Integration of Triple Sustainable Management by Considering the Multi-period Supply Chain for Next-Generation Fuel

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Abstract. Energy sources depending on biofuel have a positive impact on the environment, economy, and society. To use this next-generation fuel appropriately at a developed scale, well-designed and efficient supply chain management are desired. Therefore, it is necessary to design and develop a sustainable biofuel supply chain that is economical, minimizes environmental threats, and improves social benefits. In this study, a multi-period multi-objective sustainable supply chain management is developed. This long-term planning horizon is divided into an equivalent number of sub-periods in which all objectives are executed simultaneously. The objective is to make a framework of the multi-period sustainable supply chain management that reduces the carbon emission and take full advantage of the new job opportunities in the entire period. The parameters in this model are needed to extend during the time to meet the upward demand for markets. The augmented ε-constraint approach with an improved way of computing the step size is used to make a trade-off between contending objectives. The findings will help the organizations to respond accordingly for different parameters and regulations while designing the long-term planning for second-generation biofuel supply chain management.

Keywords: triple sustainable management, multi-period supply chain; sustainable fuel, carbon emissions, augmented ε-constraint.

1 Introduction

In the current era, a sustainable development under the umbrella of environmental and social concerns is more focus than cost reduction, because experts believe that direction on these concerns is necessary due to an elevated level of global warming and for the betterment of society. Today's business organizations face pressure to develop sustainable actions from several sources, including government regulations, environmental advocacy groups, non-availability of natural resources, stakeholders, customers, and society [1]. According to Elkington [2], to grasp sustainability, social and environmental aspects are also needed with the addition to the economic dimension.

Nowadays a new paradigm of a triple bottom line approach is introduced by sustainable value creation with the incorporation of the social aspects in addition to economic and environmental measures. Second generation biofuel (SGB) is a compelling source for next-generation energy because of concerns related to ecological safety and energy means. The SGB is a cost-effective sustainable fuel that bounds the expenditure of fossil fuel [3]. The production and supply of second-generation biofuel have not been commercialized on a large scale until now [4]. To achieve sustainability is a comprehensive and efficient optimization of a residual biomass (RB) based second-generation biofuel supply chain management (SGBSCM) is necessary. Developing a sustainable supply chain management SSCM system for SGB is one of the foremost challenges in this scenario. This study is a blend of the "triple sustainable management" (TSM) approach as shown in Figure 1. It uses a sustainable raw-material for sustainable energy with sustainable supply chain management. As the residual biomass is an agricultural waste and natural source of raw material. Additionally, the end-product which is sustainable energy in the form of biofuel is a potential source of fuel for next-generation vehicles. Lastly, in this study, the three dimensions of sustainability i.e., environmental, economic, and social are optimized during SCM activities.

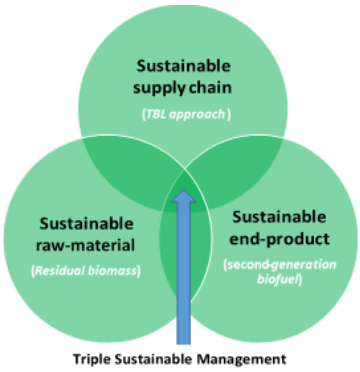

Fig. 1. Blend of triple sustainable management approach.

2 Literature Review

To deal with the uncertainties in the development of the biofuel market, the SCM of RB plays an important part [5]. Xie and Huang [6] formulated a multistage, mixed-integer stochastic model for biofuel SCM with evolving uncertainties. This model is an expansion in the biofuel SCM with demand uncertainty. Bairamzadeh et.al. [7] modeled some uncertainties in the planning and design of the biofuel supply network under a robust optimization approach. In the condition of uncertainty, a robust model is established to optimize the biomass SCM network [8]. The fuzzy goal programming approach is used to deal with uncertainties in a biomass SCM [9]. The carbon tax, as well as carbon cap, is one of the main emission policies, started by different countries to restrict emissions. Ahmed and Sarkar [10] designed an incorporated economic and environmental structure for a multi-stage SCM following the carbon tax policy scheme. Ghosh et.al. [11] considered a collaborative model to minimize carbon emissions for a two-echelon SCM with the carbon tax and uncertain demand. Their study and model benefit the organizations to minimize carbon emissions and total cost, also it will help authorities to regulate the proper carbon tax rate. Consequently, consideration of carbon rules and policies during optimizing supply chain management actions has become imperative as regulatory bodies all over the globe have implemented different schemes to reduce emissions of GHG's.

The simple ε-constraint approach has no assurance of the efficiency of the generated solution, particularly when there are more than two objectives [12]. To resolve this issue, a methodology is developed by Mavrotas and Florios [13] named as an augmented ε-constraint approach. Several authors applied this methodology to get an efficient solution in multi-objective optimization [14-18]. Du et.al. [15] stated that in augmented ε-constraint approach inefficient solutions are transferred to one efficient solution. Also from this approach efficient Pareto optimal solutions are generated and it evades inefficient ones. This technique considers all conflicting objectives simultaneously without involving weights [19]. The discussion and literature review concluded that a carbon tax policy scheme should be incorporated out in the planning and design of second-generation biofuel supply chain management. It is also concluded that uncertain factors should be present while optimizing the mathematical models for second-generation biofuel supply chain management. So, the consideration of carbon tax policy and uncertain parameters are important. Moreover, the integration of second-generation biofuel and sustainable supply chain management makes a blend of "TSM" and has a big contribution to literature.

In the TSM approach, sustainable raw-material in the shape of residual biomass is utilized, the performance of sustainable supply chain management by adopting a triple bottom line approach, and sustainable energy in the shape of second-generation biofuel is obtained. To advance this study, an improved augmented ε-constraint methodology using lexicographic optimization is proposed.

3 Problem description and notation

3.1 Problem description

A multi-period mathematical model for SGBSCM that simultaneously optimizes the multiple-objectives under the triple bottom line is developed. The long-period, which is ten years, is equally divided into ten number of the one-year planning horizon. All dimensions of sustainability are executed in the same structure for this long-term divided horizon. The impact of inflation on an annual basis is also implemented on all cost parameters, including carbon emission cost to demonstrate the actual scenarios. Residual biomass harvesting area, as well as carbon cap on agricultural zones, biorefineries and transportation nodes, need to be extended for a specific period to meet the upward demand of markets.

The uncertain parameters along with that carbon tax and cap policy scheme are also incorporated in the model. As a result, the optimal SGBSCM decisions for the individual period are connected with the entire period. The objective of this study is designing the multi-period multi-objective SGBSCM based on (i) development of the SGBSCM for long-term planning (ii) new job opportunities and carbon emission estimation for planning horizon (iii) allocation of extended quota in carbon cap and tax policy scheme for designed horizon (iv) extension of residual biomass cultivation agricultural zone to meet market demand (v) distribution of biofuel by meeting the demands of multiple particular markets. As the model considers the trade-offs between total supply chain management cost, carbon emissions, and opportunities of job employment for the individual planning period, so findings will help the organizations and government agencies to respond accordingly for different regulations and parameters while designing the long-term decisions.

3.2 Notation

Indices

C	number of total agricultural regions c
I	number of total biorefinery plants i
N	number of total market centers n
T	total planning horizon t

Decision variables

Q_{cit}	amount of biomass transported
Q_{int}	amount of the biofuel transported
T_{cit}	trips for shipment of biomass
T_{int}	trips for shipment of biofuel

Parameters

A_{ct}	area for residual biomass (Acres)
C_t^{tx}	carbon tax ($/ton)
C_{ct}^{ha}	harvesting & baling cost ($/ton)

C_{ct}^{co} collection cost for unit of biomass (\$/ton)

C_{ct}^{st} storage cost for unit of (\$/ton)

C_{ct}^{ld} loading cost for unit of biomass (\$/ton)

C_{it}^{p} production cost for unit of biofuel production (\$/gallon)

θ_{cit}^{tr} fixed transportation cost loaded/unloaded in a truck (\$/Ton)

C_{cit}^{tr} variable transportation cost (\$/ton.km)

θ_{int}^{tr} fixed transportation cost of biofuel loaded/unloaded in a truck (\$/gallon)

C_{int}^{tr} variable transportation cost of biofuel for a unit distance (\$/gallon.km)

cp_{it} maximum production ability (gallons/year)

D_{nt} demand for biofuel in planning period *t* from market center *n* (gallons)

ds_{cit} distance between agricultural region *c* to biorefinery plant *i* (km)

ds_{int} distance between biorefinery plant *i* to market *n* (km)

e_{ct} emission for unit amount biomass in an agricultural region (g of CO_2/ton)

e_{cit} emission for transporting unit of per unit distance (g of CO_2/ton.km)

e_{it} emission for production unit amount of biofuel (g of CO_2/gallons)

e_{int} emission for transporting unit of biofuel (g of CO_2/ton.km)

E_{ct}^{cap} fixed carbon cap on emission for agricultural zone (tons of CO_2)

E_{cit}^{cap} fixed carbon cap on emission at transport route (tons of CO_2)

E_{it}^{cap} fixed carbon cap on emission for biorefinery (tons of CO_2)

E_{int}^{cap} fixed carbon cap at transport from biorefineries to market (tons of CO_2)

j_{ct} number of jobs in agricultural zone *c* (jobs/year)

j_{cit} number of transporting residual biomass for unit distance (jobs/year)

j_{it} number of jobs in biorefinery *i* (jobs/year)

j_{int} number of jobs in transporting unit amount of biofuel (jobs/year)

γ_{it} conversion rate at biorefinery plant *i* (gallons/ton)

V_{cit} truck maximum capacity from agricultural region *c* to biorefinery *i* (ton)

V_{int} truck maximum capacity from biorefinery *i* to market *n* (gallons)

y_{ct} yield of residual biomass at agricultural region *c* (tons)

4 Mathematical model for a multi-period multi-objective SSCM

The long-term multi-period multi-objective function for SSCM, is explained as follows:

4.1 Multiple objectives

The economic objective is the first objective of this multi-period model. Additionally, to represent the actual scenario, the annual inflation rate i is applied with the cost parameters of operational activities at agricultural zones, biorefineries, and transportation sectors for this study. The next objective for this multi-period multi-objective SSCM study for SGB is environmental and social. For this multi-period study, all parameters of these objectives are functioned according to planning period t as shown in Equations 1-3.

$$Min\ TC = \sum_{r=1}^{R}\sum_{f=1}^{F}\sum_{t=1}^{T}\left[\begin{pmatrix} \left(C_{rt}^{ha}\times(1+i)^t\right)+\frac{1}{4}\left(\Delta_{2rt}^{ha}-\Delta_{1rt}^{ha}\right)+\left(C_{rt}^{co}\times(1+i)^t\right)+\frac{1}{4}\left(\Delta_{2rt}^{co}-\Delta_{1rt}^{co}\right) \\ +\left(C_{rt}^{st}\times(1+i)^t\right)+\frac{1}{4}\left(\Delta_{2rt}^{st}-\Delta_{1rt}^{st}\right)+\left(C_{rt}^{ld}\times(1+i)^t\right)+\frac{1}{4}\left(\Delta_{2rt}^{ld}-\Delta_{1rt}^{ld}\right)\end{pmatrix}+\left(e_{tr}\times\left(C^{tx}\times(1+i)^t\right)\times\alpha_{rt}\right)\right]Q_{rft}$$
$$+\sum_{f=1}^{F}\sum_{s=1}^{S}\sum_{t=1}^{T}\left[C_{ft}^{P}\times(1+i)^t+\left(e_{ft}\times\left(C^{tx}\times(1+i)^t\right)\times\beta_{ft}\right)\right]Q_{fst}+\sum_{r=1}^{R}\sum_{f=1}^{F}\sum_{t=1}^{T}\left[\left(\left(C_{rft}^{tr}\times(1+i)^t ds_{rft}\right)+\theta_{rft}^{tr}\right)\times V_{rft}\right]T_{rft}$$
$$+\sum_{r=1}^{R}\sum_{f=1}^{F}\sum_{t=1}^{T}\left[\left(e_{rft}\times\left(C^{tx}\times(1+i)^t\right)\times\psi_{rft}\right)\times V_{rft}\times ds_{rft}\right]T_{rft}+\sum_{f=1}^{F}\sum_{s=1}^{S}\sum_{t=1}^{T}\left[\left(\left(C_{fst}^{tr}\times(1+i)^t ds_{fst}\right)+\theta_{fst}^{tr}\right)\times V_{fst}\right]T_{fst}$$
$$+\sum_{f=1}^{F}\sum_{s=1}^{S}\sum_{t=1}^{T}\left[\left(e_{fst}\times\left(C^{tx}\times(1+i)^t\right)\times\phi_{fst}\right)\times V_{fst}\times ds_{fst}\right]T_{fst} \quad (1)$$

$$Min\ TE = \sum_{r=1}^{R}\sum_{f=1}^{F}\sum_{t=1}^{T}e_{rt}\times Q_{rft}+\sum_{r=1}^{R}\sum_{f=1}^{F}\sum_{t=1}^{T}e_{rft}\times Q_{rft}+\sum_{f=1}^{F}\sum_{s=1}^{S}\sum_{t=1}^{T}e_{ft}\times Q_{fst}+\sum_{f=1}^{F}\sum_{s=1}^{S}\sum_{t=1}^{T}e_{fst}\times Q_{fst} \quad (2)$$
$$Max\ TJ = \sum_{r=1}^{R}\sum_{f=1}^{F}\sum_{t=1}^{T}j_{rt}\times Q_{rft}+\sum_{r=1}^{R}\sum_{f=1}^{F}\sum_{t=1}^{T}j_{rft}\times Q_{rft}+\sum_{f=1}^{F}\sum_{s=1}^{S}\sum_{t=1}^{T}j_{ft}\times Q_{fst}+\sum_{f=1}^{F}\sum_{s=1}^{S}\sum_{t=1}^{T}j_{fst}\times Q_{fst} \quad (3)$$

4.2 Constraints of the model

The constraints of this multi-period model consist of resource availability, production capacity, mass balance, transportation capacity, carbon cap constraint, and demand constraint for the planning horizon. For this multi-period study, all constraints are functioned according to planning period t as shown in Equations (4-14)

$$\sum_{i=1}^{I}Q_{cit} \le A_{ct}\left(y_{ct}+\frac{1}{4}(\Delta_{2ct}-\Delta_{1ct})\right) \qquad \forall c,\ \forall t \quad (4)$$

$$\sum_{c=1}^{C}Q_{cit}\times\gamma_{it} = \sum_{n=1}^{N}Q_{int} \qquad \forall i, \forall t \quad (5)$$

$$\sum_{n=1}^{N}Q_{int} \le cp_{it} \qquad \forall i,\ \forall t \quad (6)$$

$$T_{cit} = \frac{Q_{cit}}{V_{cit}} \qquad \forall c, \forall i, \forall t \quad (7)$$

$$T_{int} = \frac{Q_{int}}{V_{int}} \qquad \forall i\ \forall n\ \forall t \quad (8)$$

$$\sum_{i=1}^{I}Q_{int} = D_{nt}+\frac{1}{4}(\Delta_{2nt}-\Delta_{1nt}) \qquad \forall n, \forall t \quad (9)$$

$$e_{ct} \times \sum_{i=1}^{I} Q_{cit} \leq E_{cit}^{cap} \qquad \forall c\ ,\ \forall t \tag{10}$$

$$\sum_{i=1}^{I} e_{cit} \times ds_{cit} \times Q_{cit} \leq \sum_{i=1}^{I} E_{cit}^{cap} \qquad \forall c\ ,\ \forall t \tag{11}$$

$$e_{it} \times \sum_{n=1}^{N} Q_{int} \leq E_{it}^{cap} \qquad \forall i\ ,\ \forall t \tag{12}$$

$$\sum_{n=1}^{N} e_{int} \times ds_{int} \times Q_{int} \leq \sum_{n=1}^{N} E_{int}^{cap} \qquad \forall i\ ,\ \forall t \tag{13}$$

$$Q_{cit}, Q_{int}, T_{cit}, T_{int}, \geq 0 \qquad \forall c, i, n, t \tag{14}$$

4.3 Solution methodology

The solution methodology used in this long-term multi-period multi-objective sustainable supply chain is the augmented ε-constraint method, additionally with some improvement in computing the step size for iterations. Furthermore, after finding the ranges of $\varepsilon 1$ and $\varepsilon 2$ by using the pay-off table generated from lexicographic optimization, the step size of iterations is calculated by a different method as mentioned in Mavrotas and Florios [13]

5 Comparative analysis based on different solution methodologies

The comparative and gap analysis based on different solution methodologies has been done for a long- term horizon to analyze the optimal values for all objectives. The result shows that augmented ε-constraint is the best method, as the difference of gap from this approach is less from target values following with goal programming and weight- sum approach. The gap between the target value and the results from augmented ε-constraint for optimal total cost is 0.005%, for optimal total emissions is 0.002%, and for the optimal total number of jobs is 0.013%. Table 1 shows the gap percentage resulted from different methodologies and target values.

Table 1. Comparative analysis of results from different methodologies.

Methodology	Augmented ε-constraint	Goal programming	Weight-sum approach
Gap % for cost (+)	0.05	1.518	2.164
Gap % for emissions (+)	0.02	4.344	5.884
Gap % for jobs (-)	0.03	11.489	22.275

6 Discussion

The key results and observations for multi-period multi-objective SSCM for SGB study show that the long- term planning period for second-generation biofuel can be well elaborated by dividing the planning horizon into an equal number of sub-periods. It determines the optimal long-period (i.e., through total horizon) and short-period (i.e., individual sub-period) decisions necessary for efficient SSCM for SGB to meet the market demand.

The findings show that for the long-term planning period, the total cost increases as the carbon emissions decrease for a specific job target. An intuitive relationship between them exists. Furthermore, as by increasing the number of new job opportunities by making it a pioneer priority, the total cost increases as well. The increment in a number of jobs thus increases the transport cost of biofuel per unit. Hence, on the other side, the optimal emissions and jobs can be minimized and maximized, respectively by a marginal increase in the total cost of the SCM. The multi-period study will also benefit from reviewing the allotted quota of a carbon cap in different sectors. As it is observed that in the seventh year of the planning period instead of increasing the number of carbon emissions which was 5.18% averagely increment annually, it is decreased by 1.4%. This is due to the reason that allocated carbon cap quota is reviewed and increased, to satisfy the market demand. The total optimal emissions for the individual period, except for the seventh year, increased linearly.

The implementation of carbon cap restricted carbon emissions for a certain amount, as it helps to control emissions for a specific route and sector. But if the same value of carbon cap exists for the next period, it restricts emissions for that route but will increase the total emissions of the SCM. It is a result of the fact that as demand increase more carbon is emitted as transportation and operational activities increase to satisfy that demand under the same carbon cap. Similarly, the optimal total cost and optimal total jobs are also increased linearly for the whole planning horizon.

The comparative analysis between the target value of objectives with different methodologies shows that augmented ε-constraint is the best suitable approach. The resulted gap percentage of this approach from the target value is very small as compared to goal programming and weight-sum approach.

7 Conclusions

In this research, the long-term multi-period multi-objective SSCM for SGB is presented. This study considered that the long-term horizon is permitted to divide into an identical sub-terms. The multi-period multi-objective model determines the decisions required for optimal long-term planning horizon and short-term individual planning period in second-generation biofuel supply chain management under all dimensions of sustainability. The objective was to maximize the number of job opportunities and minimizes the carbon emissions and cost for this long-term planning horizon.

The annual inflation rate on cost parameters of operational activities and the transportation sector is incorporated to make a real scenario. The decisions throughout the whole planning period will lower the uncertainty connected with sub-period planning. The study shows that the implementation of a carbon cap scheme regulates carbon emissions for specific sectors and routes. But in contrast, if the allocated quota of carbon cap is not reviewed after a specific period, then it may disrupt satisfying the market demand. The optimal cost, emissions, and the number of new job opportunities increased linearly along the planning horizon. The integrated cost of biofuel per gallon also increases by the end of the planning period as compared with the initial period.

The literature is familiarized with a new terminology named “triple sustainable management”. A multi-period multi-objective SSCM for SGB under uncertain parameters and carbon tax policy scheme will, therefore, turn out to be an efficacious supporting tool which can be used for decision-making within TSM. This research shows the application of the improved augmented ε-constraint approach in the context of second-generation biofuel supply chain management, it will be valuable to consider this approach in any supply chain management for future direction i.e., food supply chain management or steel supply chain management, where multi-objective optimization problems are considered.

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