Journal of Cleaner Production 110 (2016) 149–157

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

A model proposal for green supply chain network design based on consumer segmentation

Semih Coskun, Leyla Ozgur, Olcay Polat, Askiner Gungor*

Dept. of Industrial Engineering, Pamukkale University, 20160, Pamukkale, Denizli, Turkey

ARTICLE INFO

Article history:
Received 15 August 2014
Received in revised form
17 February 2015
Accepted 24 February 2015
Available online 4 March 2015

Keywords:
Customer segmentation
Consumer behavior
Green supply chain network
Goal programming

ABSTRACT

The consumption-based economy has created enormous ecological footprint of product and service life cycles. Therefore, the environmental sustainability has become one of the major concerns of today's society and sparked tremendous amount of research. According to the related literature analysis, there is no specific study to design the green supply chain network based on consumers' green expectations. This study aims to contribute to the fulfillment of this research gap by proposing a goal-programming model considering three consumer segments, i.e., green, inconsistent and red consumers. A hypothetical real-life-like example problem is solved to demonstrate clearly the value and applicability of the proposed model. A set of scenarios is also studied to offer an insight on how the consumer determination level of greenness affects the green supply network. The findings of the study present a way to measure the relations between green supply chains and consumer behavior.

1. Introduction

The concern on environmental sustainability has lead to “green” practices related to entire cradle to grave life cycles of products. Designing products based on green initiatives, generating environmentally benign production environments and processes, warehouse management and designing forward and backward distribution networks based on green principles are very important decision domains related to environmental sustainability (Gungor and Gupta, 1999; Ilgin and Gupta, 2010; Sarkis, 2003).

The entire supply chain is sort of a pull system triggered by consumers' demand. The success of the chain is mainly determined by the satisfaction of the consumer expectations. In order to realize the efficient utilization of natural resources and minimization of pollution, consumer behavior is one of the critical factors and needs to be taken into account by the decision makers of involved companies on the supply chain. In other words, consumers' purchasing attitudes towards green products are important information when managing the entire supply networks. Consumers develop their perceptions on green products based on their own experiences or the information they receive from other sources such as media and/or word-of-mouth. Some may think green products are expensive or some may think there is no need to purchase green products based on the claim that they are just a marketing trend. All these issues can negatively influence the spread of green practices (Hervani et al., 2005; Lin, 2013; Mathiyazhagan et al., 2013; Sarkis, 2003; Solér et al., 2010).

There are some consumer research studies to understand the consumers' behavior towards green products (GfK, 2012; Goldstein, 2012). These studies indicate that while environmental issues are on the rise, its effect on consumers' purchasing behavior is not as high. American consumers prefer green products and services with 79% in 2011, slightly up from 78% in 2010 and 76% in 2009. In addition, 31% of them stated they were willing to pay extra for a green product, up from 28% in 2010. 32% of the consumer said the same in 2009 (Goldstein, 2012). Results of a consumer research study in Turkey in 2012 indicated that 80.5% of the consumers are able to define what an environmentally friendly product is and 68% of them very often or sometimes use environmentally friendly products (GfK, 2012). Only 13% of Turkish consumers stated they usually buy green products. More than half of the consumers in the same study stated they do not prefer green products since they are expensive as compared to non-green alternatives. Another interesting finding of the study is 51.7% of the respondents state that green products are not easily accessible (GfK, 2012).

The above representative research findings indicate there are various types of consumers according to their approach towards

* Corresponding author.
E-mail addresses: scoskun@pau.edu.tr (S. Coskun), lozgur@pau.edu.tr (L. Ozgur), opolat@pau.edu.tr (O. Polat), askiner@pau.edu.tr (A. Gungor).

http://dx.doi.org/10.1016/j.jclepro.2015.02.063
0959-6526/

green products. Accessibility and the price of green products are very important factors on consumers' purchasing decision (Akenji, 2014; Lin, 2013) for both developed and developing countries (GfK, 2012; Goldstein, 2012). Therefore, the expectations of consumer types need to be satisfied through the efficient management of the green supply chain (Tseng and Hung, 2013). This study is designed based on this idea.

We define three consumer segments based on their purchasing behavior and their green consciousness. *Green consumer* segment defines consumers who demand green products for sure and willing to pay extra for them. These consumers also pay attention to the environmental issues on products' life cycle. The second segment define *inconsistent consumers* who have some level of awareness towards environment yet they prefer a green product only if the price is same or little above the price of alternative non-green one. Third segment hosts *red consumers* who do not pay any attention to products' greenness and make up his/her purchasing decision based on other commonly used criteria. We then optimize retailer-managed supply chain network consisting of manufacturers, carriers and distribution centers, based on the green expectations of consumer segments. This problem is modeled using goal programming approach in order to meet several predefined objectives. It matches the product and the consumer so that it satisfies the expectations of consumer segments and the retailer and network restrictions. Furthermore, the paper presents a set of scenarios to provide with the decision maker an insight on how the green determination level of consumers influences the green supply chain.

The paper is organized as follows: In Section 2, related literature is provided and the contribution of the study is clearly identified. Section 3 presents the proposed theoretical mathematical model. An example study and several scenarios are given to demonstrate the value of model in Section 4. The last section contains conclusions and future research directions.

2. Literature review

Supply chain management has become a popular topic of academic research worldwide. Hence, a wealth of papers has been published in recent years, cf. Aikens (1985), Vidal and Goetschalckx (1997), Beamon (1998), Sahin and Sural (2007), Melo et al. (2009), Melnyk et al. (2014) for comprehensive reviews. For establishing a supply chain, decision makers face various problem types in different levels. In strategic level, selection of markets, technology and equipment types and strategic options for facilities are common problems. In tactical level, supplier evaluation and selection are main interest. On the other hand, operational level problems include deployment, routing and scheduling of resources (Olivares-Benitez et al., 2013). Design of supply chain networks involves strategic and tactical level issues. In general, the supply chain design problem aims to determine suppliers, warehouse and transfer system combination (or chains) in an optimal way in order to fulfill the customer demand. The related academic literature contains several extensions of supply chain network design problems, cf. Daskin et al. (2005), Martel (2005), Klose and Drexl (2005), Cordeau et al. (2006), Amiri (2006), Altiparmak et al. (2006), Olivares-Benitez et al. (2013) for literature reviews.

Green supply chain management is becoming increasingly important for companies with heightened global awareness in environmental impacts. Parallel to this awareness the number of academic studies related to green supply chains is increasing, cf. Srivastava (2007), Sarkis et al. (2011), Govindan et al. (2013) and Seuring (2013) for comprehensive reviews. Green supply chain network design problems are also important issues in establishing environmentally conscious supply chains (Gungor and Gupta, 1999; Hugo and Pistikopoulos, 2005; Paksoy et al., 2011). Studies related to green supply chain network design can be categorized into two groups.

The first group studies are related to leveling the toxic gases over supply chain networks. Hugo et al. (2005) discussed the balance between investment costs and greenhouse gases in hydrogen supply chain network. By developing a mixed integer linear programming model, the authors compared several investment strategies and integrated supply chain configurations. Ramudhin et al. (2008) presented a mixed integer mathematical model formulation for the carbon trade market sensitive green supply chain network design problem where carbon trading considerations integrated within the supply chain network design phase. Chaabane et al. (2011) integrated carbon trading with the supply chain network design and proposed multi-objective mixed integer linear optimization model to decide on the supply chain configuration.

The second group studies are interested in investigating the effects of carbon emissions of facilities and carriers on green supply chain networks. Hugo and Pistikopoulos (2005) presented a multi-objective mixed integer programming model related to the designing and planning of supply chain networks by considering the multiple environmental concerns together with the traditional economic criteria. Nagurney et al. (2007), Cruz and Matsypura (2009), Paksoy et al. (2010), Bouzembrak et al. (2011), Wang et al. (2011) and Paksoy et al. (2012) addressed the optimization of the design and planning of supply chains by simultaneously considering the maximization of profit and the minimization of the environmental impact. Bojarski et al. (2009), Guillén-Gosálbez and Grossmann (2009), Elhedhli and Merrick (2012), Paksoy and Özceylan (2014) and Pan et al. (2013) also provided sustainable design alternatives for supply chain networks.

As stated earlier in the introduction section, there is a need to improve the green supply network design in order to improve their practical efficiency (Darnall et al., 2008; Mathiyazhagan et al., 2013; Solér et al., 2010; Vachon and Klassen, 2006). Especially, when designing supply networks, consumer expectations have been either left out of consideration or paid very little attention (Güner and Coşkun, 2010; Li et al., 2012; Sarkis, 2003; Tseng and Hung, 2013; Vachon and Klassen, 2006). Yet we learn from the literature that green consumers pose a very different purchasing behavior as compared to non-green consumers (Akenji, 2014; Gilg et al., 2005; Green et al., 2000; Lin and Huang, 2012; Lin, 2013; Mainieri et al., 1997). Pankaew and Tobe (2010) investigated the effects of green supply network management of purchasing behavior of consumers. They also demonstrated that consumer purchasing behavior is also affected by the occurrence of negative environmental events. However, for consumers except the green ones, greenness is just an ordinary or disregarded criterion for purchasing decision. Furthermore, Dan-li et al. (2011) demonstrated that in order for green products to be preferable by all types of consumers, their price should also be competitive.

According to our literature survey, based on the feedback received from various conferences, and recently emphasized by Tseng and Hung (2013), although there is a good amount of research related to green supply chain design and management, there is no specific study to design the green supply chain network based on the consumer greenness expectations. This study aims to contribute to the fulfillment of this research gap by proposing a mathematical model based on the goal programming approach in order to satisfy optimally the expectations of consumer segments and the retailer under network restrictions. A retailer that manages its own entire supply chain network can use the proposed model.

To the best of authors' knowledge, this is the first study to present a way of measuring the relations between green supply chains and consumer behavior. Consumer behavior is integrated into the model by twofold: expectations of different consumer segments, and determination multiplier defining how determined consumers on their expectations are. The ultimate goal of this study is to increase the market share of green products by managing the network to offer products with expected greenness level determined by consumer without ignoring profitability. Therefore, the study contributes to practical applications when re-designing supply chain networks and may lead improving suppliers' capabilities and/or reducing prices of green products.

3. Model definition

The problem considered in this study is related to designing a supplier network based on green expectations of consumer segments defined previously and the retailer's general expectations from candidate suppliers (i.e. manufacturers, carriers and distribution centers on the network). The problem is modeled by using goal-programming approach to satisfy simultaneously several goals relevant to the decision-making environment.

This model is developed for a general supply chain network consisting of four different stages (see Fig. 1). The first stage hosts stores(c) that sell various products (i) suitable to the related consumer segments. There is also an outlet store offering second quality products originating from manufacturers, each of which may have different low quality production rates. The presence of outlet store in the model is desired to represent a green supply chain network that exists in real-life. The second stage holds distribution centers (d) that store and distribute products between manufacturers and stores. The third stage has carriers (t) needed to transport products among manufacturers, distribution centers and stores. The last stage is for manufacturers (s) each of which may have different levels of green production capability. Let U_{ci}^{tds} is the amount of demand to be fulfilled in store c for product i by using carrier t and distribution center d from manufacturer s. In other words, U_{ci}^{tds} defines in which way demands of stores are satisfied. Accordingly, let X_{ci}^{tds} is the binary variable form of U_{ci}^{tds} under same conditions. Let ys_{ci} is the lost sales which is unsatisfied demand amount of store c from product i.

In the model, each consumer segment has a green expectation level that can be determined by market analysts. The retailer expects suppliers to meet various criteria (r) including greenness. In addition, each supplier has scores determined by evaluators for each of these criteria. Let nps_{ci}^{tds},npt_{ci}^{tds} and npd_{ci}^{tds} are the deviational variables that define the positive or negative differences between green expectations of segments and green scores of suppliers, i.e., manufacturers, carriers and distribution centers, respectively. On the other hand, let nrs_{cir}^{tds}, nrt_{cir}^{tds} and nrd_{cir}^{tds} are the deviational variables that define the positive or negative differences between expectations of retailer and scores of suppliers for each criteria. When the criteria score of a supplier is below the expectation of the consumer segment or the retailer, the related negative deviational variable for related criteria r is multiplied by the determination multiplier (β_r). Fig. 2 depicts an example scale to show how the changes on the determination multiplier affects the consumer behavior. If the related criterion is not critical for the consumer segment, this multiplier will be smaller as compared to the one for a critical criterion. When this multiplier is equal to zero for a criterion, the consumer segments are not concerned negative changes in this criterion. On the other side, value N for this multiplier defines the ultimate point for their determination. After this point, the consumers are totally determined and do not accept any product under their expectation. On the other hand, when the greenness score of the product is more than the expectation level of the consumer, the positive deviational variable is multiplied with the market bonus multiplier (α_i) to promote the consumers' green purchasing behavior.

The proposed model aims to maximize the total utility resulting from the network by assuring to provide the right product to the right consumer in related segment. The total utility of the green supply chain network is calculated using the total income, cost, market penalty and bonus and the lost sales.

There are some assumptions made in order to exclude elements of minor relevance and to focus on those aspects that are of paramount interest.

- All parameters are deterministic and known.
- Lost sales and sales of products below expectations are allowed but penalized.
- There is no cost associated with store or retailer management.
- Second quality production is considered; but there is no waste.
- All second (or low) quality products are completely sold in the outlet store.
- One planning period is considered.
- Demands are divisible.

According to the definitions and assumption given above, the following goal-programming model is proposed:

3.1. Sets & indices

$i \in I$ Set of products
$s \in S$ Set of manufacturers
$d \in D$ Set of distribution centers
$c \in C$ Set of stores
$t \in T$ Set of carriers
$r \in R$ Set of criteria (1 represents the greenness)

3.2. Parameters

e_i Selling price of product i
g_i Discounted selling price of product i
q_i^s Unit production cost of manufacturer s for product i
h^t Unit transportation cost of carrier t
k^d Unit storage cost of distribution center d
f^s Low quality production ratio of manufacturer s
se_i Green expectation level of related segment for product i
re_r The retailer's expectation level for criteria r
sl_r^s Evaluation score of manufacturer s for criteria r
tl_r^t Evaluation score of carrier t for criteria r
dl_r^d Evaluation score of distribution center d for criteria r
y^s Production capacity of manufacturer s
z^d Storage capacity of distribution center d
v^t Transportation capacity of carrier t
a_c^d Distance between store c and distribution center d
b^{ds} Distance between distribution center d and manufacturer s

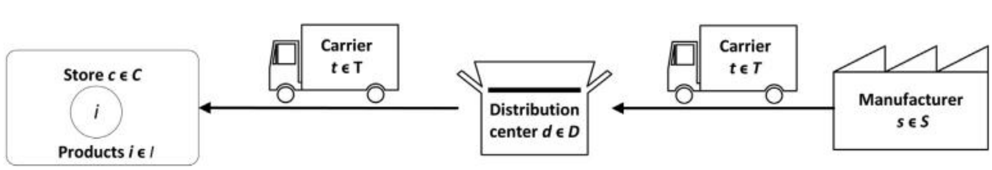

Fig. 1. Supply chain network design with four stages.

Fig. 2. Effect of determination multiplier on consumer behavior.

e^d Distance between outlet store and distribution center d
de_{ci} Demand of store c for product i
pm^s Minimum production amount of manufacturer s
tm^t Minimum transportation amount of carrier t
α_i Market bonus multiplier for product i
β_r Determination multiplier for criterion r
l_i Lost sales cost for product i

3.3. Decision variables

U_{ci}^{tds} Decision variable defining the amount of demand to be fulfilled in store c for product i by using carrier t and distribution center d from manufacturer s
X_{ci}^{tds} 1: if store c for product i by using carrier t and distribution center d from manufacturer s uses this path; 0: otherwise.
ys_{ci} Lost sales amount for demand of store c for product i
nps_{ci}^{tds-} Deviational variable for manufacturers for staying under expectations of segments
nps_{ci}^{tds+} Deviational variable of manufacturers for exceeding expectations of segments
nrs_{cir}^{tds-} Deviational variable for manufacturers for staying under expectations of retailer
nrs_{cir}^{tds+} Deviational variable of manufacturers for exceeding expectations of retailer
npt_{ci}^{tds-} Deviational variable for carriers for staying under expectations of segments
npt_{ci}^{tds+} Deviational variable of carriers for exceeding expectations of segments
nrt_{cir}^{tds-} Deviational variable for carriers for staying under expectations of retailer
nrt_{cir}^{tds+} Deviational variable of carriers for exceeding expectations of retailer
npd_{ci}^{tds-} Deviational variable for dist. centers for staying under expectations of segments
npd_{ci}^{tds+} Deviational variable of dist. centers for exceeding expectations of segments
nrd_{cir}^{tds-} Deviational variable for dist. centers for staying under expectations of retailer
nrd_{cir}^{tds+} Deviational variable of dist. centers for exceeding expectations of retailer

3.4. Goal programming model

$$\textit{maximize} \quad (TR - TC - ML + GU - LS) \tag{1}$$

where

$$TR = \sum_{c\in C}\sum_{i\in I}\sum_{t\in T}\sum_{d\in D}\sum_{s\in S} U_{ci}^{tds}\left((1-f^s)e_i + f^s g_i\right) \tag{1.1}$$

$$TC = \sum_{c\in C}\sum_{i\in I}\sum_{t\in T}\sum_{d\in D}\sum_{s\in S} U_{ci}^{tds}\left(q_i^s + k^d + b^{ds}h^t + (1-f^s)a_c^d h^t + f^s o^d h^t\right) \tag{1.2}$$

$$ML = \sum_{c\in C}\sum_{i\in I}\sum_{t\in T}\sum_{d\in D}\sum_{s\in S} \beta_1\left(nps_{ci}^{tds-} + npt_{ci}^{tds-} + npd_{ci}^{tds-}\right) + \sum_{c\in C}\sum_{i\in I}\sum_{t\in T}\sum_{d\in D}\sum_{s\in S}\sum_{r\in R} \beta_r\left(nrs_{cir}^{tds-} + nrt_{cir}^{tds-} + nrd_{cir}^{tds-}\right) \tag{1.3}$$

$$GU = \sum_{c\in C}\sum_{i\in I}\sum_{t\in T}\sum_{d\in D}\sum_{s\in S} \alpha_i\left(nps_{ci}^{tds+} + npt_{ci}^{tds+} + npd_{ci}^{tds+}\right) \tag{1.4}$$

$$LS = \sum_{c\in C}\sum_{i\in I} ys_{ci} l_i \tag{1.5}$$

s.t.

$$\sum_{t\in T}\sum_{d\in D}\sum_{s\in S} U_{ci}^{tds}(1-f^s) + ys_{ci} = de_{ci} \quad \forall c\in C,\ i\in I \tag{2}$$

$$U_{ci}^{tds} \ge X_{ci}^{tds} \quad \forall c\in C,\ i\in I,\ t\in T,\ d\in D,\ s\in S \tag{3}$$

$$U_{ci}^{tds} \le X_{ci}^{tds} M \quad \forall c\in C,\ i\in I,\ t\in T,\ d\in D,\ s\in S \tag{4}$$

$$\sum_{c\in C}\sum_{i\in I}\sum_{t\in T}\sum_{d\in D} U_{ci}^{tds} \le y^s \quad \forall s\in S \tag{5}$$

$$\sum_{c\in C}\sum_{i\in I}\sum_{t\in T}\sum_{s\in S} U_{ci}^{tds} \le z^d \quad \forall d\in D \tag{6}$$

$$\sum_{c\in C}\sum_{i\in I}\sum_{d\in D}\sum_{s\in S} U_{ci}^{tds} \le v^t \quad \forall t\in T \tag{7}$$

$$\sum_{c\in C}\sum_{t\in T}\sum_{d\in D}\left(U_{ci}^{tds} - X_{ci}^{tds} pm^s\right) \ge 0 \quad \forall i\in I,\ s\in S \tag{8}$$

$$\sum_{c\in C}\sum_{i\in I}\sum_{d\in D}\sum_{s\in S}\left(U_{ci}^{tds} - X_{ci}^{tds} tm^t\right) \ge 0 \quad \forall t\in T \tag{9}$$

$$X_{ci}^{tds} sl_1^s + nps_{ci}^{tds-} - nps_{ci}^{tds+} = X_{ci}^{tds} se_i \quad \forall c\in C,\ i\in I,\ t\in T,\ d\in D,\ s\in S \tag{10}$$

$$X_{ci}^{tds} tl_1^t + npt_{ci}^{tds-} - npt_{ci}^{tds+} = X_{ci}^{tds} se_i \quad \forall c\in C,\ i\in I,\ t\in T,\ d\in D,\ s\in S \tag{11}$$

$$X_{ci}^{tds} dl_1^d + npd_{ci}^{tds-} - npd_{ci}^{tds+} = X_{ci}^{tds} se_i \quad \forall c \in C,\ i \in I,\ t \in T,\ d \in D,\ s \in S \tag{12}$$

$$X_{ci}^{tds} sl_r^s + nrs_{cir}^{tds-} - nrs_{cir}^{tds+} = X_{ci}^{tds} re_r \quad \forall c \in C,\ i \in I,\ t \in T,\ d \in D,\ s \in S,\ r \in R \tag{13}$$

$$X_{ci}^{tds} tl_r^t + nrt_{cir}^{tds-} - nrt_{cir}^{tds+} = X_{ci}^{tds} re_r \quad \forall c \in C,\ i \in I,\ t \in T,\ d \in D,\ s \in S,\ r \in R \tag{14}$$

$$X_{ci}^{tds} dl_r^d + nrd_{cir}^{tds-} - nrd_{cir}^{tds+} = X_{ci}^{tds} re_r \quad \forall c \in C,\ i \in I,\ t \in T,\ d \in D,\ s \in S,\ r \in R \tag{15}$$

$$X_{ci}^{tds} \in [0,1],\ nps_{ci}^{tds-},\ nps_{ci}^{tds+},\ nrs_{cir}^{tds-},\ nrs_{cir}^{tds+},\ npt_{ci}^{tds-},\ npt_{ci}^{tds+},\ nrt_{cir}^{tds-},\ nrt_{cir}^{tds+},\ npd_{ci}^{tds-},\ npd_{ci}^{tds+},\ nrd_{cir}^{tds-},\ nrd_{cir}^{tds+},\ U_{ci}^{tds},\ ys_{ci} \geq 0 \quad \forall c \in C,\ i \in I,\ t \in T,\ d \in D,\ s \in S,\ r \in R \tag{16}$$

The objective function (1) maximizes the total utility of the green supply chain network. Equation (1.1) calculates the total income (i.e., *TR*) from sales of first and second quality products. Equation (1.2) calculates the total cost (i.e., *TC*) related to production, storage and distribution. Equation (1.3) defines the total market penalty (i.e., *ML*) imposed by supplying products from manufacturers though carriers and distribution centers, which are below expectations of consumer segments and the retailer. Equation (1.4) determines the total market bonus (i.e., *GU*) collected for providing products above the green expectation levels of consumers. To provide a further observation about constraints (1.3) and (1.4), please note that when any of the multipliers for a criterion is low, then, the associated constraint behaves like a soft constraint whereas when it is too high the constraint behaves as a hard constraint. Equation (1.5) calculates the total lost sales (i.e., *LS*) occurring due to not being able to meet a demand for an item because the criteria score and/or capacity of a supplier is below the required level. Please note that staying below the expectation of the consumers or the retailer is allowed in the model. The model may select staying below expectations option by getting market penalty as long as the market penalty is less than the cost of lost sales. Equations (2)–(4) are production and demand constraints including lost sales and low quality production ratios of manufacturers. Equations (5)–(7) are the capacity constraints for manufacturers, carriers and distribution centers, respectively. Constraint (8) defines the minimum acceptable production amount of manufacturers for each product. Constraint (9) defines the minimum acceptable total transportation amount of each carrier. Constraints (10), (11), and (12) evaluate manufacturers, carriers and distribution centers according to green expectations of consumer segments, respectively. Constraints (13), (14), and (15) evaluate manufacturers, carriers and distribution centers according to expectations of the retailer, respectively. Finally, constraint (16) defines the variable domains.

4. An example study

A hypothetical real-life-like example is developed to prove the assets of the model. Please note that the main objective for presenting the example study is to show the importance of the consumer segment integration into supply chain applications rather than optimally solving a real life problem. This section also provides various scenarios considering variations of green determination multiplier to provide further understanding of the main idea.

4.1. Description of the example study

The sample supply network consists of four stores selling four types of products demanded by consumers in previously defined three segments. There is also an outlet store for second quality products. There are five manufacturers with different production capabilities. In the network, there are two distribution centers and three carrier alternatives. The network presentation of the example is depicted in Fig. 3.

Table 1 shows green expectation levels of segments for products. Greenness level of each product for a related consumer segment is scaled from 1 to 7 where 1 means "totally not critical" and level 7 means "extremely critical". Table 2 presents the retailer's criteria defined by Shaik and Abdul-Kader (2011) and their expected levels from suppliers using 1 to 7 scale. The evaluation scores of suppliers according to criteria are given in Table 3 using the same scale. Evaluation score 1 means the supplier capability to maintain the associated criterion is "very low" and whereas 7 means "very high". Table 4 shows levels of market bonus and determination multipliers. As it is explained in previous sections, these multipliers determine the importance of related criteria for consumer segments and the retailer.

Data related to products are given in Table 5 including demand, the first and second quality sale prices and the lost sale cost for each product. Table 6 presents data related to manufacturers including production costs, maximum production capacity, minimum production amount and low quality production ratio. From the table it can be drawn that some manufacturers are not capable of offering some products; may be due to technical reasons. Yet some of them can produce most of the products but with higher production costs. Unit capacity requirement of different products are accepted to be the same.

Data related to transportation activities are given in Table 7. We assume that the unit capacity requirements of different products are the same. Table 8 shows data related to distribution centers including distances, capacities and storage costs.

4.2. Numerical results and discussion

The open form of the proposed model for the example study contains 21,620 variables and 11,108 constraints. All computational experiments were conducted on a workstation with Intel Xeon 2.5 GHz processor and 8 GB of RAM. The computation time required to solve the model to optimality using the ILOG CPLEX solver is under 4 CPU seconds.

Since our main interest is towards the greenness of the network, a set of scenarios with different levels of green determination multiplier (i.e., β_1) is performed in order to understand how the decisiveness of consumers on their green expectations influences the network. In fact, this analysis is like a simulation of a real life observation where consumers may have different determination levels on greenness criterion for making their purchasing decisions. For example, a customer with a very low green determination level could purchase a product with greenness level below his/her expectation. However, when the customer becomes extremely determined, he/she will not purchase a product with greenness level below expectations.

For this purpose, β_1 was first set to a very low level of 10 (i.e., consumers are not concerned with greenness) as given in Table 4.

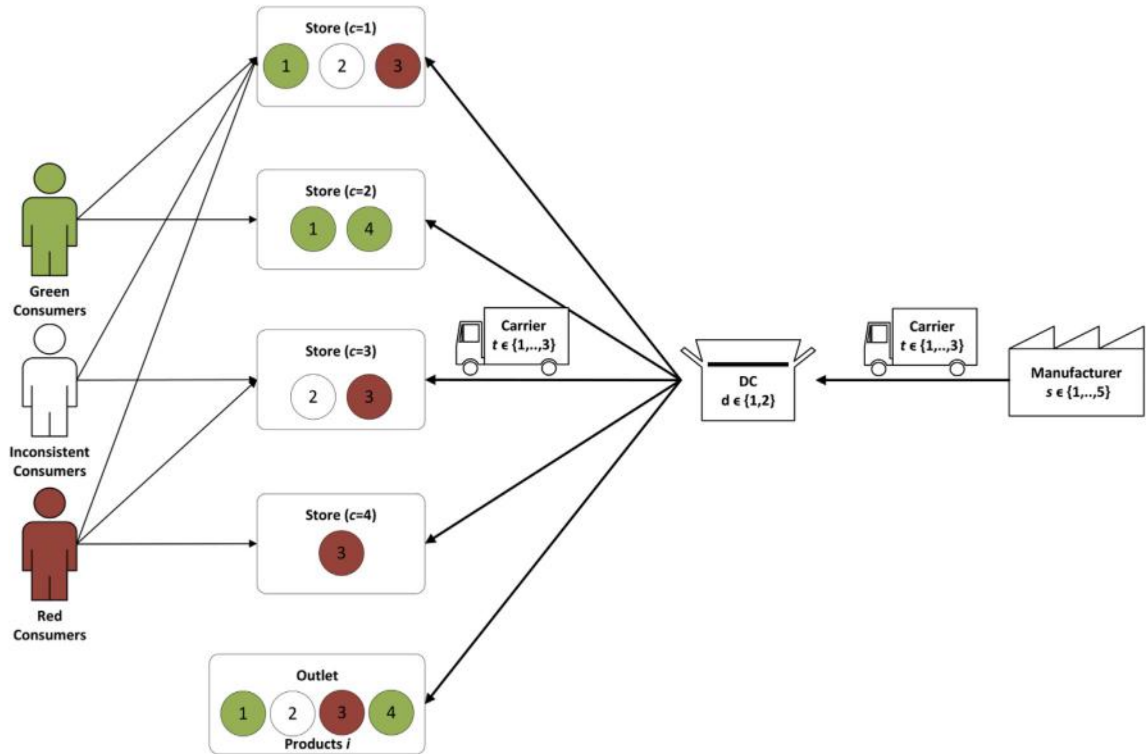

Fig. 3. Network representation of the example.

Table 1
The green expectation levels of consumer segments for products.

Segments	se_1	se_2	se_3	se_4
Green	6			6
Inconsistent		4		
Red			2	

Table 2
The retailer criteria and their expected levels from suppliers.

r	Criteria name	re_r
1	Greenness	3
2	Quality	5
3	Technical	4
4	Service	4
5	Organization and Partnership	5
6	Financial	4

Table 3
Evaluation scores of suppliers for criteria.

r	sl_r^1	sl_r^2	sl_r^3	sl_r^4	sl_r^5	tl_r^1	tl_r^2	tl_r^3	dl_r^1	dl_r^2
1	5	6	6	4	2	5	3	6	5	7
2	5	5	6	3	4	3	3	3	6	5
3	4	5	4	5	4	4	3	4	5	7
4	4	4	3	4	6	4	5	5	4	5
5	3	3	5	3	2	4	3	5	4	6
6	6	5	5	5	5	3	3	5	5	5

Table 4
Values of market bonus (α_i) and determination (β_r) multipliers.

Multipliers	α_1	α_2	α_3	α_4	β_1	β_2	β_3	β_4	β_5	β_6
Values	5	2	0	5	10	8	8	7	5	5

Table 5
Data related to products.

i	de_{1i}	de_{2i}	de_{3i}	de_{4i}	e_i	g_i	l_i
1	100	100	0	0	30	9	15
2	200	0	200	0	15	8	8
3	300	0	300	500	20	5	10
4	0	50	0	0	40	14	20

Table 6
Data related to manufacturers.

s	q_1^s	q_2^s	q_3^s	q_4^s	y^s	pm^s	f^s
1	10	6	4	13	1000	50	0.03
2	–	10	4	–	400	50	0.05
3	8	6	4	10	200	50	0.06
4	–	3	8	–	700	50	0.07
5	–	–	4	–	500	50	0.08

Table 7
Data related to carriers.

t	v^t	h^t	tm^t
1	500	0.005	200
2	1500	0.002	200
3	500	0.008	50

Table 8
Data related to distribution centers.

d	b^{d1}	b^{d2}	b^{d3}	b^{d4}	b^{d5}	a_1^d	a_2^d	a_3^d	a_4^d	e^d	z^d	k^d
1	476	66	1012	626	182	173	503	314	158	582	1000	0.2
2	222	358	782	514	136	287	332	257	449	296	1000	0.5

Then it was set to a very high level of 2500 (i.e. consumers are extremely determined on demanding products no less than the expected greenness level) while the values of the other multipliers were kept the same as in Table 4.

Table 9 presents the demand fulfillment details in relation to orders where β_1 equals to 10. An order describes the way by which a demand of a store is fulfilled from suppliers. In the table, the order names, illustrated by the letters starting from A, are given in association with related suppliers. For instance, demand for product 1 of store 1 is fulfilled from the manufacturer 1 using carrier 2 via distribution center 2. In the table, when the evaluation score of a supplier for a criterion is below the expectation of the related consumer segment and the retailer, its order name is put in [-]. For instance, while consumer's green expectation level for product 1 is 6 and the retailer's is 3, the order is fulfilled by manufacturer 1 whose greenness score is 5 and transported by carrier 2 whose greenness score is 3. Therefore, the order name A is shown as [A] for manufacturer 1 and carrier 2. This means that fulfilling the demand from a supplier who does not meet expectations of consumers and the retailer is more reasonable. In other words, the penalty cost occurred for staying under expectations is less than the earned revenue for fulfilling the demand from suppliers whose greenness score are below the expected level.

Table 10 demonstrates the demand fulfillment details in relation to orders when β_1 is 2500. As explained in Section 3, this caused the related constraints to behave as hard constraints in the model. According to Table 10, as expected due to high level of β_1, suppliers who meet green expectations of consumers and the retailer fulfill all demands of stores. In this solution, penalty related to not meeting greenness levels of consumers and the retailer is zero. However, the total market penalty occurs for staying below the expectations of retailer for other criteria. Monetary results of solutions for both cases (i.e. for $\beta_1 = 10$ and $\beta_1 = 2500$) can be seen in Table 11.

Several conclusions can be drawn from Table 11. The model provides higher total utility value for low level of β_1 as compared to very high value of β_1. When β_1 increases, the model becomes more sensitive towards the cost of market penalty caused by meeting the demand using a supplier below the expected greenness level. The model then tends to choose the “lost sales” option, because it becomes economically viable. The increase in lost sales not only reduces the total income but also the total cost since there is no production, storage and transportation costs for that amount. However, the lost sales cost increases as seen in the table. In order to guarantee not to fall below the expected greenness levels of consumer and the retailer, the model also selects suitable green carriers and distribution centers; they usually impose higher costs. That explains the raise in storage and transportation costs for higher value of β_1 in Table 11.

Table 9
Demand fulfillment details in relation to orders ($\beta_1 = 10$).

—	c	1	1	1	2	2	3	3	4
	i	1	2	3	1	4	2	3	3
	se_i	6	4	2	6	6	4	2	2
	re_1	3	3	3	3	3	3	3	3
sl_1^1	5	[A]				[E]		G	
sl_1^2	6			C					H
sl_1^3	6				D				
sl_1^4	4		B				F		
sl_1^5	2								[I]
tl_1^1	5			C					H
tl_1^2	3	[A]	[B]		[D]	[E]	[F]	G	I
tl_1^3	6								
dl_1^1	5			C					H,I
dl_1^2	7	A	B		D	E	F	G	

Table 10
Demand fulfillment details in relation to orders ($\beta_1 = 2500$).

—	c	1	1	1	2	2	3	3	4
	i	1	2	3	1	4	2	3	3
	se_i	6	4	2	6	6	4	2	2
	re_1	3	3	3	3	3	3	3	3
sl_1^1	5			C				F	G
sl_1^2	6								H
sl_1^3	6	A			D				
sl_1^4	4		B				E		
sl_1^5	2								
tl_1^1	5		B				E		
tl_1^2	3			C				F	G,H
tl_1^3	6	A			D				
dl_1^1	5			C					G,H
dl_1^2	7	A	B		D		E	F	

In order to have a broader understanding of the effect of β_1 on the monetary measures, the model was also solved with various values of β_1 between 0 and 2500 in each solution. Fig. 4 depicts the results. Please note that values of criteria are the same.

The figure demonstrates that when β_1 equals to 0, the total utility is maximum simply because there is no penalty related to unsatisfying the greenness. In fact for the case of $\beta_1 = 0$, the model completely ignores the greenness criterion. Increase in β_1 causes the model to start to find the best balance among all related positive and negative monetary terms to maximize the total utility. However, when the value of $\beta_1 > 2100$, the model avoids the total penalty related to falling below the expected greenness level. In other words, $\beta_1 = 2100$ defines the ultimate level of consumer determination (i.e. N in Fig. 2) and the values of β_1 beyond it does not affect the model. The figure also shows the change in *total negative deviation* for greenness criterion, represented by *tnd* in Fig. 4, is changing in relation to β_1.

From Fig. 4, we can also draw some practical conclusions as follows. Once a retailer realizes according to a targeted market research that the green consumer segment is enlarging, it can redesign the green supply chain network to cooperate with suppliers at the expected greenness level. If re-designing the network is not enough or not possible, the retailer can demand its suppliers to meet more strict greenness levels in order to be able to supply products from them for its green consumers. Therefore, the suppliers of the retailer become obligated to increase their greenness capacity through a serious of investments and/or process improvements. Otherwise, suppliers and the retailer will end up lost sales as depicted in Fig. 4. However, if increasing the greenness

Table 11
Monetary results of solutions.

Monetary term	$\beta_1 = 10$		$\beta_1 = 2500$	
Total utility (=***TR*** − ***TC*** − ***ML*** + ***GU*** − ***LS***)	24,795.30	100.00%[a]	20,218.40	100.00%
Total profit (=***TR*** − ***TC***)	25,268.00	101.91%	21,605.40	106.86%
(***TR***) Total income (=***TR1*** + ***TR2***)	36,670.60	147.89%	34,200.20	169.15%
(***TR1***) First quality product income	35,994.00	145.16%	33,640.00	166.38%
(***TR2***) Second quality product income	676.56	2.73%	560.20	2.77%
(***TC***) Total cost (=***TC1*** + ***TC2*** + ***TC3***)	11,402.50	45.99%	12,594.80	62.29%
(***TC1***) Total production cost	8504.40	34.30%	7459.40	36.89%
(***TC2***) Total storage cost	671.30	2.71%	636.29	3.15%
(***TC3***) Total transportation cost	2227.19	8.98%	4499.09	22.25%
(***ML***) Total market penalty	612.00	2.47%	361.00	1.79%
(***GU***) Total market bonus	142.00	0.57%	154.00	0.76%
(***LS***) Total lost sales cost	3.04	0.01%	1180.00	5.84%

[a] Calculated by (Respected monetary term/Total utility) × 100.

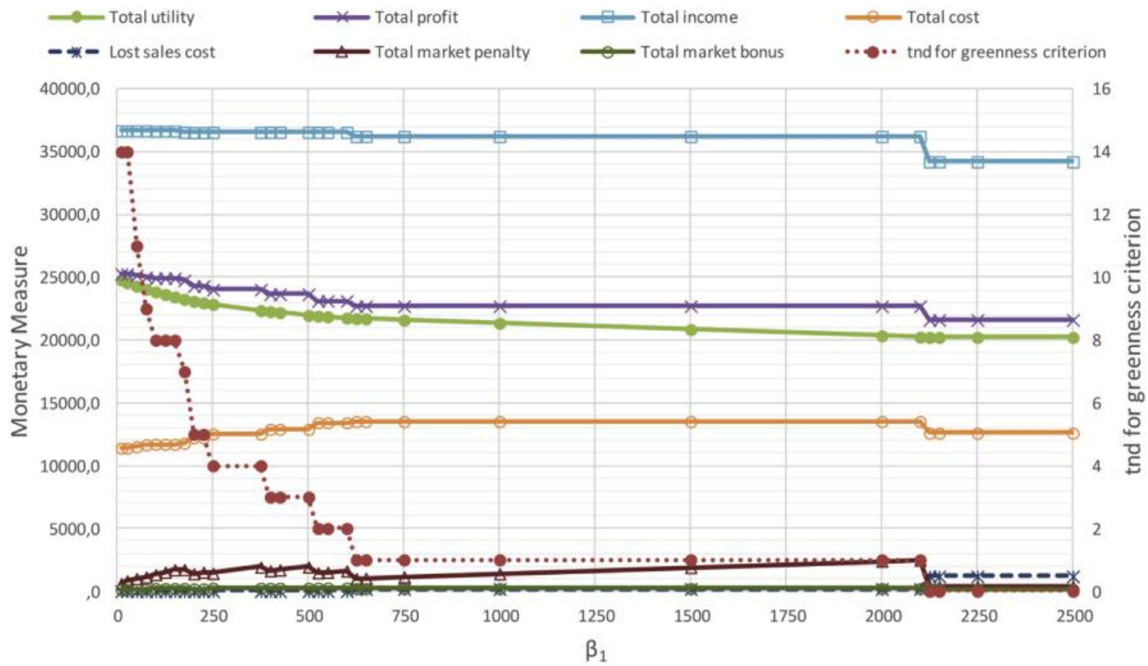

Fig. 4. The effect of β_1 on the monetary measures.

capacity generates a cost beyond the budget, the decision maker of the supplier company can consider rather inexpensive alternative decisions to lower the green products' sales prices. The reduction in the sales price can positively influence the purchasing decision of customers in inconsistent consumer segment, who can pay little bit more money to a green product as compared to a non-green product and are less demanding on greenness. This is a valuable insight considering the fact that inconsistent consumer segment is the largest one according to various reports in the literature (Goldstein, 2012). Therefore, targeting the consumers in this segment can drastically enhance the spread of green products and contribute to the advancement of environmentally benign market.

5. Conclusions

Research findings indicate that there are various types or segments of consumers according to their attitudes for green products in the market. In order to improve the practical efficiency of green supply chain networks, they must be designed considering the customer segments. In this study, we defined three consumer segments based on their purchasing behavior and their green consciousness i.e., *green consumers, inconsistent consumers* and *red consumers*. We proposed a goal programming model to optimize the supply chain network for a retailer, which include manufacturers, carriers and distribution centers, based on the green expectations of consumer segments. We demonstrated the value of the model on a hypothetical real-life-like example. Furthermore, in order to understand the influence of a higher greenness determination level on the solution, a set of scenarios was evaluated.

There is a significant impact of the paper on both theoretical and practical sides. On the theoretical side, according to the best knowledge of the authors, this is the first study to design the green supply chain network based on consumers' behaviors. Thus, it contributes to the fulfillment of this research gap. On the practical side, the paper provides significant insight to companies on a green supply chain when they make decisions related to the design and the management of the entire business processes. For example, scenario analysis carried out in the paper indicated that once a retailer realizes according to a certain market research that the green consumer segment is enlarging, it can re-design its green supply chain network cooperating with suppliers at the expected greenness level. On the other hand, the suppliers of the retailer can work on projects to increase their greenness levels.

This study comes with several limitations for practical applications. As we stated in the model assumptions, in order to easily focus on the main idea of developing the model by integrating the consumer segmentation, all parameters were accepted to be known and deterministic. However, in real life, finding the data required to solve the model will not be easy especially considering the many of the green related applications are still in their infancy. For example, for a retailer, it can be a challenge to classify its customers into segments, determine their green expectation levels, evaluating the greenness of suppliers on its own supply network etc. Therefore, the proposed model by itself is not enough to enhance the green application on the practical side. Companies of supply chains must also improve their green capacity through better understanding of the green market. Since gathering the data required to solve the proposed model under certainty, the authors are currently working on the fuzzy extension of the model in order to cope with the fuzzy nature related to green market and evaluation of suppliers. Meanwhile when the complexity issue becomes a challenge, heuristics can also be investigated as solution methodologies.

Acknowledgments

This study was supported by the Pamukkale University Scientific Research Project Fund (BAP) with the Project Number 2011FBE046.

References

Aikens, C.H., 1985. Facility location models for distribution planning. Eur. J. Oper. Res. 22, 263–279.
Akenji, L., 2014. Consumer scapegoatism and limits to green consumerism. J. Clean. Prod. 63, 13–23.
Altiparmak, F., Gen, M., Lin, L., Paksoy, T., 2006. A genetic algorithm approach for multi-objective optimization of supply chain networks. Comput. Ind. Eng. 51, 196–215.

Amiri, A., 2006. Designing a distribution network in a supply chain system: formulation and efficient solution procedure. Eur. J. Oper. Res. 171, 567–576.
Beamon, B.M., 1998. Supply chain design and analysis: models and methods. Int. J. Prod. Econ. 55, 281–294.
Bojarski, A., Lainez, J., Espuna, A., Puigjaner, L., 2009. Incorporating environmental impacts and regulations in a holistic supply chains modeling: an LCA approach. Comput. Chem. Eng. 33, 1747–1759.
Bouzembrak, Y., Allaoui, H., Goncalves, G., Bouchriha, H., 2011. A multi-objective Green Supply chain network design. In: 4th International Conference on Logistics, Hammamet/Tunisia.
Chaabane, A., Ramudhin, A., Kharoune, M., Paquet, M., 2011. Trade-off model for carbon market sensitive green supply chain network design. Int. J. Oper. Res. 10, 416–441.
Cordeau, J.F., Pasin, F., Solomon, M.M., 2006. An integrated model for logistics network design. Ann. Oper. Res. 144, 59–82.
Cruz, J., Matsypura, D., 2009. Supply chain networks with corporate social responsibility through integrated environmental decision-making. Int. J. Prod. Res. 47, 621–648.
Dan-li, D., Zhen, F., Hong-yan, Z., 2011. Research on the Price negotiation mechanism of Green Supply chain of manufacturing Industry from the angle of customer behavior. In: International Conference on Management Science & Engineering, Rome, Italy.
Darnall, N., Jolley, G.J., Handfield, R., 2008. Environmental management systems and green supply chain management: complements for sustainability? Bus. Strategy Environ. 17, 30–45.
Daskin, M., Snyder, L., Berger, R., 2005. Facility Location in Supply Chain Design, Logistics Systems: Design and Optimization. Springer, New York, pp. 39–65.
Elhedhli, S., Merrick, R., 2012. Green supply chain network design to reduce carbon emissions. Transp. Res. Part D 17, 370–379.
GfK, 2012. Yeşil Tüketim Araştırması Schneider Electric Ve Sürdürülebilirlik Akademisi (In Turkish).
Gilg, A., Barr, S., Ford, N., 2005. Green consumption or sustainable lifestyles? Identifying the sustainable consumer. Futures 37, 481–504.
Goldstein, D., 2012. Green Still Follows Green: the Environment Retains Influence on Spending (The Harris Poll #46), pp. 1–4.
Govindan, K., Rajendran, S., Sarkis, J., Murugesan, P., 2013. Multi criteria decision making approaches for green supplier evaluation and selection: a literature review. J. Clean. Prod. 1–18.
Green, K., Morton, B., New, S., 2000. Greening organizations. Organ. Environ. 13 (2), 206–225.
Guillén-Gosálbez, G., Grossmann, I., 2009. Optimal design and planning of sustainable chemical supply chains under uncertainty. AIChE J. 55, 99–121.
Gungor, A., Gupta, S.M., 1999. Issues in environmentally conscious manufacturing and product recovery: a survey. Comput. Ind. Eng. 36, 811–853.
Güner, S., Coşkun, E., 2010. The role of customer choices in Green Supply chain management-an ampirical study in Sakarya region. In: International Logistics & Supply Chain Congress Istanbul, Turkey, vol. VIII, pp. 65–75.
Hervani, A.A., Helms, M.M., Sarkis, J., 2005. Performance measurement for green supply chain management. Benchmarking An Int. J. 12, 330–353.
Hugo, A., Pistikopoulos, E.N., 2005. Environmentally conscious long-range planning and design of supply chain networks. J. Clean. Prod. 13, 1471–1491.
Hugo, A., Rutter, P., Pistikopoulos, S., Amorelli, A., Zoia, G., 2005. Hydrogen infrastructures strategic planning using multi-objective optimization. Int. J. Hydrog. Energy 30, 1523–1534.
Ilgin, M.A., Gupta, S.M., 2010. Environmentally conscious manufacturing and product recovery (ECMPRO): a review of the state of the art. J. Environ. Manag. 91, 563–591.
Klose, A., Drexl, A., 2005. Facility location models for distribution system design. Eur. J. Oper. Res. 162, 4–29.
Li, T., Ma, C.S., Liu, X.C., Yang, X., 2012. Value research of option mechanism in a Green Supply chain considering strategic customer behavior. In: International Conference of Logistics Engineering and Management, Chengdu, China, pp. 840–846.
Lin, P.-C., Huang, Y.-H., 2012. The influence factors on choice behavior regarding green products based on the theory of consumption values. J. Clean. Prod. 22, 11–18.
Lin, R.-J., 2013. Using fuzzy DEMATEL to evaluate the green supply chain management practices. J. Clean. Prod. 40, 32–39.
Mainieri, T., Barnett, E.G., Valdero, T.R., Unipan, J.B., Oskamp, S., 1997. Green buying: the influence of environmental concern on consumer behavior. J. Soc. Psychol. 137 (2), 189–204.
Martel, A., 2005. The design of production-distribution networks: a mathematical programming approach. In: Geunes, J., Pardalos, P. (Eds.), Supply Chain Optimization. Springer, pp. 265–306.
Mathiyazhagan, K., Govindan, K., NoorulHaq, A., Geng, Y., 2013. An ISM approach for the barrier analysis in implementing green supply chain management. J. Clean. Prod. 47, 283–297.
Melnyk, S.A., Narasimhan, R., DeCampos, H.A., 2014. Supply chain design: issues, challenges, frameworks and solutions. Int. J. Prod. Res. 52, 1887–1896.
Melo, M.T., Nickel, S., Saldanha-da-Gama, F., 2009. Facility location and supply chain management-a review. Eur. J. Oper. Res. 196, 401–412.
Nagurney, A., Liu, Z., Woolley, T., 2007. Sustainable supply chain and transportation networks. Int. J. Sustain. Transp. 1, 29–51.
Olivares-Benitez, E., Rios-Mercado, R.Z., Gonzalez-Velarde, J.L., 2013. A metaheuristic algorithm to solve the selection of transportation channels in supply chain design. Int. J. Prod. Econ. 145, 161–172.
Paksoy, T., Bektaş, T., Özceylan, E., 2011. Operational and environmental performance measures in a multi-product closed-loop supply chain. Transp. Res. Part E: Logist. Transp. Rev. 47, 532–546.
Paksoy, T., Ozceylan, E., Weber, G.-W., 2010. A multi objective model for optimization of a green supply chain network. In: 3rd Global Conference on Power Control and Optimization, Queensland, Australia.
Paksoy, T., Özceylan, E., 2014. Environmentally conscious optimization of supply chain networks. J. Oper. Res. Soc. 65, 855–872.
Paksoy, T., Pehlivan, N.Y., Özceylan, E., 2012. Fuzzy multi-objective optimization of a Green Supply chain network with risk management that includes enviromental hazards. Hum. Ecol. Risk Asses. 18, 1120–1151.
Pan, S., Ballot, E., Fontane, F., 2013. The reduction of greenhouse gas emissions from freight transport by pooling supply chains. Int. J. Prod. Econ. 143, 86–94.
Pankaew, P., Tobe, M., 2010. Consumer Buying Behavior in a Green Supply Chain Management Context – a Study in the Dutch Electronics Industry. Business Administration. Jönköping University.
Ramudhin, A., Chaabane, A., Kharoune, M., Paquet, M., 2008. Carbon market sensitive Green Supply chain network design. In: The IEEE International Conference on Industrial Engineering and Engineering Management, Singapore.
Sahin, G., Sural, H., 2007. A review of hierarchical facility location models. Comput. Oper. Res. 34, 2310–2331.
Sarkis, J., 2003. A strategic decision framework for green supply chain management. J. Clean. Prod. 11, 397–409.
Sarkis, J., Zhu, Q., Lai, K.-H., 2011. An organizational theoretic review of green supply chain management literature. Int. J. Prod. Econ. 130, 1–15.
Seuring, S., 2013. A review of modeling approaches for sustainable supply chain management. Decis. Support Syst. 54, 1513–1520.
Shaik, M., Abdul-Kader, W., 2011. Green supplier selection generic framework: a multi-attribute utility theory approach. Int. J. Sustain. Eng. 4 (01), 37–56.
Solér, C., Bergström, K., Shanahan, H., 2010. Green supply chains and the missing link between environmental information and practice. Bus. Strategy Environ. 19, 14–25.
Srivastava, S.K., 2007. Green supply-chain management: a state-of-the-art literature review. Int. J. Manag. Rev. 9, 53–80.
Tseng, S.-C., Hung, S.-W., 2013. A framework identifying the gaps between customers' expectations and their perceptions in green products. J. Clean. Prod. 59, 174–184.
Vachon, S., Klassen, R.D., 2006. Extending green practices across the supply chain: the impact of upstream and downstream integration. Int. J. Oper. Prod. Manag. 26 (7), 795–821.
Vidal, C.J., Goetschalckx, M., 1997. Strategic production-distribution models: a critical review with emphasis on global supply chain models. Eur. J. Oper. Res. 98, 1–18.
Wang, F., Lai, X., Shi, N., 2011. A multi-objective optimization for green supply chain network design. Decis. Support Syst. 51, 262–269.