} > Q^{DB^*}$	$Q^{IF^*} > Q^{DF^*}$	$Q^{IV^*} > Q^{DV^*}$
E	$E^{IB^*} > E^{DB^*}$	$E^{IF^*} > E^{DF^*}$	$E^{IV^*} > E^{DV^*}$
$\prod_{SC}$	$\prod_{SC}^{IB^*} > \prod_{SC}^{DB^*}$	$\prod_{SC}^{IF^*} > \prod_{SC}^{DF^*}$	$\prod_{SC}^{IV^*} > \prod_{SC}^{DV^*}$

To sum up, the relationship among $\prod_{SC}^{IB}$, $\prod_{SC}^{IF}$ and $\prod_{SC}^{IV}$ and corresponding selection strategies can be seen in Table 5, in which, B represents the strategy that the supply chain directly purchases additional carbon emission permission from open carbon market; F represents the strategy of the supply chain to invest in fixed carbon emission reduction, and V represents the strategy of investment in unit product carbon emission reduction.

According to Table 5, different strategies may all meet requirements of environmental regulations for carbon emission. However, the profits of the supply chain are greatly different.

Conclusion 5: When the carbon trading price P is low, the supply chain will directly purchase additional emission permission right from carbon open to meet requirements;

Conclusion 6: When the carbon trading price P is high, the supply chain will invest in unit product carbon emission reduction;

Conclusion 7: When the carbon trading price P is in the middle scope, the investment of the supply chain in carbon emission depends on fixed carbon emission target (ω), which relies on the ratio of unit product emission reduction investment cost and fixed target emission reduction investment cost (ε / α). If the fixed carbon emission target (ω) is high, the supply chain chooses to invest in unit product carbon emission reduction; if the fixed carbon emission target (ω) is low, the supply chain chooses to investment in fixed carbon emission target.

4.5 Coordination model analysis

The price discount contract is a kind of effective supply chain coordination strategy. Under the price discount contract, if the supply chain could make investment and production according to decentralized decision-making mode, the optional expected profits member enterprises under coordinative status will no larger than that under decentralized status.

For the strategy of direct procurement of carbon emission right, assume the discount price negotiated is w^{CB}, the expected profits of the manufacturer and the retailer are respectively:

$$\prod_{M}^{CB^*} = \left(w^{CB} - c\right)Q^{IB^*} - \left(eQ^{IB^*} - G\right)P \tag{18}$$

$$\prod_{R}^{CB^*} = \left(\upsilon - \kappa eQ^{IB^*} - w^{CB}\right)Q^{IB^*} \tag{19}$$

It is necessary to make $\prod_{M}^{CB^*} \geq \prod_{M}^{DB^*}$ and $\prod_{R}^{CB^*} \geq \prod_{R}^{DB^*}$ tenable simultaneously. Put formula (18) and (19) into aforesaid inequations,

$$w^{CB'} \leq w^{CB} \leq w^{CB''}$$

In which, $w^{CB'} = \frac{\Pi_{M}^{DB^*} + (eQ^{IB^*} - G)P}{Q^{IB^*}} + C$; $w^{CB''} = \upsilon - \kappa eQ^{IB^*} - \frac{\Pi_{R}^{DB^*}}{Q^{IB^*}}$.

$w^{CB'}$ is the minimum product price acceptable for the manufacturer; $w^{CB''}$ is the wholesale price of products acceptable for the retailer; w^{CB} is the agreed discount price. The specific value shall be decided by negotiation ability of both parties.

Table 5 Strategy selection under centralized decision-making mode

Selection conditions	Selection strategy				
$\omega > \varepsilon / \alpha$	Carbon trading price	$P < P_{FV}$	$P_{FV} \leq P < P_{BV}$	$P_{BV} < P < P_{BF}$	$P \geq P_{BF}$
	Expected profit relationship	$\prod_{SC}^{IV} < \prod_{SC}^{IF} < \prod_{SC}^{IB}$	$\prod_{SC}^{IF} < \prod_{SC}^{IV} < \prod_{SC}^{IB}$	$\prod_{SC}^{IF} < \prod_{SC}^{IB} < \prod_{SC}^{IV}$	$\prod_{SC}^{IB} < \prod_{SC}^{IF} < \prod_{SC}^{IV}$
	Optimal strategy	B	B	V	V
$\omega < \varepsilon / \alpha$	Carbon trading price	$P < P_{BF}$	$P_{BF} \leq P < P_{BV}$	$P_{BV} \leq P < P_{FV}$	$P \geq P_{FV}$
	Expected profit relationship	$\prod_{SC}^{IV} < \prod_{SC}^{IF} < \prod_{SC}^{IB}$	$\prod_{SC}^{IV} < \prod_{SC}^{IB} < \prod_{SC}^{IF}$	$\prod_{SC}^{IB} < \prod_{SC}^{IV} < \prod_{SC}^{IF}$	$\prod_{SC}^{IB} < \prod_{SC}^{IF} < \prod_{SC}^{IV}$
	Optimal strategy	B	F	F	V

Table 6 Decision making results of each strategy under price discount contract

Selection situations	Discount price value interval
Direct procurement of carbon emission right	$\frac{\prod_{M}^{DB^*}+(eQ^{IB^*}-G)P}{Q^{IB^*}}+c\leq w^{CB}\leq \upsilon-\kappa eQ^{IB^*}-\frac{\prod_{R}^{DB^*}}{Q^{IB^*}}$
Investment in fixed carbon emission target	$\frac{\prod_{M}^{DF^*}+(eQ^{IF^*}-\omega-G)P+\alpha\omega^2}{Q^{IF^*}}+c\leq w^{CF}\leq \upsilon-\kappa\left(eQ^{IF^*}-\omega\right)-\frac{\prod_{R}^{DF^*}}{Q^{IF^*}}$
Investment in unit product carbon emission	$\frac{\prod_{M}^{DV^*}+((e-e_{\Delta})Q^{IV^*}-G)P}{Q^{IV^*}}+\left(c+\varepsilon e_{\Delta}\right)\leq w^{CV}\leq \upsilon-\kappa\left(e-e_{\Delta}\right)Q^{IV^*}-\frac{\prod_{R}^{DV^*}}{Q^{IV^*}}$

Similarly, the discount price value interval under the price discount contract for investment in fixed emission reduction target and investment in unit product carbon emission can be acquired, as shown in Table 6.

5 Numerical analysis

Based on aforesaid theoretical analysis, the optimal decision making of supply chain members under decentralized and coordinative status and centralized decision-making status for different strategies can be acquired. Next, the optimal decision makings under different strategies are verified by numerical analysis. Suppose $\upsilon = 100$, upper limit of supply chain carbon emission $G = 200$, carbon trading price $P = 2.4$, unit product carbon emission $e = 0.9$, unit product production cost $c = 3$, $\alpha = 2$ and $\varepsilon = 1.2$, and consumer carbon sensitivity coefficient $\kappa = 0.8$. Since $\omega > eQ - G$ and $e - G/Q < e_{\Delta} < e$, under aforesaid

Table 7 Optimal decision-making results for each strategy under decentralized decision-making mode

	Direct procurement of carbon emission right	Investment in fixed carbon emission target	Investment in unit product carbon emission reduction
w	$w^{DB^*}=52.58$	$w^{DF^*}=60.58$	$w^{DV^*}=52.16$
Q	$Q^{DB^*}=32.93$	$Q^{DF^*}=38.49$	$Q^{DV^*}=149.5$
E	$E^{DB^*}=29.64$	$E^{DF^*}=14.64$	$E^{DV^*}=29.9$
p	$p^{DB^*}=76.29$	$p^{DF^*}=88.4$	$p^{DV^*}=76.08$
$\prod_R$	$\prod_{R}^{DB^*}=780.78$	$\prod_{R}^{DF^*}=1066.45$	$\prod_{R}^{DV^*}=3576.04$
$\prod_M$	$\prod_{M}^{DB^*}=2041.57$	$\prod_{M}^{DF^*}=1860.9$	$\prod_{M}^{DV^*}=7632.08$
$\prod_{SC}$	$\prod_{SC}^{DB^*}=2822.34$	$\prod_{SC}^{DF^*}=2927.35$	$\prod_{SC}^{DV^*}=11208.12$

Table 8 Optimal decision-making results for each strategy under centralized decision-making mode

	Direct procurement of carbon emission right	Investment in fixed carbon emission target	Investment in unit product carbon emission reduction
Q	$Q^{IB^*}=65.86$	$Q^{IF^*}=76.97$	$Q^{IV^*}=299$
E	$E^{IB^*}=59.28$	$E^{IF^*}=49.28$	$E^{IV^*}=59.8$
p	$p^{IB^*}=52.58$	$p^{IF^*}=60.58$	$p^{IV^*}=52.16$
$\prod_{SC}$	$\prod_{SC}^{IB^*}=3063.13$	$\prod_{SC}^{IF^*}=3993.80$	$\prod_{SC}^{IV^*}=14784.16$

assumption, $\omega = 20$ and $e_{\Delta} = 0.7$, the optimal decision making results of the supply chain for each strategy under decentralized status and centralized status can be seen in Tables 7 and 8.

Comparing Table 8 with Table 7, we can see that under centralized decision-making mode, the optimal output and optimal profits of the supply chain for each strategy are higher than that under decentralized decision-making mode. Tables 7 and Table 8 show that the discount price value interval of each strategy under price discount contract can be seen in Table 9.

In aforesaid discount price value intervals, compared to decentralized decision-making mode, the optimal profits of the manufacturer and the retailer are increased. The optimal profits of the manufacturer and retailer for each strategy can be seen in Table 10, Tables 11 and 12. The price discount contract makes supply chain coordination possible. However, the value of discount price in aforesaid intervals is decided by the status of the manufacturer and the retailer and their negotiation ability.

When the carbon sensitivity coefficient varies, the changes in retailer optimal order, and both retailer and manufacturer optimal profits can be seen in Table 13; when the carbon trading price varies, the changes in optimal order of the retailer, product wholesale price and selling price can be seen in Table 14.

According to Table 13, when consumer carbon sensitivity coefficient is higher, consumers are more sensitive to carbon, and consequently, retailer optimal order quantity, as well as retailer and manufacturer optimal expected profits are all reduced under all three strategies. It means that retailer optimal order quantity, both retailer and manufacturer optimal expected profits are negatively related to the consumer carbon sensitivity coefficient. According to Table 14, when the carbon trading price is higher, and unit product wholesale price and selling price are higher, then the retailer optimal order quantity is reduced. It proves that the unit product wholesale price and selling price is of positive correlation with the carbon trading price, while the optimal retailer order quantity is negatively correlated with the carbon trading price.

6 Theoretical implications

Humanitarian supply chain operations is a fast-growing research field with multiple emerging research themes (Akter and Wamba 2019; Banomyong et al. 2019; Chiappetta et al. 2019) amongst which lies the theme of sustainability. In this study, we have addressed two research questions, namely: RQ1) What is the optimal strategy for carbon emission reduction amongst direct procurement of carbon emission right, investment in fixed carbon reduction targets and investment in reducing carbon emissions per unit product?, and RQ2) What is the role of decision-making and coordination related to carbon reduction within humanitarian supply chain?

Table 9 Wholesale price value of each strategy under price discount contract

Selection situations	Discount price value interval
Direct procurement of carbon emission right	$28.87 \le w^{CB} \le 40.72$
Investment in fixed carbon emission target	$32.87 \le w^{CF} \le 46.72$
Investment in unit product carbon emission	$28.24 \le w^{CV} \le 40.2$

Table 10 Optimal profit of the manufacturer and retailer under the price discount for direct procurement of carbon emission right

	Discount price value interval											
	28.87	29.87	30.87	31.87	32.87	33.87	34.87	35.87	36.87	37.87	38.87	40.72
$\Pi_M^{CB^*}$	2041.57	2107.40	2173.26	2239.12	2304.98	2370.84	2436.70	2502.56	2568.42	2634.28	2700.14	2821.98
$\Pi_R^{CB^*}$	1561.56	1495.73	1429.87	1364.01	1298.15	1232.29	1166.43	1100.57	1034.71	968.85	902.99	781.15

Table 11 Optimal profit of the manufacturer and retailer under the price discount for investment in fixed carbon emission reduction target

	Discount price value interval												
	32.87	34.87	35.87	36.87	37.87	38.87	39.87	40.87	41.87	42.87	43.87	44.87	46.72
Π_M^{CF*}	1860.90	2014.78	2091.75	2168.72	2245.69	2322.66	2399.63	2476.60	2553.57	2630.54	2707.51	2784.48	2926.87
Π_R^{CF*}	2132.90	1979.02	1902.05	1825.08	1748.11	1671.14	1594.17	1517.20	1440.23	1363.26	1286.29	1209.32	1066.93

Table 12 Optimal profit of the manufacturer and retailer under the price discount for investment in unit product carbon emission reduction

	Discount price value interval										
	28.24	30.24	31.24	32.24	33.24	34.24	35.24	36.24	37.24	38.24	40.2
Π_M^{CV*}	7632.08	8230.08	8529.08	8828.08	9127.08	9426.08	9725.08	10,024.08	10,323.08	10,622.08	11,208.12
Π_R^{CV*}	7152.08	6554.08	6255.08	5956.08	5657.08	5358.08	5059.08	4760.08	4461.08	4162.08	3576.04

Table 13 Influence of changes in consumer carbon sensitivity coefficient

	Consumer carbon sensitivity coefficient							
	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
Q^{DB*}	32.93	29.27	26.34	23.95	21.95	20.26	18.82	17.56
Q^{DF*}	38.49	34.83	31.9	29.51	27.51	25.82	24.37	23.12
Q^{DV*}	149.5	132.89	119.6	108.73	99.67	92	85.43	79.73
Π_M^{DB*}	2041.57	1868.06	1729.25	1615.69	1521.04	1440.96	1372.32	1312.84
Π_R^{DB*}	2041.57	1868.06	1729.25	1615.69	1521.04	1440.96	1372.32	1312.84
Π_M^{DF*}	1860.9	1692.95	1559.7	1451.69	1362.6	1288.08	1224.99	1171.06
Π_R^{DF*}	1066.45	982.47	915.85	861.84	817.3	780.04	748.5	721.53
Π_M^{DV*}	7632.08	6837.4	6201.66	5681.51	5248.05	4881.28	4566.9	4294.44
Π_R^{DV*}	3576.04	3178.7	2680.83	2600.76	2384.03	2200.64	2043.45	1907.22

Table 14 Influence of changes in carbon trading price

	Carbon trading price							
	2.4	3.0	3.5	4.0	4.5	5.0	5.5	6.0
Q^{DB*}	32.93	32.74	32.59	32.43	32.27	32.12	31.96	31.81
Q^{DF*}	38.49	38.30	38.14	37.99	37.83	37.67	37.52	37.36
Q^{DV*}	149.50	149.31	149.16	149.00	148.84	148.69	148.53	148.38
w^{DB*}	52.58	52.85	53.08	53.30	53.53	53.75	53.98	54.20
w^{DF*}	60.58	60.85	61.08	61.30	61.53	61.75	61.98	62.20
w^{DV*}	52.16	52.22	52.27	52.32	52.37	52.42	52.47	52.52
p^{DB*}	76.29	76.43	76.54	76.65	76.76	76.88	76.99	77.10
p^{DF*}	88.29	88.43	88.54	88.65	88.76	88.88	88.99	89.10
p^{DV*}	76.08	76.11	76.14	76.16	76.19	76.21	76.24	76.26

Based on our modeling approach considering a two-stage supply chain made of a single manufacturer and a single retailer, as well as product market demands affected by carbon sensitive consumers, and various carbon emission reduction strategies, multiple game models have been established under decentralized decision-making, centralized decision-making and coordinative status, and the influence law of customer carbon sensitivity coefficient and carbon trading price on supply chain carbon reduction investment decision making and member enterprise optimal decision making have been disclosed. Our research findings have indicated that the choice of supply chain carbon reduction strategies depends on carbon trading price and fixed emission reduction target, both the wholesale price and selling price of products are positively correlated with carbon trading price, and both optimal production volume of supply chain and optimal expected profit of supply chain operations are negatively correlated with consumer carbon sensitivity coefficient.

Given the absence of research studies considering the criterion of carbon emission reduction in the optimization models within the field of humanitarian supply chain operations, the main theoretical implication of our study is to provide one of the first decision-making models integrating carbon emission reduction in the field of humanitarian supply chain management. The model we have come up with adds to a series of other decision-making models—in the area of humanitarian supply chain management—based on other criteria (Flores-Garza et al. 2017; Goldschmidt and Kumar 2019; Kim et al. 2019; Mediouni et al. 2019; Yang et al. 2016). In addition, the coordination of carbon reduction within humanitarian supply chain operations has not been studied yet in the extant literature, and our study is one of the first indicating that the price discount contract may realize coordination within a supply chain, but the value of discount price depends on respective negotiation ability.

7 Managerial implications

Nowadays, sustainability with humanitarian supply chain operations appears to be more and more at stake, and from now on, both operations managers and supply chain managers in the humanitarian field should be aware that optimal supply chain members' decision making can be acquired for different strategies under decentralized and coordinative status and centralized decision-making status. In addition, managers in the humanitarian field should be aware and should take into account the following insights in their mindset: compared to the decentralized status, the optional output and optional expected profits of the supply chain for each strategy under the centralized decision-making status will increase, but the carbon emission in the supply chain will add accordingly. The centralized decision-making process is an ideal way to make decisions. At that time, a supply chain becomes an integral whole, and under such status, decisions made are the overall optimal, and could provide both standards and references for coordinative research on decentralized supply chain. Overall, both operations managers and supply chain managers in the field of humanitarian supply chain operations should consider the criterion of carbon emission reduction in their decision-making processes, humanitarian managers and should consider our insights regarding coordination of carbon emission reduction from now on.

8 Limitations and further research directions

Our research findings indicate that total supply chain carbon emissions increase under centralized decision making and coordination status, and further research is still needed regarding the problem about ways to lower supply chain carbon emission while realizing higher profits for supply chain members. First, one potential research direction may be to build on Balcik et al. (2010)'s study investigating various coordination mechanisms practiced in humanitarian relief chains. Second, when supply chain operations have clear preferences about carbon emission reduction, both optimization and coordination within a humanitarian supply chain should be considered for future research. Our study explores the optimal strategy for carbon emission reduction amongst direct procurement of carbon emission right, investment in fixed carbon reduction targets and investment in reducing carbon emissions per unit product, and one further research direction would be to consider a multi-stage supply chain network. Third, another research direction may be to expand existing hybrid decision-making models in humanitarian supply chain management by taking into account carbon reduction criteria, including Kim et al. (2019)'s hybrid multi-criteria decision-making model for logistics service providers selection in the disaster preparedness stage, or Mediouni et al. (2019)'s hybrid evaluation methodology to determine the most appropriate expert to develop and implement humanitarian projects, with a view to start investigating the impact of carbon reduction criteria within more sophisticated decision-making models in the field of humanitarian supply chain management. Fourth, our decision-making model based on information symmetry between supply chain members, and in order to move forward, a further research direction could be to design an asymmetric-information model.

In addition, over the recent years, tremendous developments in big data analytics which the domain of humanitarian supply chain management should leverage on (Gupta et al. 2019; Prasad et al. 2018), and consequently, further research directions could focus on the impact of big data analytics in improving carbon emission reduction decision-making and coordination processes within humanitarian supply chains. Indeed, sustainability in humanitarian supply chain operations is at stake from now on, and for instance, Big Data could play a key role in explaining disaster resilience in supply chains for sustainability (Papadopoulos et al. 2017). Therefore, it is crucial that further research projects focus on the extent to which big data analytics could help and support sustainable humanitarian supply chain operations (Griffith et al. 2019).

Overall, the future research agenda should consider the extent to which both decision-making and coordination within humanitarian supply chain operations could benefit from more elaborated decision-making models, and the recent developments in big data analytics, to name a few.

To conclude, academic research on humanitarian supply chain management is growing at a fast pace (Anaya-Arenas et al. 2014; Burkat et al. 2017; Duhamel et al. 2017), and this emerging research field is still in need of relevant theories for a deeper scholarly understanding of a concept such as humanitarian operations (Oloruntoba et al. 2019). Accordingly, the future research agenda should integrate the identification of relevant theoretical lenses making sense of both carbon emission reduction decision-making and coordination within humanitarian supply chain operations.

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