Computers & Industrial Engineering 98 (2016) 483–497

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Low carbon chance constrained supply chain network design problem: a Benders decomposition based approach

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ARTICLE INFO

Article history:
Received 20 September 2015
Received in revised form 15 March 2016
Accepted 9 June 2016
Available online 18 June 2016

Keywords:
Green supply chain network design
Carbon footprint
Chance constrained programming
Benders decomposition
Stochastic programming
Sustainability

ABSTRACT

This paper proposes a chance constrained based green supply chain network design model addressing carbon emissions and carbon trading issues. The model determines the optimal flow of materials as well as emissions across the supply chain network. The basic model has been further extended into two models addressing different carbon emission issues. This study has contributed to the body of existing green supply chain literature through addressing uncertainties of suppliers' capacities, plants' capacities, warehouses' capacities and demand for sustainable supply chain network design problem. This study applies Benders decomposition algorithm to handle chance constrained sustainable supply chain network design problem. The proposed models are illustrated with suitable examples and results are carefully analyzed and discussed. The results demonstrated that the flow of materials across the supply chain network varies with the change of the probability as well as carbon credit price. The number of openings of the plants is also influenced with the change of carbon credit price. Similarly, variable cost and variable emissions have been found increased and decreased, respectively with the increase of carbon credit price for the base model. The model is also equipped with dissimilar carbon prices for handling cap and trade scenario. This paper may help managers to deal uncertainties as well as managing emissions of a supply chain network.

1. Introduction

Rapid industrialization, increase of logistics services, modernization of human lives, ever growing population, depletion of greeneries have broadly resulted into increasing the temperature of the earth, which can be called as global warming (Du, Hu, & Wang, 2015). The harmful effects of global warming are being faced by the mankind in terms of various kinds of natural calamities like flood, drought, cyclone, unnatural monsoon, unusual heat, unusual cold, and melting of ice at unusual rate (Dore, 2005). Global warming is a complex problem and certainly, numerous factors are responsible for it. However, most of the studies across the world have unanimously accepted the over emissions of green house gases in the environment as one of the key reasons behind rapid increase of earth's temperature (Pachauri & Reisinger, 2008). The international communities are assembled on periodic basis and are engaged in negotiation to develop legally binding international laws for carbon footprint reduction (Du et al., 2015; Duan, Zhu, & Fan, 2014). Several negotiations at global level have resulted into various carbon reduction policies such as carbon emissions tax, inflexible cap, and cap and trade which are gradually being adopted by various economies across the world (Benjaafar, Yanzhi, & Daskin, 2013). As a result, a purely economic oriented approach of conducting business is now facing wide criticism across the world.

Over the period of time, eminent scholars have emphasized on sustainability and its incorporation in corporate strategy to improve the competitiveness of supply chain (Gunasekaran, Subramanian, & Rahman, 2015; Hart, 1997; Lash & Wellington, 2007; Packard & Reinhardt, 2000; Porter & Kramer, 2006; Subramanian & Gunasekaran, 2015). Most of them suggested that environmental sustainability should be viewed as an opportunity rather than a risk. Recently, many firms have realized that sustainability is a bottom-line requirement, which cannot be ignored further. The concept of sustainable supply chain is not new. The readers can refer the following review papers for developing an overall idea about various issues related to sustainable or green supply chain (Ahi & Searcy, 2013; Brandenburg, Govindan, Sarkis, & Seuring, 2014; Fahimnia, Sarkis, & Davarzani, 2015; Seuring & Müller, 2008; Srivastava, 2007).

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http://dx.doi.org/10.1016/j.cie.2016.06.011
0360-8352/

The concept of low carbon supply chain has recently been established, and received wide attentions across the business communities within very short span of time (Hongjuan & Jing, 2011). According to Alyson Slater, "whatever sector or business you're in, disclosure is increasingly expected, and failure to disclose can put you at a strategic disadvantage", Global Reporting Initiative (Bortz, 2007).

Numerous researchers have suggested different ways to manage emissions of a supply chain such as supplier selection (Govindan, Rajendran, Sarkis, & Murugesan, 2015), carbon constrained lot sizing (Purohit, Shankar, Dey, & Choudhary, 2016), supply chain network optimization (Choudhary, Sarkar, Settur, & Tiwari, 2015; Govindan, Jafarian, & Nourbakhsh, 2015; Zhang, Shah, Wassick, Helling, & Egerschot, 2014), and application of game theory in the context of sustainability (Hafezalkotob, 2015; Ren, Bian, Xu, & He, 2015). Supply chain network design is one of many options to reduce the emissions. Over the period of time, firms have realized the importance of restructuring their supply chain networks to become more sustainable. This realization was observed in a survey, conducted by Aberdeen Group over 300 firms, located in various parts of the world. It was observed that 50% of the surveyed firms wished to redesign their supply chains for becoming more sustainable than earlier (Chaabane, Ramudhin, & Paquet, 2011; Chaabane, Ramudhin, & Paquet, 2012; Viswanathan, Jhana, & Robert, 2008). According to Wu and Dunn (1995) transportation is the largest source of emissions in the logistics system. Therefore, proper optimisation of the supply chain may decrease the emissions of a supply chain. Choudhary et al. (2015) have given significant stress on the development of strategic supply chain network that should serve cost and emissions reductions simultaneously.

Traditionally, supply chain network design problems were mostly analyzed from the perspective of fixed and variable costs without taking carbon footprint factor into account (Elhedhli & Merrick, 2012). However, this trend has been changing rapidly. Environmentally conscious supply chain planning intends to build optimization models where economic aspects such as profit maximization and cost minimization are integrated with environmental goal such as carbon footprint reduction (Sundarakani, deSouza, Goh, Wagner, & Manikandan, 2010; Varsei, Soosay, Fahimnia, & Sarkis, 2014). Over a short span of time, a significant amount of studies have been conducted over sustainable supply chain network design. Despite all the studies, there is a huge potential for developing quantitative models addressing the sustainability issues (Gunasekaran & Spalanzani, 2012).

Interestingly, most of the studies were conducted taking consideration of deterministic environment. As of now, very few studies have been conducted addressing stochastic issues for sustainable supply chain network design (Alhaj, Svetinovic, & Diabat, 2016; Govindan, Jafarian et al., 2015; Rezaee, Dehghanian, Fahimnia, & Beamon, 2015). Alhaj et al. (2016) study especially considered demand as a stochastic variable and ignored stochastic properties of other variables such as supplier's capacity, plant's capacity, and warehouse's capacity. Their study did not consider the fixed emissions factor for supply chain network design. In the same line, Govindan, Jafarian et al. (2015) and Rezaee et al. (2015) did not consider the fixed emissions for sustainable supply chain network design. We believe that fixed emissions are an integral part for carbon focused supply chain network design. In addition, applications of decomposition techniques (for example: Benders, Lagrangian and Dantzig-Wolfe decompositions) to handle the stochastic sustainable network design problems were sparsely reported in the scientific journals (Rezaee et al., 2015). Most of the time uncertainty issues for green supply chain were managed by applying fuzzy programming techniques (Pishvaee & Razmi, 2012; Pishvaee, Torabi, & Razmi, 2012; Pishvaee, Razmi, & Torabi, 2014; Talaei, Moghaddam, Pishvaee, Amiri, & Gholamnejad, 2016).

Apart from these, the impacts of probabilities on the flow of materials across the supply chain network have not been adequately studied in the context of sustainable supply chain network design problem. As per our knowledge a combined Benders and chance constrained programming based approach to handle sustainable supply chain network design problems has been inadequately addressed in literature. Most of the time stochastic sustainable supply chain network models were developed considering various scenarios of probabilities (Alhaj et al., 2016; Govindan, Jafarian et al., 2015). This study addresses all the above discussed research gaps of the existing literature.

The aim of this paper is to develop a sustainable supply chain network design model considering the uncertainties of suppliers' capacities, uncertainties of plants' capacities, uncertainties of warehouses' capacities and uncertainties of customers' demands. The study also applies Benders based solution methodology to solve the proposed problem.

Few contributions of this paper are as follows. This paper applies the chance constrained programming to handle uncertainties of various variables in sustainable supply chain network design problem. A Benders based solution methodology is proposed to handle the proposed model. This paper also conducted various sensitivity analyses considering different probability levels of different factors. The analyses may be helpful for managers to manage the carbon footprint as well as cost in the competitive world. The remainder of the paper is organized as follows. Section 2 discusses the relevant literature related to sustainable supply chain network design, stochastic supply chain network design, and network design using Benders decomposition. Section 3 presents the proposed model and the proposed methodology. Section 4 addresses the illustrative example. And lastly, Section 5 reports the conclusion of the paper.

2. Literature review

Supply chain network design is an ever green research topic. As of now, a significant amount of studies have been conducted addressing various aspects of the business. For more details about the existing literature related to supply chain network design, readers may refer the following review papers: Vidal and Goetschalckx (1997), Meixell and Gargeya (2005), Melo, Nickel, and Saldanha-da-Gama (2009), Klibi, Martel, and Guitouni (2010), and Farahani, Asgari, Heidari, Hosseininia, and Goh (2012). Carbon constrained supply chain network design is relatively new concept as compared to conventional supply chain network design problem. A significant amount of studies have been carried out across the world with in a very short span of time addressing the carbon footprint issues. This study classifies the literature into three groups such as: literature related to green supply chain network design; literature on uncertain sustainable supply chain network design problem; literature on supply chain network design by applying Benders decomposition.

2.1. Literature related to green supply chain network design

Sundarakani et al. (2010) were among the few seminal authors who talked about the carbon footprint reduction of a supply chain network. The authors suggested an analytical model to capture the carbon emissions of a supply chain by applying heat flux technology. They have provided some valuable suggestions to minimize the carbon footprints across the supply chain. Wang, Lai, and Shi (2011) proposed a single period multi-objective mixed integer linear programming model for optimizing the global supply chain