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Sustainability in paper industry closed-loop supply chain (Case study: East Azerbaijan province, Iran)

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Abstract

Governments and customers are forcing the paper manufacturers to become more sustainable. Accordingly, there still exists a gap in the quantitative modeling of these issues. In this paper, this gap is covered through simultaneously considering economical, environmental and social impacts in the paper closed-loop supply chain network design. The proposed multi-objective, multi-echelon, multi-product and single-period model is composed of suppliers, plants, regional wholesalers, retailers, customer zones, collection sites, centralized collection points, recycling facilities, energy recovery and disposal centers.The objectives considered are minimization of total cost; environmental benefit through maximizing coverage of collected waste paper by opened centralized collection centers; and maximization of the social impact of the network in a way that would prefer the location of facilities in the less populated regions.The proposed model is applied to an illustrative example designed utilizing real data of the paper industry in East Azerbaijan of Iran and interactive fuzzy goal programming approach is used to solve the developed model. Sensitivity analysis of the proposed model is also performed by considering key parameters.

Keywords: Closed-loop supply chain, multi-objective programming, location model, paper recovery

1- Introduction

The increasing consumption of paper imposes excessive pressure on the forests and the environment. Paper as a strategic product, 85% of which is produced from natural forests, covers higha large proportion

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of household, administrative and commercial waste. However, high amounts of waste paper aredisposed all over the word causing health hazard and environmental damages instead of being recovered. The design of an effective collection and recovery system without damaging the environment is affected by facilities' location decisions which are strategic. Therefore, the strategic planning problem is crucial for the paper industry and a recent review by Govindan et al. (2015a) emphasized the lack of the multi-objective closed loop supply chain (CLSC) network design models.Sustainability is an increasingly important topic in multi-objective supply chain management areas as companies respond to pressures from stakeholders, consumers, management, governmental legislation, global competition and profit and non-profit organizations dedicated to environmental and social impacts of industry (Ageron et al., 2011).Climate change, resource depletion, and human health problems are leading to a point of no return (Cardoso et al., 2013). Sustainable supply chain management (SSCM) is defined as the consideration all three dimensions of sustainable development, i.e., economic, environmental and socialin the management of information, material and capital flow (Seuring and Müller, 2008).The literature related to the area of sustainable network design lacks the simultaneous consideration of triple bottom lines of sustainability. The balance between the addressed lines offers a challengewhich can be attributed to the complexity of modeling social impacts and to some extent environmental aspects.Based on the aforementioned considerations,the aim of this research is to develop a new mixed integer linear programming model for a multi-objective, multi-echelon, multi-product and single period CLSC which simultaneously considers economic, environmental and social aspects for the paper industry. In the proposed model, minimization of the total cost of CLSC which consists of fixed investment costs, production costs, transportation costs, purchasing costs regarding materials and waste paper, collection costs, sortingcosts, recycling costs, and disposal cost; environmental benefitthrough maximizing coverage of collected waste paper by opened centralized collection centers; and finally maximization ofthe social impact of the network in a way that would preferthe location of facilities in the less populated regions are introduced as the objective functions. Furthermore, the proposed model is applied to an illustrative example designed utilizing real data of the paper industry in East Azerbaijanof Iran and interactive fuzzy goal programming (IFGP) approach is used to solve the developed model.The rest of the paper has the following structure. In the Section 2, the background literature is presented. In section 3, the developed model is characterized. IFGP approach is given in section 4. Then in section 5, application of the proposed model to an example problem inspired by East Azerbaijan of Iran is discussed and a sensitivity analysis of key parameters is done. Finally, conclusions are given along with the future work directions in section 6.

2- Literature review

Despite the fact that the area of sustainability is considered quite new, interest in SSCM has increased rapidly over recent years (Ageron et al., 2011). An increasing number of papers on sustainability and SSCM were published in different researches recently (e.g. Linton et al., 2007; Bai and Sarkis, 2010; Tseng et al., 2012; Govindan et al., 2014; Esfahbodi, 2016; Raut et al., 2017; Silva and Gouveia, 2017; Sgarbossa and Russo, 2017). A systematic review of SSCM is published by Teuteberg and Wittstruck (2010). Erol et al. (2011) introduced a fuzzy multi-criteria framework to evaluate sustainability performance of a grocery retailers supply chain in Turkish.The designof sustainable supply chains under emissions trading schemes proposed by Chaabane et al (2012). Seuring (2013) has reviewed in detail 36 papers which have utilized quantitative models for SSCM among more than 500 papers published until 2010. Govidnan et al. (2015b) applied a novel hybrid optimization approach to design a sustainableforward supply chain network under uncertainty. The very few published papers about SSCM focus on three demotions of suitability and most of related surveyed papers focus on greenness and cost-effectiveness of networks (e.g.Cruz and Matsypura, 2009; Pishvaee et al., 2012).

The study of the literature on supply chain network design reveals that an increasing number of models confronting with forward and reverse logistics. Govindan et al. (2015a) analyzed and categorized a set of 382 papers published in the area of reverse logistics and CLSC.Recent studies of CLSC have started to take environmental impacts of sustainability into account (Krikke et al., 2003; Fonseca et al., 2010; Kannan et al., 2012; Amin and Zhang, 2013; Garg et al., 2015). Although,the very few works that exist at

CLSCare focused social aspects as wellas economic and environmental aspects (Dehghanian and Mansour, 2009;Devika et al., 2014).Among different researches about SSCM, our paper is about sustainable closed loop network design which aims at considering the three dimensions of sustainability in the design phase. This is a new approach that seeks to embed economic, environmental, and social issues into closed loop during the design process (Chaabane et al., 2012).Therefore, this paper considers both forward and reverse flows of the supply chain together with their mutual interactions simultaneously in an integrated model in order to design a sustainable close loop supply chain for the paper industry.End users of this study can be the managers of the paper industry, thelogistics service providers and the government.

3- Model development

3-1- Problem description and assumptions

Paper as a key product requires an optimal CLSC network design. The scheme of the paper CLSC network structure is depicted in figure. 1. In the forward supply chain, different types of new paper are transported to the wholesalers to meet the paper dealers' demands. Furthermore, recycled paper is shipped from recycling facilities to the wholesalers to meet the secondary market requirements. In the reverse chain, collection centers collect waste paper from customer zones and supply it to the centralized collection points, where the sorting for waste paper occurs. Based on the sorting process, the appropriate paper is shipped to the recycling facilities or sold for energy recovery while contaminated paper is transported to the disposal sites. Incineration of waste paper with the production of steam for heating or electric power production is an accepted method of energy recovery. Waste paper can be categorized into eleven easily identifiable types of paper. Of the eleven components, newspaper has the highest calorific value while glossy paper has the lowest calorific value. Card board and white office paper are appropriate for recycling while colored office paper and oily papers are suitable for incineration.Furthermore, centralized collection points can be considered as a temporary storage area for the waste paper. Appropriate processing technologies need to be installed at each recycling facility location, depending on the type of the input materials and the requirements for the output materials. The proposed mathematical model will be developed based on the following assumptions:

- There are two different points for wholesalers to supply demands. One is achieving them from different manufacturers; and the other is acquiring them by recycling from the recycling facilities.
- Cost parameters at all stages of the CLSC network do not vary and inventory and shortages holding are not authorized.Backordering levels and inventory are not considered in the scope of strategic planning since they are generally taken into account in tactical and/or operational levels of CLSC planning.
- Transportation lead times between the stages are not mentioned because of the single period consideration which is a basic characteristic of strategic planning problems.

3-2- Indices and sets

p	index of paper types $p \in P$
p'	index of recycled paper types $p' \in P'$
v	index of virgin pulps $v \in V$
i	index of new paper manufacturers $i \in I$
w	index of potential regional wholesalers $w \in W$
k	index of paper dealers and retailers $k \in K$
j	index of initial collection centers $j \in J$
l	index of centralized collection points $l \in L$
r	index of potential recycling facilities $r \in R$
h	index of potential recycling technologies $h \in H$

b	index of energy recovery centers $b \in B$
d	index of disposals sites $d \in D$
m	index of vendors $m \in M$

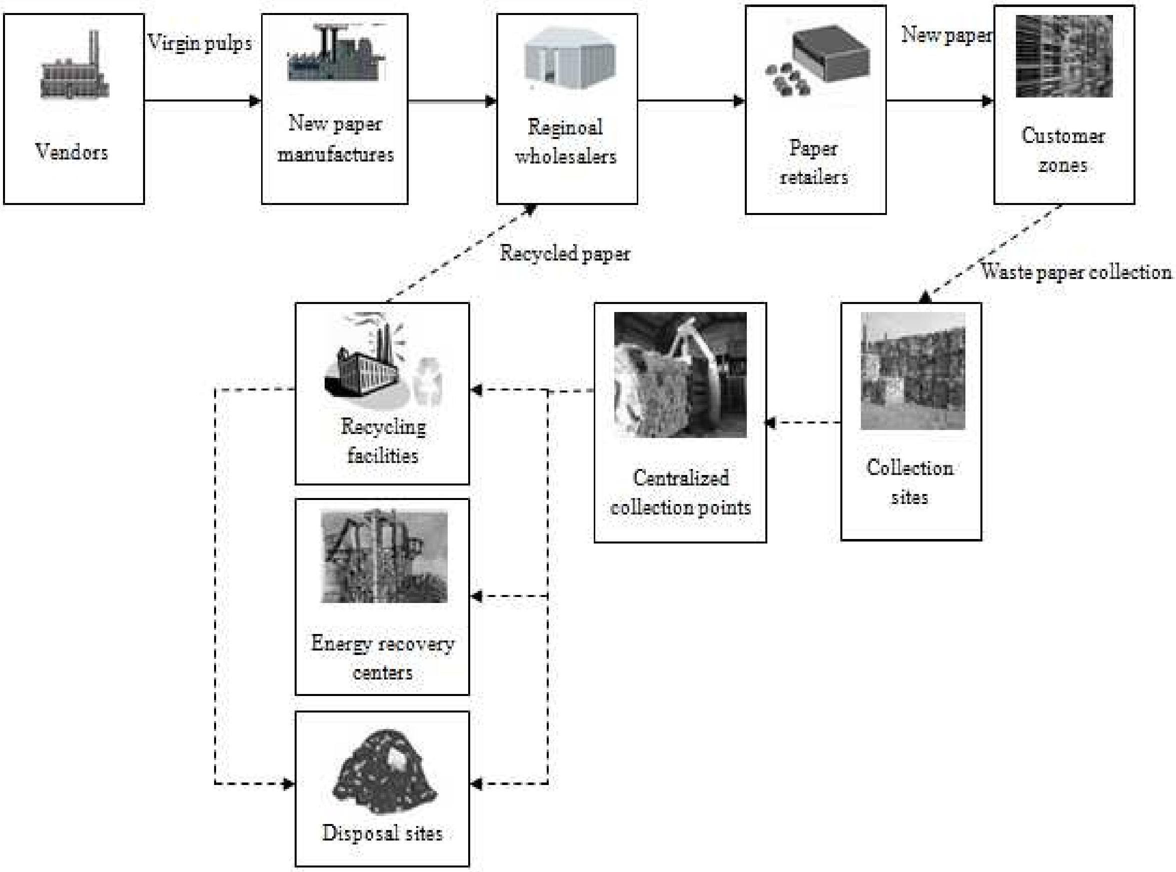

Figure 1. Presentation of the paper CLSC network

3-3- Model parameters

f_w	fixed set-up cost of regional wholesaler *w*
f_l	fixed set-up cost of centralized collection point l
f_r	fixed set-up cost of recycling facility *r*
f_{rh}	fixed set-up cost of recycling facility *r* using technology *h*
PRC_p	production cost of paper type *p* in each new paper manufacturer (in terms of monetary unit per kilogram)
TC_p	transportation cost of per kilogram paper type *p* (in terms of monetary unit per kilometer)
$TC1_{p'}$	transportation cost of per kilogram recycled paper type *p'* (in terms of monetary unit per kilometer)
$TC2_p$	transportation cost of per kilogram waste paper type *p* (in terms of monetary unit per kilometer)
PUC_{vmi}	purchasing cost of virgin pulp type *v* from vendor *m* for manufacturer *i* (in terms of monetary unit per kilogram)

RC_{prh}	recycling cost of waste paper type $p$in recycling facility r using technology h (in terms of monetary unit per kilogram)
CC_{pj}	collection costs of waste paper type $p$through the initial collection center j (in terms of monetary unit per kilogram)
SC_{pl}	sorting costs of waste paper type p through the centralized collection point l (in terms of monetary unit per kilogram)
DIC_{p}	disposal cost of waste paper type p (in terms of monetary unit per kilogram)
DE_{pk}	demand of paper dealer k for paper type p (in terms of kilogram)
$DE1_{p'k}$	demand of paper dealer k for paper type p' (in terms of kilogram)
SP_{p}	sales price of waste paper type p to energy recovery center (in terms of monetary unit per kilogram)
RE_{pj}	returned volume of waste paper type p to the initial collection center j (in terms of kilogram)
a_{lj}	binary parameter which is equal to 1, if the distance between the collection center j and the centralized collection point $l$is within the maximum acceptable distance and 0, otherwise
$\varepsilon_{p},\theta_{p},\tau_{p}$	fraction of waste paper type p shipped from centralized collection point to recycling, energy recovery and disposal sites, respectively noting that $\varepsilon_{p}+\theta_{p}+\tau_{p}=1$.
σ_{p}	fraction of waste paper type p satisfying the quality specifications for recycling process
$Л_{vp}$	amount of virgin pulp type v to produce paper type p (in terms of kilogram)
$Wcapf_{w}$	capacity of regional wholesaler w for forward flows of paper
$Prcap_{pi}$	production capacity of new paper manufacturer i for paper type p
$Ccapr_{l}$	capacity of centralized collection point l for reverse flow of waste paper
$Recap_{prh}$	recycling capacity of technology h at recycling facility r for waste paper type p
$Vcap_{vm}$	supply capacity of vendor m for virgin pulp type v
$d1_{iw}$	the distance between new paper manufacturer i and regional wholesaler w
$d2_{wk}$	the distance between regional wholesaler w and paper dealer k
$d3_{jl}$	the distance between initial collection center j and centralized collection point l
$d4_{lr}$	the distance between centralized collection point l and recycling facility r
$d5_{rw}$	the distance between recycling facility r and regional wholesaler w
$d6_{lb}$	the distance between centralized collection point l and energy recovery b
$d7_{ld}$	the distance between centralized collection point l and disposal site d
$d8_{rd}$	the distance between recycling facility r and disposal site d
$DMAX$	maximum allowable distance from a given regional wholesaler to a paper dealer for new paper distribution
$DMAX1$	maximum allowable distance from a collection center to a centralized collection point for waste paper collection
u_{w}	the number of job opportunities created during establishment of regional wholesaler w
z_{l}	the number of job opportunities created during establishment of centralized collection point l
e_{r}	the number of job opportunities created during establishment of recycling center r
μ_{w}	Regional index in establishing area of regional wholesaler w
μ_{l}	Regional index in establishing area of centralized collection point l
μ_{r}	Regional index in establishing area of recycling center r
M	an arbitrary big positive number
N	maximum number of opened centralized collection points

3-4- Decision variables

W_{w}	1, if a regional wholesaler is opened at location w; 0, otherwise
L_{l}	1, if a centralized collection point is opened at location l; 0, otherwise

H_{rh}	1, if a technology *h* is activated at recycling location *r*; 0, otherwise
R_r	1, if a recycling facility is opened at location *r*; 0, otherwise
Q_{pi}	production quantity of paper type *p* in paper manufacturer *i* (in terms of kilogram)
$X1_{piwk}$	quantity of paper type *p* shipped to paper dealer *k* from new paper manufacturer *i* via regional wholesaler w(in terms of kilogram)
$X2_{p'rwk}$	quantity of paper type *p'* shipped to paper dealer *k* from recycling facility *r* via regional wholesaler *w* (in terms of kilogram)
$X3_{plb}$	quantity of waste paper type *p* shipped to energy recovery center *b* from centralized collection center *l*(in terms of kilogram)
$X4_{pld}$	quantity of waste paper type *p* shipped to disposal site *d* from centralized collection center *l*(in terms of kilogram)
$X5_{plr}$	quantity of waste paper type *p* shipped to the recycling facility *r*from centralized collection center *l*(in terms of kilogram)
$X6_{prd}$	quantity of waste paper type *p* shipped to the disposal site *d* from recycling facility *r*(in terms of kilogram)
QP_{vmi}	amount of virgin pulp v purchased from vendor *m* by new paper manufacturer *i* (in terms of kilogram)
RE_{prh}	recycling quantity of waste paper type *p* using technology *h* at recycling facility *r*(in terms of kilogram)
Y_{wk}	1, if regional wholesaler *w* serves paper dealer *k* for meeting its demand in the forward chain; 0, otherwise
$Y1_{jl}$	1, if collection center *j* is allocated to centralized collection point *l*; 0, otherwise

3-5- Objective functions

As mentioned earlier, three conflicting objectives functions are considered in the formulation of the problem which are: (1) total costs, (2) total environmental benefit and (3) total social impact.

3-5-1- First objective: total cost

The first objective function is to minimize the total CLSC costs which is the summation of fixed opening costs (FOC), purchasing costs (PUC), production costs (PC), transportation costs (TC)collection costs (CC), sortingcosts (SC), recycling costs (REC), disposal costs (DC) minus revenue obtained from selling collected waste papers to energy recovery centers. Equation (1) gives the objective function as the sum of its addressed components. Equations (2)-(10) give the details of each component.

$$Min\, Z1 = FOC + PUC + PC + TC + CC + SC + REC + DC - REV \tag{1}$$

$$FOC = \sum_{w\in W} f_w . W_w + \sum_{l\in L} f_l . L_l + \sum_{r\in R} f_r . R_r + \sum_{r\in R}\sum_{h\in H} f_{rh} . H_{rh} \tag{2}$$

$$PUC = \sum_{v\in V}\sum_{m\in M}\sum_{i\in I} QP_{vmi} . PUC_{vmi} \tag{3}$$

$$PC = \sum_{p\in P}\sum_{i\in I} Q_{pi} . PRC_{pi} \tag{4}$$

$$\begin{aligned} TC = & \sum_{p\in P}\sum_{i\in I}\sum_{w\in W}\sum_{k\in K} X1_{piwk} . TC_p . (d1_{iw} + d2_{wk}) + \sum_{p'\in P'}\sum_{r\in R}\sum_{w\in W}\sum_{k\in K} X2_{p'rwk} . TC1_{p'} . (d5_{rw} + d2_{wk}) + \\ & \sum_{p\in P}\sum_{l\in L}\sum_{b\in B} X3_{plb} . TC2_p . d6_{lb} + \sum_{p\in P}\sum_{l\in L}\sum_{d\in D} X4_{pld} . TC2_p . d7_{ld} + \sum_{p\in P}\sum_{l\in L}\sum_{r\in R} X5_{plr} . TC2_p . d4_{lr} + \\ & \sum_{p\in P}\sum_{r\in R}\sum_{d\in D} X6_{prd} . TC2_p . d8_{rd} \end{aligned} \tag{5}$$

$$CC = \sum_{p\in P}\sum_{j\in J}\sum_{l\in L} Y1_{jl} . RE_{pj} . ((TC2_p . d3_{jl}) + CC_{pj}) \tag{6}$$

$$SC = \sum_{p\in P}\sum_{j\in J}\sum_{l\in L} Y1_{jl} . RE_{pj} . SC_{pl} \tag{7}$$

$$REC = \sum_{p\in P}\sum_{r\in R}\sum_{h\in H} RE1_{prh} . RC_{prh} \tag{8}$$

$$DC = \sum_{p\in P}\sum_{l\in L}\sum_{d\in D} X4_{pld} . DIC_{P} + \sum_{p\in P}\sum_{r\in R}\sum_{d\in D} X6_{prd} . DIC_{P} \tag{9}$$

$$REV = \sum_{p\in P}\sum_{l\in L}\sum_{b\in B} X3_{plb} . SP_{p} \tag{10}$$

3-5-2- Second objective: total environmental benefit

The second objective function is environment benefit through maximizingcoverage of collected waste paper by opened centralized collection centers as represented in equation (11). This would increase wastepaper recovery and the recovery of the waste paper conserves the natural resources, consumes less energy and decreases the environmental pollution. This objective is based on maximal coverage problem in the case of limited financial resources. Davari et al. (2011) defined this problem to investigate the location of facilities on a network in order to maximize the covered population. For covering a population, at least one facility must be opened within a predefined distance of it.

$$MaxZ2 = \sum_{p\in P}\sum_{j\in J}\sum_{l\in L} Y1_{jl} . RE_{pj} \tag{11}$$

3-5-3- Third objective: total social impact

The third objective function is to maximize the social impact of the network in a way that would prefer the location of facilities in the less populated regions as represented in equation (12).This would develop theseinland regions, move people away from the overpopulated areas, homogenize the ecological footprint of the population and improve access to public service facilities. Therefore, regional index for establishing area of facilities is introduced through dividing population density of the division(state) bythe population density of the region (city). Regional index ≈ 0 represents an overpopulated region while regional index> 1 indicates an under populated region, when compared to the population density of division. The bigger regional index, the less populated the region is.So, when deciding on facility locations, the proposed model choosesless populated regions to installfacilities.

$$MaxZ3 = \sum_{w\in W} u_{w} . \mu_{w} . W_{w} + \sum_{l\in L} z_{l} . \mu_{l} . L_{l} + \sum_{r\in R} e_{r} . \mu_{r} . R_{r} \tag{12}$$

Constraints are given as in equations (13)-(37).

$$\sum_{k\in K} Y_{wk} \le M . W_{w} \quad \forall w \tag{13}$$

$$\sum_{w\in W} Y_{wk} = 1 \quad \forall k \tag{14}$$

$$\sum_{l\in L} L_{l} \le N \tag{15}$$

$$Y1_{jl} \le a_{lj} . L_{l} \quad \forall j, \forall l \tag{16}$$

$$\sum_{l\in L} Y1_{jl} \le 1 \quad \forall j \tag{17}$$

$$\sum_{p\in P}\sum_{p'\in P'}\sum_{k\in K} Y_{wk} . (DE_{pk} + DE1_{p'k}) \le Wcap_{w} . W_{w} \quad \forall w \tag{18}$$

$$\sum_{i\in I} X1_{piwk} = DE_{pk}.Y_{wk} \qquad \forall p, \forall w, \forall k \tag{19}$$

$$\sum_{r\in R} X2_{p'rwk} = DE1_{p'k}.Y_{wk} \qquad \forall p', \forall w, \forall k \tag{20}$$

$$\sum_{w\in W}\sum_{k\in K} X1_{piwk} \le Q_{pi} \qquad \forall p, \forall i \tag{21}$$

$$Q_{pi} \le Prcap_{pi} \qquad \forall p, \forall i \tag{22}$$

$$d2_{wk}.Y_{wk} \le DMAX \qquad \forall w, \forall \mathrm{k} \tag{23}$$

$$d3_{jl}.Y1_{jl} \le DMAX1 \qquad \forall j, \forall l \tag{24}$$

$$\sum_{j\in J} RE_{pj}.Y1_{jl} \le Ccapr_l.L_l \qquad \forall p, \forall l \tag{25}$$

$$\sum_{b\in B} X3_{plb} = \varepsilon_p.\sum_{j\in J} RE_{pj}.Y1_{jl} \qquad \forall p, \forall l \tag{26}$$

$$\sum_{d\in D} X4_{pld} = \theta_p.\sum_{j\in J} RE_{pj}.Y1_{jl} \qquad \forall p, \forall l \tag{27}$$

$$\sum_{r\in R} X5_{plr} = \tau_p.\sum_{j\in J} RE_{pj}.Y1_{jl} \qquad \forall p, \forall l \tag{28}$$

$$\sum_{h\in H} RE_{prh} = \sigma_p.\sum_{l\in L} X5_{plr} \qquad \forall p, \forall r \tag{29}$$

$$\sum_{p\in P} RE_{prh} \le H_{rh}.Recap_{prh} \qquad \forall r\ , \forall h \tag{30}$$

$$\sum_{w\in W}\sum_{k\in K} X2_{p'rwk} \le \sum_{h\in H} RE_{prh} \qquad \forall p', \forall p, \forall \mathrm{r} \tag{31}$$

$$\sum_{d\in D} X6_{prd} = (1-\sigma_p).\sum_{l\in L} X5_{plr} \qquad \forall p, \forall r \tag{32}$$

$$\sum_{h\in H} H_{rh} = R_r \qquad \forall r \tag{33}$$

$$\sum_{i\in I} QP_{vmi} \le Vcap_{vm} \qquad \forall v, \forall m \tag{34}$$

$$\sum_{m\in M} QP_{vmi} = \sum_{p\in P} Q_{pi}.\pi_{vp} \qquad \forall v, \forall \mathrm{i} \tag{35}$$

$$W_w, L_l, R_r, H_{rh}, Y_{wk}, Y1_{jl} \in (0,1) \tag{36}$$

$$\text{All other varibles are continuous} \ge 0 \tag{37}$$

According to constraint (13), if a regional wholesaler is opened, it may serve to any dealer or retailer. In other words, there may be an outgoing flow (distribution operation) from this wholesaler to the dealers. Constraint (14) ensures that a paper dealer is assigned to a single regional wholesaler for forward flow of newly produced paper. In other words, demands of the paper dealers must be satisfied by a single regional wholesaler. Constraint (15) gives an upper bound for the number of centralized collection points to be opened.Constraint (16) determines which paper returns are covered within the acceptable service distance. Service means the collection of waste papers from the initial collection centers. If no centralized collection centre is located, the right hand side of that constraint will be zero and forces the $y1_{jl}$ equal to zero.Constraint (17) guarantees that a paper collection center may be assigned to at most a single centralized collection point for waste paper returns. Since these assignments may be impossible because of the logic of maximal covering problem, ≤1 is used in that constraint set.Constraint (18) limits the amount of newly produced and recycled paper shipped through the regional wholesaler to its capacity of performing forward flows. Constraint (19) and (20) ensure that the demands of paper dealers for newly produced and recycled paper to be satisfied. Constraint (21) guarantees that the outgoing flows from a new paper manufacturer cannot exceed the production quantity at that manufacturer. Constraint (22) ensures that the production quantity of each paper type not to exceed the production capacity of the new paper manufacturers. Constraint (23) guarantees that each regional wholesaler to be located within acceptable proximity of paper dealers. Constraint (24) makes sure that each collection centre to be located within acceptable proximity of centralized collection point. Capacities ofcentralized collection center are restricted by Constraint (25). Constraint (26) to (28) ensure that the sum of the waste paper taken from a centralized collection point to recycling facilities, energy recovery centers and disposal sites do not exceed the amount of waste paper available at the centralized collection center.Constraint (29) represents that the input rate of waste paper is satisfied by the quality specifications for recycling process. According to constraint (30), the recycling quantity of each paper type not to be over the recycling capacity of the different technologies of recycling center. Constraint (31) guarantees that the outgoing flows from a recycling center cannot exceed the recycling quantity at each recycling center. Constraint (32) represents the flow of non-recyclable waste paper from recycling facilities to disposal centers. Constraint (33) guarantees that each opened facility location has exactly one technology in use at each time. Constraint (34) gives the capacity constraint for vendors. Constraint (35) gives the authorized share of virgin pulp in order to satisfy quality conditions for paper types. Constraint (36) represents the binary variables such as opening decisions for the facilities (regional wholesalers, centralized collection points and recycling facilities) and activating decisions for the technologies at recycling facilities; assignment decisions for allocating paper dealers to the regional wholesalers and collection centers to the centralized collection points. Constraint (37) ensures the non-negativity of other variables.

4-IFGP approach

To solve the proposed multi-objective problem, IFGP method is used. IFGP was first introduced by Ferrao et al. (2008) and applied to multi-objective transportation problems in order to determine the preferred compromise solutions.In IFGP, three commonly used approaches namely interactive programming, goal programming and fuzzy programming are incorporated in order to generate more efficient method which reflects the advantages of all these approaches.The most important advantage of IFGP from the perspective ofa decision maker (DM) is controlling the search direction during the solution phase by updating both nadir solution and aspiration level of each goal in order to provide other optimal solutions. In the last iteration, the accepted solution by the DM represents the preferred compromise solution and this solution is perceived as a more realistic one. The steps of IFGP method can be summarized as follows:

Step 1: Solve the proposed multi-objective mixed-integer linear programmingmodel for each objective separately. If all the solutions are the same, select one of them as an optimal compromise solution and go to Step 7. Otherwise, go to Step 2.

Step 2: Determine the range of each objective function over the efficient set by calculating the optimal and nadirsolutions for each objective function. The optimal solutions, i.e., $(Z_1^{optimal}, x_1^{optimal})$, $(Z_2^{optimal}, x_2^{optimal})$ and $(Z_3^{optimal}, x_3^{optimal})$, are obtained from step 1 by solving each objective function separately; then a solution for each objective function can be obtained from equations (38) to (40).

$$Z_1^{nadir} = max\,(Z_1(x_2^{optimal})\ and\ Z_1(x_3^{optimal})) \tag{38}$$

$$Z_2^{nadir} = min\,(Z_2(x_1^{optimal})\ and\ Z_2(x_3^{optimal})) \tag{39}$$

$$Z_3^{nadir} = min\,(Z_3\,(x_1^{optimal}\,)\ and\ Z_3\,(x_2^{optimal}\,)) \tag{40}$$

Step 3: Identify a linear membership function for each objective function using equations (41)-(43) and also the initial aspiration level.

$$\mu_1(x) = \begin{cases} 1 & if\ \ Z_1 \leq Z_1^{optimal} \\ \dfrac{Z_1^{nadir} - Z_1}{Z_1^{nadir} - Z_1^{optimal}} & if\ \ Z_1^{optimal} < Z_1 < Z_1^{nadir} \\ 0 & if\ \ Z_1 \geq Z_1^{nadir} \end{cases} \tag{41}$$

$$\mu_2(x) = \begin{cases} 1 & if\ \ Z_2 \geq Z_2^{optimal} \\ \dfrac{Z_2 - Z_2^{nadir}}{Z_2^{optimal} - Z_2^{nadir}} & if\ \ Z_2^{nadir} < Z_2 < Z_2^{optimal} \\ 0 & if\ \ Z_2 \leq Z_2^{nadir} \end{cases} \tag{42}$$

$$\mu_3(x) = \begin{cases} 1 & if\ \ Z_3 \geq Z_3^{optimal} \\ \dfrac{Z_3 - Z_3^{nadir}}{Z_3^{optimal} - Z_3^{nadir}} & if\ \ Z_3^{nadir} < Z_3 < Z_3^{optimal} \\ 0 & if\ \ Z_3 \leq Z_3^{nadir} \end{cases} \tag{43}$$

where $\mu_h(x)$ denotes the satisfaction degree of the *h*-th objective function. Step 4: Solve the equivalent crisp mixed-integer goal programming formulation of the fuzzy mixed-integer goalprogramming using (44)-(49).

$$Max\ \beta \tag{44}$$

$$s.t.$$

$$\beta \leq \mu_{Z_h}(x) \qquad h = 1, 2, ..., H \tag{45}$$

$$Z_h(x) - d^{+h} + d^{-h} = G^h \qquad h = 1, 2, ..., H \tag{46}$$

$$x \in Q(x) \tag{47}$$

$$\beta \in [0,1] \tag{48}$$

$$d^{+h}, d^{-h} \geq 0 \tag{49}$$

In this model, the aim is to reach the maximum satisfaction level, namely β-value, in such a way that the constraints can be satisfied noting that, G_h is the aspiration level of the objective function and *Q(x)* represents the feasible area concerning the constraints of the equivalent crisp model.

Step 5: Present the solution to the DM. If the DM accepts it, go to Step 7; otherwise, go to Step 6.

Step 6: Evaluate each objective function of the solution. Compare nadir solution of each objective with the new valueof the objective function. If the new value is better than the nadir solution, consider this as a new nadirsolution;otherwise, keep the old one as is. Repeat this process *h*times and go to Step 3.

Step 7: Stop.

5- Model implementation

In order to observe the performance of the proposed model, a case study whose data originated from the paper industry in East Azerbaijan of Iran is studied. The CLSC network involves two paper plants, three vendors to supply virgin pulps, four potential regional wholesalers, twenty five paper dealers, five initial collection centers, four potential sites for centralized return points, two potential sites for paper recycling facilities, two potential recycling technologies, one energy recovery center and six sites for disposal. Four types of papers including glossy, printing and writing, kraft, and fluting, together with four types of virgin pulps and two types of recycled papers are considered. Parameter intervals used in the case study are given in table 1.

Table 1.Range of the values of the parameters.

Parameter	Range of values
Fixed set-up cost of opening regional wholesalers (million Rials)	3200-9800
Fixed set-up cost of opening centralized collection points(million Rials)	1800-3500
Fixed set-up cost of opening recycling facilities (million Rials)	5000-7000
Fixed set-up cost of opening recycling facilities using technologies (million Rials)	2500-8000
Production cost (Rials/kg)	9500-48000
Transportation cost for newly produced paper (Rials/km×kg))	1-3
Transportation cost for waste paper (Rials/km×kg)	2-3
Transportation cost for recycled paper (Rials/km×kg)	1-3
Purchasing cost of waste paper from waste vendors (Rials/kg)	1000-4000
Purchasing cost of virgin pulps from vendors (Rials/kg)	1000-3000
Selling price of waste paper to waste customers (Rials/kg)	1000-4000
Selling price of waste paper to energy recovery center (Rials/kg)	500-2400
Recycling cost using different technologies (Rials/kg)	1000-5000
Collection cost (Rials/kg)	2000-4000
Sorting cost (Rials/kg)	1000-2000
Disposal cost (Rials/kg)	1000-3000
Demand forecasts of new paper dealers (kgs)	640000-3200000
Demand forecasts of waste paper dealers (kgs)	100000-800000
Returned volume of per waste paper to the initial collection centers (kgs)	180000-2800000
Production capacity of paper manufacturers (kgs)	80000000-90000000
Capacity of regional wholesalers (kgs)	50000000-100000000
Capacity of centralized collection points (kgs)	80000000-117000000
Recycling capacity of different technologies (kgs)	20000000-250000000
Capacity of virgin pulps (kgs)	160000000-180000000
Rate of satisfying the quality specifications for recycling	80-90
Recycling rate	52-70
Disposal rate	10-15
Energy recovery rate	20-40
Distances (km)	0-260
Maximum acceptable distances (km)	70-120
Maximum number of opened centralized collection points	4
Job opportunities created during establishing facilities	90-130
Population density in establishing area of facilities (people/ km)	6.73-15.76

We have solved the problem using the CPLEX solver of GAMS commercial software version 23.6.5 on a computer Intel(R), Core (TM) 2 Duo CPU P8400 @ 2.26 GHz, and 3.00 GB of RAMfor each objective separately. In this way, nadir and ideal solutions (lower and Upper bounds) to form fuzzy membership functions are obtained separately. Tables 2 and 3 illustrate the results.

Table 2. Results from solving each single objective model

	Total costs (Z_1)	Total environmental benefit (Z_2)	Total social impact (Z_3)
Total value of the CLSC	6.767E9	1.160E7	1027
Number of opened paper recycling facilities	1	2	2
Number of opened regional wholesalers	3	4	4
Number of opened centralized return points	2	4	3
Number of activated technologies	1	1	1

Table 3. Lower and upper bounds of each objective function.

Goals	Lower bound	Upper bound
Total costs	6.767E9	3.915E10
Total environmental benefit	5.452E6	1.160E7
Total social impact	556	1027

After definition of the membership functions and aspiration levels, the problem can be transformed into an equivalent crisp auxiliary single objective mixed integer linear programming model as stated in section 4. It is assumed that the DM is satisfied with results at the end of iteration 3.Optimization results provided by solving the auxiliary models are iteratively given in table 4.With this compromise solution, three of the regional wholesalers, three of the centralized collection points and one of the paper recycling facilities with one type of technologies are opened.

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Table 4. Optimization results obtained from all iterations.

Iteration	Auxiliary variable β	Total costs (Z_1)	Total environmental benefit (Z_2)	Total social impact (Z_3)
1	0.65	1.628E10	7.593E6	746
2	0.32	9.374E9	8.121E6	802
3	0.01	8.964E9	8.854E6	851

In order to investigate the sensitivity of the proposed model and decision parameters of the collection-recovery system to variations of each fuzzy goal, the proposed fuzzy multi-objective problem is resolved with different scenarios. In scenarios 1-4, the variations of each fuzzy goal are analyzed changing the maximum number of opened centralized collection points. In scenarios 5-8, changing recycling capacity of different technologies at recycling facilities is analyzed. In scenarios 9-12, returns of waste papers are investigated. Sensitivity analysis is applied to scenarios using the data given in table 5. Different upper and lower bounds are obtained for each scenario, while considering each scenario. For this reason, boundary values of the fuzzy goals vary. In other words, since the max-min bounds of the fuzzy goals will change in each scenario, membership functions should be revised for each scenario before performing each scenario.Results of scenario analysis for simultaneous consideration of fuzzy objectives after two iterations are given by figure 2.

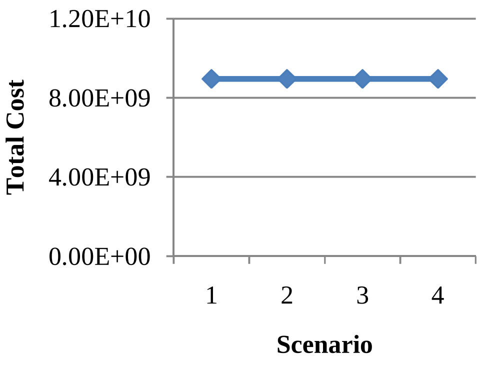
In scenarios 1-4, effects of the maximum number of opened centralized collection points are examined. According to figure 2, when the maximum number of opened facilities increases, both total environment benefit and social impact increase. Moreover, total cost will not decrease too much due to operating one more centralized collection point. In scenarios 5-8, different recycling capacities of technologies are taken into account. It is clearly understood from figure 2 that higher recycling capacities provide lower costs, higher significant social impact and equal environment benefit considering all fuzzy goals simultaneously.

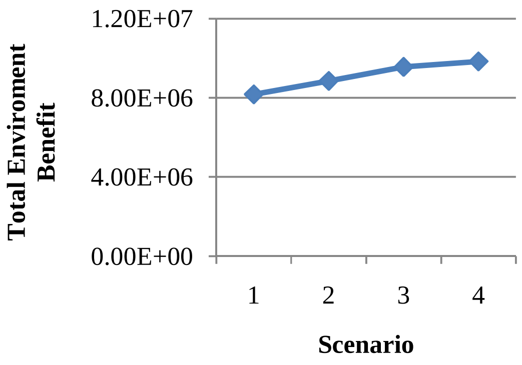
In scenarios 9-12, different returns of waste papers are taken into account. It is understood from figure 2 that higher returns provide lower cost, higher amount of environment benefit and equal social impact considering all fuzzy goals simultaneously.

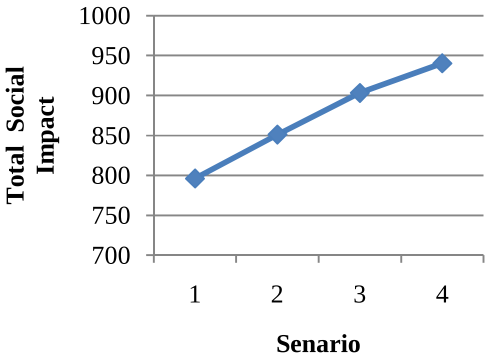
In summary, DMs should increase the recycling capacities of technologies in order to decrease total cost and increase the total social impact. They may increase the number of opened centralized collection points in order to increase both total environment benefit and social impact. Furthermore, they may increase the returns of waste paper in order to decrease total cost and increase total environment benefit.

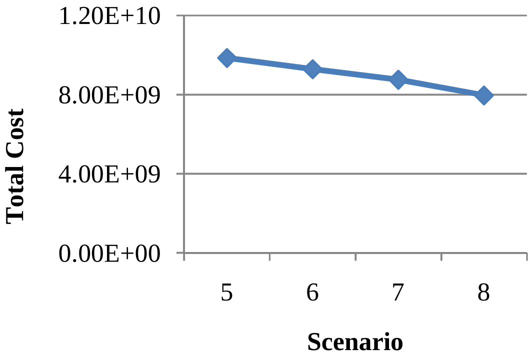
Table 5.Application data of different scenarios.

Scenario	Item	Scenario	Item	Scenario	Item
	N		$Recap_{prh}$ (kg)		RE_{pj} (kg)
Scenario 1	3	Scenario 5	10000000	Scenario 9	745000
Scenario 2	4	Scenario 6	16000000	Scenario 10	1192000
Scenario 3	5	Scenario 7	24000000	Scenario 11	1788000
Scenario 4	6	Scenario 8	30000000	Scenario 12	2235000









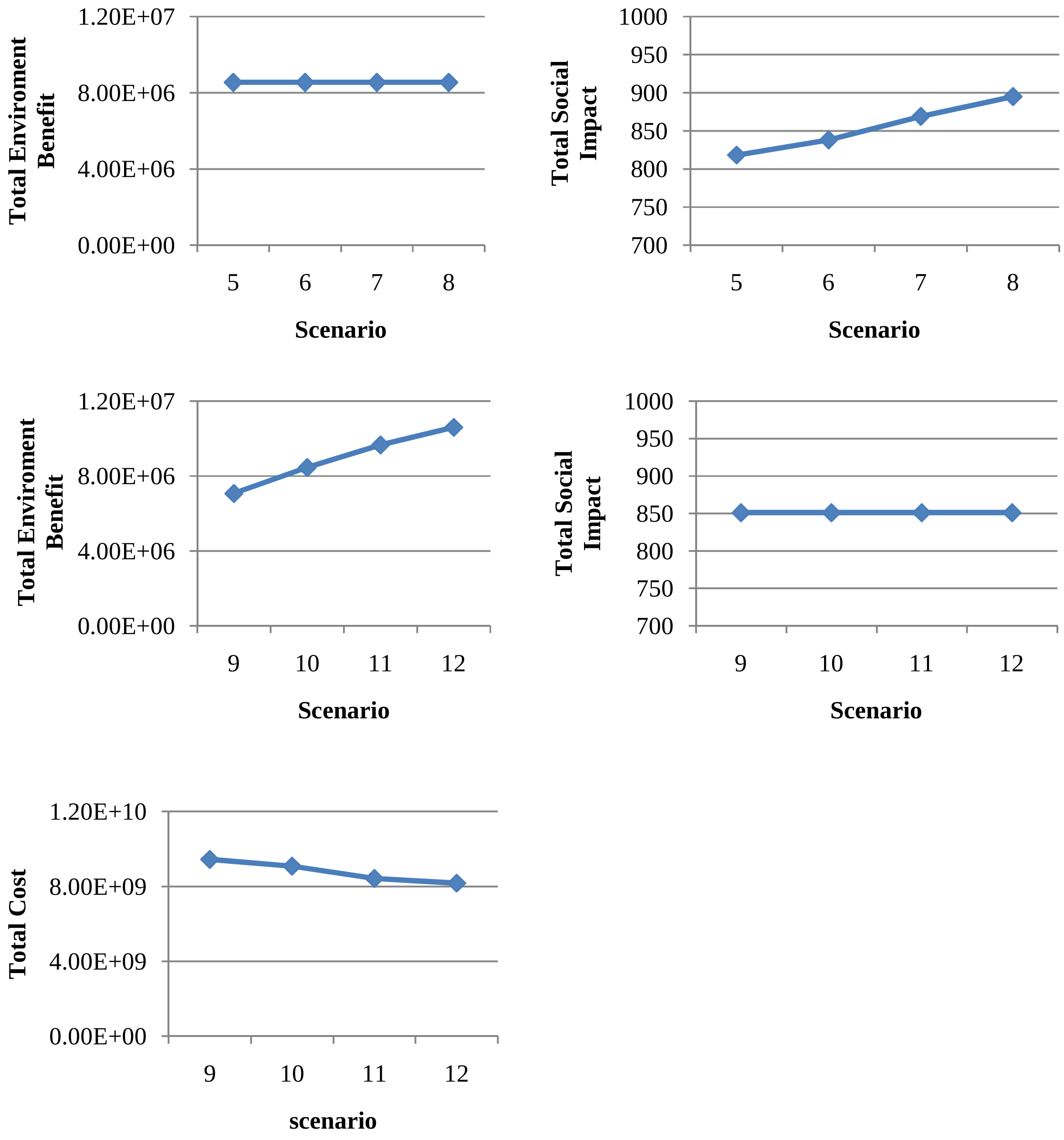


Figure 2. Evaluating scenarios considering all the fuzzy goals simultaneously

6-Conclusion and future research

In this study, a new mixed integer linear programming model was developed for a multi-objective, multi-echelon, multi-product and single period sustainable CLSC in the paper industry. The objectives considered were minimization of total cost; environmental benefit through maximizing coverage of collected waste paper by opened centralized collection centers; and maximization of the social impact of the network in a way that would prefer the location of facilities in the less populated regions. Furthermore the proposed model was applied to an illustrative example designed utilizing real data of the paper industry in East Azerbaijan of Iran and IFGP approach was used to solve the developed model.

From the case study, we can conclude that the proposed model improves all the three objectives of sustainability and offers important managerial insights. DMs should increase the recycling capacities of technologies in order to decrease total cost and increase the total social impact. They may increase the number of opened centralized collection points in order to increase both total environment benefit and social impact. Furthermore, they may increase the returns of waste paper in order to decrease total cost and increase total environment benefit.

Considering dynamic behavior of the network as well as the presence of uncertainty in some of the parameters for instance levels of the demand of new and recycled papers, return quantities of waste paper, return rates and capacities of facilities can be good idea for future studies. Integrating operational decisions such as routing decisions or inventory may also be useful. Finally, solving the proposed model using multi-objective meta-heuristic algorithms is definitely worth of consideration, especially for the large-sized instances of the problem.

References

Ageron, B.,Gunasekaran, A., &Spalanzani, A. (2011). Sustainable Supply Management: An Empirical Study. *International Journal of Production Economics*, 140 (1), 168-182.

Amin, S.H.,& Zhang, G. (2013). A multi-objective facility location model for closed loop supply chain networkunder uncertain demand and return.*Appl. Math. Model*, 37, 4165–4176.

Bai, C., &Sarkis, J., (2010). Integrating sustainability into supplier selection with grey system and rough set methodologies. *International Journal of Production Economics,* 124 (1), 252-264.

Cardoso, S.R., Barbosa-Póvoa, A.P.F., &Relvas, S. (2013). Design and planning of supply chains withintegrationofreverse logistics activities under demand uncertainty.*European Journal of Operational Research*, 226,436-451.

Cruz, J., &Matsypura, D. (2009). Supply chain networks with corporate social responsibility through integrated environmental decision-making. *International Journal of Production Research*, 47 (3), 621-648.

Chaabane, A., Ramudhin, A., &Paquet, M.(2012). Design of sustainable supply chains under the emission trading scheme. *International Journal of Production Economics,* 135 (1), 37-49.

Davari S., Zarandi M.H.F.,&Hemmati A. (2011). Maximal covering location problem (MCLP) with fuzzy travel times. *ExpSystAppl*,38,14535–41.

Dehghanian, F. & Mansour, S. (2009). Designing sustainable recovery network of end-of-life products usinggenetic algorithm.*Resources, Conservation andRecycling*, 53(10), 559–570.

Devika, K., Jafarian, A., &Nourbakhsh, V. (2014). Designing a sustainable closed-loop supply chainnetwork based on triple bottom line approach: A comparison of metaheuristics hybridizationtechniques.*European Journal of Operational Research,* 235, 594-615.

Erol, I., Sencer, S., &Sari, R. (2011). A new fuzzy multi-criteria framework for measuring sustainability performance of a supply chain,*Ecological Economics*, 70(6), 1088-1100.

Esfahbodi, A. Zhang Y., &Watson, G. (2016). Sustainable supply chain management in emerging economies: Trade-offs between environmental and cost performance.*International Journal of Production Economics*, 181, 350-366.

Ferrao P., Ribeiro, P., &Silva P.A. (2008). Management system for end-of-life tyres: A Portuguese case study.*Waste Management*, 28, 604-614.

Fonseca, M. C., García-Sánchez, Á., Ortega-Mier, M., &Saldanha-da-Gama, F. (2010). A stochastic biobjective location model for strategic reverse logistics. *Top,* 18(1), 158–184.

Garg, K., Kannan, D., Diabat, A., &Jha, P.C. (2015). A Multi-criteria optimization approach to manageenvironmental issues in closed loop supply chain network design. *Journal of Cleaner Production*, 100, 297-314

Govindan, K. Soleimani, H. & Kannan, D. (2015a). Reverse logistics and closed-loop supply chain: A comprehensivereview to explore the future.*European Journal of Operational Research*, 240 (3), 603–626.

Govindan, K., Jafarian, A., Nourbakhsh (2015b). Bi-objective integrating sustainable order allocation and sustainable supply chain networkstrategic design with stochastic demand using a novel robust hybrid multi-objective metaheuristic.*Computers & Operations Research*,62, 112-130.

Govindan, K., Jafarian, A., Khodaverdi, R., &Devika K. (2014). Two-echelon multiple vehicle location-routing problem with time windows for optimization of sustainable supply chain network of perishable food.*International Journal of Production Economics*, 152, 9-28

Kannan, D., Diabat, A., Alrefaei, M., Govindan, K.,& Yong, G. (2012). A carbon footprint based reverselogistics network design model. *Resources, Conservation and Recycling*, 67, 75–79.

Krikke, H., Bloemhof-Ruwaard, J., &Van Wassenhove, L.N. (2003) .Concurrent product and closed-loop supplychain design with an application to refrigerators.*International Journal ofProduction Research*, 41(16), 3689-3719.

Linton, J.D., Klassen, R., &Jayaraman, V. (2007). Sustainable supply chains: An introduction. *Journal of Operations Management*, 25 (6), 1075-1082.

Pishvaee, M. S., Razmi, J., &Torabi, S. A. (2012). Robust possibilistic programming for socially responsible supply chain network design: A new approach. *Fuzzy Sets and Systems*, 206(0), 1–20.

Raut, R.D., Narkhede, B., &Gardas, B.B. (2017).To identify the critical success factors of sustainable supply chain management practices in the context of oil and gas industries: ISM approach.*Renewable and Sustainable Energy Reviews*, 68 (1),33-47.

Seuring, S. (2013). A review of modeling approaches for sustainable supply chain management. *Decision Support Systems*, 54 (4), 1513-1520.

Seuring, S. & Müller, M. (2008).From a literature review to a conceptual framework for sustainable supplychainmanagement.*Journal of Cleaner Production*, 16(15),1699–1710.

Sgarbossa, F., & Russo, I. (2017). A proactive model in sustainable food supply chain: Insight from a case study. *International Journal of Production Economics,* 183(B), 596-606.

Silva, C., & Gouveia, J.B. (2017). Sustainable Supply Chain Management: A Case Study.*Engineering Systems and Networks*, 243-250.

Tseng, M. L., Tan, R.R., &Siriban-Manalang, A.B. (2012). Sustainable consumption and production for Asia: sustainability through green design and practice. *Journal of Cleaner Production*,40,1-5.

Teuteberg, F., &Wittstruck, D. (2010). A Systematic Review of Sustainable Supply Chain Management, MultikonferenzWirtschaftsinformatik2010. 203.