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ORIGINAL RESEARCH

Biofuel supply chain considering depreciation cost of installed plants

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Abstract Due to the depletion of the fossil fuels and major concerns about the security of energy in the future to produce fuels, the importance of utilizing the renewable energies is distinguished. Nowadays there has been a growing interest for biofuels. Thus, this paper reveals a general optimization model which enables the selection of preprocessing centers for the biomass, biofuel plants, and warehouses to store the biofuels. The objective of this model is to maximize the total benefits. Costs of the model consist of setup cost of preprocessing centers, plants and warehouses, transportation costs, production costs, emission cost and the depreciation cost. At first, the deprecation cost of the centers is calculated by means of three methods. The model chooses the best depreciation method in each period by switching between them. A numerical example is presented and solved by CPLEX solver in GAMS software and finally, sensitivity analyses are accomplished.

Keywords Biomass · Biofuel supply chain · Multi-echelon · Depreciation costs

Introduction

By considering depletion of fossil fuel in the future, the importance of using renewable energy increases production (Petroleum 2015). One of the disadvantages of fossil fuels is air pollution. Greenhouse gases spread out in environment via burning of these fuels and cause global warming. On the other hand, renewable energy has less global warming effects and increases the energy security. Renewable energy divides into solar, wind power, biomass, geothermal, and tidal energy. The types of biomass feedstock which are utilized for energy purposes are categorized as: agricultural, dedicated energy crops, forestry, industry, gardens residues (Tumuluru et al. 2011). In this study, the supply chain of the biomass is proposed as:

1. Procuring of the feedstock (i.e., purchasing biomass, importing, and cultivating them).
2. Transporting to preprocessing centers.
3. Preprocessing biomass.
4. Transporting the preprocessed biomass to plants.
5. Producing biofuel in the plant.
6. Transporting the biofuels to the warehouses.
7. Distributing the biofuels.

Literature review

Ayoub et al. (2007) proposed a general bioenergy decision system. They believe that planners have to consider social concerns, environmental and economic impacts related to establishing the biomass systems. Leduc et al. (2008) developed a model to determine the locations and sizes of methanol plants and gas stations in Austria. The objective function of the model consisted of plant and gas station setup cost, methanol production cost, and material transportation cost. Mele et al. (2009) proposed a model that simultaneously minimizes the total cost of the network and its environmental performance over the entire life cycle of the product. Zamboni et al. (2009) proposed the bioethanol supply chain optimization in which they presented a model

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for the strategic design of biomass-based fuel supply networks. Finally, they applied the model for a case study in Italy. Jackson et al. (2009) found that firms using accelerated depreciation make significantly larger capital investments than firms that use straight line depreciation and found that there has been a migration away from accelerated depreciation to straight line depreciation over the past two decades. Finally, results suggest that a choice made for external financial reporting purposes influences managers' capital investment decisions. Ayoub et al. (2009) proposed an optimization model for designing and evaluating integrated system of bioenergy production supply chains. Their model was applied in a case study in Japan. Rentizelas and Tatsiopoulos (2010) utilized a hybrid optimization method to find the optimum location of a bioenergy generation facility considering the maximization of the net present value (NPV) of the investment for the project's lifetime. Velazquez-Marti and Fernandez-Gonzalez (2010) supposed two criteria for the location of established plants for producing the biofuel as: minimizing the transportation costs of biofuels and using all the energy produced by the plant. They applied the model to Spanish rural regions. Akgul et al. (2011) presented the model to optimize the locations and scales of the bioethanol production plants, biomass and bioethanol flows between regions. The purpose of this study is minimizing the total supply chain costs. Kim et al. (2011) formulated a model that enables the selection of fuel conversion technologies and capacities, biomass locations and the logistics of transportation from forestry resources to conversion, and from conversion to final markets. The objective function to be maximized was the overall profit. The revenue of the model includes selling various products in the final market and the credits for the utility energy produced at each plant location. The cost encompassed operating cost, annualized capital cost, transportation cost and biomass acquisition cost for each biomass type. Mobini et al. (2011) developed a simulation model to evaluate the cost of delivered forest biomass, the equilibrium moisture content, and carbon emissions from the logistics operations. Zhu and Yao (2011) proposed a multi-commodity network flow model to design the logistics system. They formulated a model to determine the locations of warehouses, the size of harvesting group, the types and amounts of biomass harvested or purchased, stored, and processed, and the transportation of biomass in the system. The objective function of Leão et al. (2011) consisted of investments for the production plants, transportation costs, agricultural production costs, processing costs and purchasing cost of any additional volumes of oil in the market to meet the demand of the plants. Chen and Fan (2012) developed a two-stage stochastic programming model to minimize the system cost. The system includes bioethanol production, feedstock procurement, fuel delivery, ethanol transportation and possible penalty on fuel shortage. The model was used to evaluate the economic possibility and system robustness in a case study of California. Finally, the model was solved by a Lagrange relaxation-based decomposition solution algorithm. Ayoub and Yuji (2012) utilized a demand-driven approach for optimizing biomass utilization networks cost by applying genetic algorithm to solve the network problem. Judd et al. (2012) proposed a mathematical programming to determine satellite storage locations and equipment routes to minimize the total cost of designing a feedstock logistics system. The feedstock logistics system includes transporting biomass from production fields to the bioenergy plant. Kostin et al. (2012) integrated bioethanol and sugar production supply chain under demand uncertainty. They considered several financial risk mitigation options in the supply chain model. They applied the model in the Argentinean sugarcane industry. Finally the problem was solved by applying the sample average approximation algorithm. Akgul et al. (2012) presented an optimization framework for the strategic design of a hybrid first/second-generation ethanol supply chain. The applicability of the model is demonstrated with a case study of ethanol production in the UK. The potential cost reductions of second-generation biofuel systems are likely to lead to the deployment of these technologies at a larger scale. Bio-based supply chain that was proposed by Pérez-Fortes et al. (2012) led to produce electricity or other bio-products. Their model took into account three main objectives: economic, environmental and social criteria. Biomass storage periods, location and capacity of plants, material transportation between echelons and biomass utilization to produce biofuel are determined in their model. They applied the model for a case study in Ghana. To produce a low-cost urban energy system, Keirstead et al. (2012) accomplished the trade-offs between the alternatives by considering the air pollution impacts. According to their exploration of the trade-offs, biomass energy system is the best choice. Supply chain that worked by Čuček et al. (2012) is included agricultural, preprocessing, processing, and distribution layers. Also they presented a multi-criteria optimization for the conversion of biomass to energy. Fazlollahi and Maréchal (2013) simultaneously minimized costs and CO_2 emission of integrated biomass resources using multi-objective evolutionary algorithms. Zhang et al. (2013) focused on switch grass as one of the best second-generation feedstock for bioethanol production. They proposed an integrated mathematical model to minimize the total switch grass-based bioethanol supply chain cost. The proposed model considered the impact of switch grass crop yield, switch grass densification, switch grass dry-matter loss during storage, and economies of scale in bio refinery capacities on the total SBSC cost.

Meier et al. (2005) evaluated the economic concept of the industrial solar production of lime. The three capital investment decision indicators used in economic analysis are: (1) the payback time (PBT), defined as time required for an investment project to recover its initial cost; (2) NPV, defined as the present value of the flow of net incomes subtracted by the present value of the flow of investments; and (3) the internal rate of return (IRR), defined as the discount rate at which NPV equals zero.

Mahmoudi et al. (2014) investigated the problem of source selection of competitive power plants under government intervention. Kumar et al. (2015) investigated the impact of various factors affecting coal-fired power plant economics for electricity generation.

There are plentiful papers in biofuel supply chain and a lot of mathematics models are presented in this field but there are not any papers which regard the depreciation cost as an important element of the model. The significant part of our model is considering the depreciation cost within supply chain model. In this case, depreciation cost is defined as a crucial element of any supply chain design. Our study is the extension of Akgul et al. (2012) and the contributions of our study are as follows:

- Considering penalty on fuel shortage.
- Considering environmental impact of biofuel plants such as CO_2 emission.
- Considering two manners for plants; purchasing or renting.
- Calculating NPV of the project.
- Considering total depreciable capital and salvage value of the network.
- Revenue of selling the fuels in the market.

The remainder of this paper is organized as follows. The description, assumptions and the mathematical model are introduced in "Problem description and assumption". "Computational results" embraces a numerical example, and also the results of the solved model are presented here. In "Sensitivity analysis", sensitivity analysis is applied to verify the accuracy of the model. Finally, "Conclusion" represents the conclusions of the paper.

Problem description and assumption

There are many influencing factors in biofuel supply chain which impact on each other. The whole system may change unpredictably by changing any of these factors. Given that the mathematical model can calculate these very detailed interactions, in this study, a mathematical model is applied for designing biofuel supply chain. Biofuel supply chain consists of the following echelons:

1. Biomass centers.
2. Biomass preprocessing center.
3. Plants for biofuel production.
4. Biofuel warehouses.
5. Demand points.

Three types of biomass exists generally; woody source, non-woody source, and animal fat and waste. In this paper, we consider woody source of biomass as an input to biofuel supply chain. At the first echelon, we have three ways to procure biomass from the biomass centers: cultivating the biomass, purchasing them from domestic supplier and importing them from abroad. When the biomass is procured, we need a place for storing and drying them; therefore, echelon 2 is assigned to these warehouses. Echelon 3 represents plants of biofuel production. Fourth echelon states warehouses for biofuel storage, and the last echelon is the demand center (customer), as shown in Fig. 1.

We considered three capable regions for warehouses of biomass and K capable regions for plants. The model chooses j, k and l regions to establish warehouses for biomass, plants and warehouses of biofuels. We can purchase or rent the warehouses needed for biomass, plants and biofuel warehouses. The plants can be established in three sizes (small, medium and large). The interest rate is monthly. In the process of plants, α percent of biomass has become biofuel, β percent of the biomass are dried. In addition, we have inventory costs in each warehouse.

Mathematical programming

There are so many papers which considered mathematical programming for modeling the problems in various areas (Mousavi et al. 2014; AriaNezhad et al. 2013; Alimardani et al. 2013; Seifbarghy et al. 2015). In this section, we develop mixed integer linear programming (MILP) model. For modeling the problem we need to present the indices, parameters, and variables which are introduced in Tables 1, 2 and 3 respectively.

To simplify the problem, two models are introduced as follows. First model selects the best depreciation method from sum-of-the-years-digits method (SOYD), straight line and double declining balance (DDB) to determine the best switch points to maximize the cash flow. The second model calculates all costs of biofuel supply chain by considering

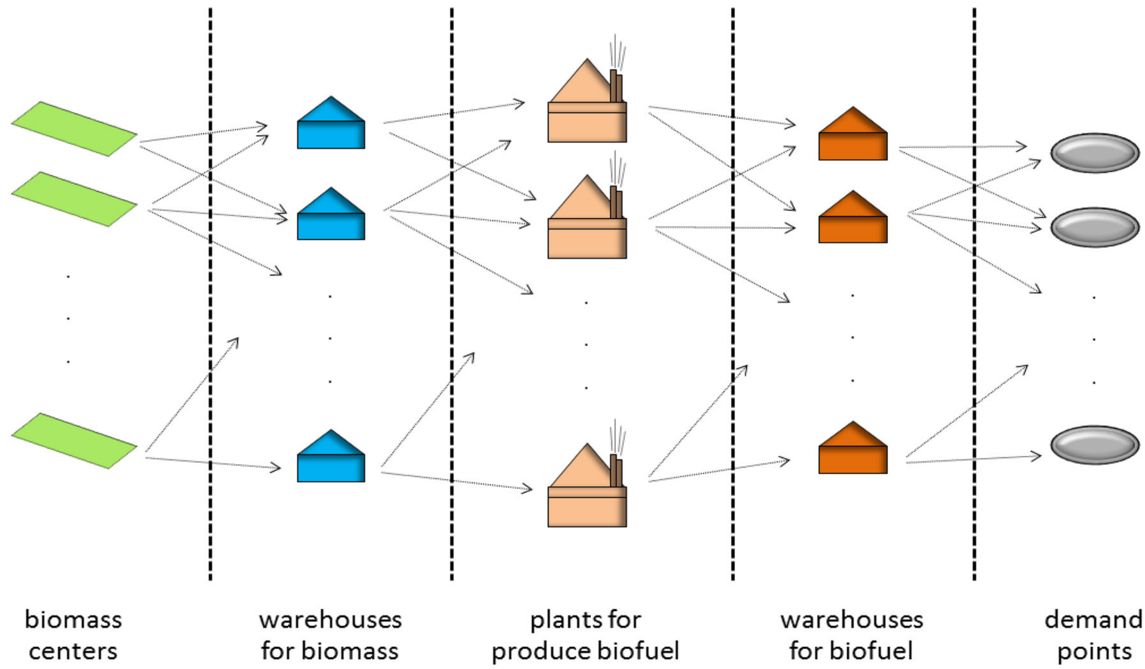

Fig. 1 Biofuel supply chain

Table 1 The indices of the model

Indices	Description	Set
$i \in I$	Biomass center	$I = 1,2, \ldots, I$
$j \in J$	Preprocessing center of biomass	$J = 1,2, \ldots, J$
$k \in K$	Biofuel production plants	$K = 1,2, \ldots, K$
$p \in P$	Plant size	$P = 1,2,3$
$l \in L$	Warehouse for biofuel	$L = 1,2, \ldots, L$
$t \in T$	Time period	$T = 1,2, \ldots, T$
$w \in W$	Demand point	$W = 1,2, \ldots, W$

the depreciation cost of installed plants which is obtained from the first model.

First model

According to the fact that each organization desires to select the best depreciation method to reduce their costs, this model facilitates selecting the depreciation cost by which they could be able to choose the best one with regards to the net present value of depreciation in every year.

$$\min z1 = \sum_{t=1}^{T} \sum_{p=1}^{P} \frac{D_{pt} T}{(1 + ir)^t} \quad (1)$$

$$D_{pt} \geq \frac{\mathrm{BV}_{t-1} - \mathrm{SV}_p}{n - t + 1} \quad \forall p, t \quad (2)$$

$$D_{pt} \geq \mathrm{BV}_0 \left(\frac{\alpha}{N}\right) \left(1 - \frac{\alpha}{N}\right)^{t-1} \quad \forall p, t \quad (3)$$

$$D_{pt} \geq \frac{2(\mathrm{BV}_0 - \mathrm{SV}_p)(N - t + 1)}{N(N + 1)} \quad \forall p, t \quad (4)$$

$$\mathrm{BV}_{t+1} = \mathrm{BV}_t - D_{pt} \quad \forall p, t \quad (5)$$

The objective function (1) calculates the total net present value of depreciations of the all plants for all periods of time. Constraints (2–5) represent the depreciation methods which could be utilized to calculating the depreciation. Almost always the owner of any factory would like to state that the depreciation of the equipment in the factory is a lot, to pay as little tax as they can. So the straight line, SOYD and DDB methods are introduced as the depreciation methods.

Second model

In the second model, at first, biomass is provided through three different ways, purchasing, importing and harvesting the provided inputs maintained in preprocessing centers. The plants producing biofuels could be established in three sizes: small, medium and large. Biofuels are sold to the customers from biofuel warehouses where biofuels are kept. The second model is presented as follows:

$$
\begin{aligned}
\max z2 = & \sum_{l=1}^{L}\sum_{w=1}^{W}\sum_{t=1}^{T}(1-T)/(1+ir)^t \cdot s'_{lwt} \cdot P'_t - \Bigg[\sum_{k=1}^{K}\sum_{p=1}^{P}(\mathrm{BC}_{kp} \cdot z^1_{kp} + \mathrm{RC}_{kp} \cdot z^{1'}_{kp}) + \sum_{j=1}^{J}(\mathrm{BC}_j \cdot z^2_j + \mathrm{RC}_j \cdot z^{2'}_j) \\
& + \sum_{l=1}^{L}(\mathrm{BCC}_l \cdot z^3_l + \mathrm{RCC}_l \cdot z^{3'}_l) + \sum_{t=1}^{T}\sum_{j=1}^{J}(1-T)/(1+ir)^t \cdot (\mathrm{CC}_t \cdot x_{1jt} + \mathrm{BCB}_t \cdot x_{2jt} + \mathrm{ICB}_t \cdot x_{3jt}) \\
& + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=1}^{T}(1-T)/(1+ir)^t \cdot C_{ijt} \cdot d_{ijt} \cdot x_{ijt} + \sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{t=1}^{T}(1-T)/(1+ir)^t \cdot C_{jkpt} \cdot d_{jkpt} \cdot y_{jkpt} \\
& + \sum_{k=‘}^{K}\sum_{p=1}^{P}\sum_{l=1}^{L}\sum_{t=1}^{T}(1-T)/(1+ir)^t \cdot C_{kplt} \cdot d_{kplt} \cdot s_{kplt} + \sum_{w=1}^{W}\sum_{l=1}^{L}\sum_{t=1}^{T}(1-T)/(1+ir)^t \cdot C_{lwt} \cdot d_{lwt} \cdot s'_{lwt} \\
& + \sum_{j=1}^{J}\sum_{t=1}^{T}(1-T)/(1+ir)^t \cdot \mathrm{SC}_{jt} \cdot I_{jt} + \sum_{l=1}^{L}\sum_{t=1}^{T}(1-T)/(1+ir)^t \\
& \cdot \mathrm{SC}'_{lt} \cdot \mathrm{II}_{lt} + \sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{t=1}^{T}(1-T)/(1+ir)^t \cdot \alpha \cdot \mathrm{PC}_t \cdot y_{jkpt} \\
& + \sum_{w=1}^{W}\sum_{t=1}^{T}\sum_{l=1}^{L}(1-T)/(1+ir)^t \cdot \rho \cdot B_{lwt} + \sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{t=1}^{T}\gamma \cdot \mathrm{EM}_{kpt} \cdot \alpha \cdot y_{jkpt}\Bigg]
\end{aligned} \tag{6}
$$

Subject to:

$$z^{1'}_{kp} + z^1_{kp} \le 1 \quad \forall k, p \tag{7}$$

$$z^{2'}_j + z^2_j \le 1 \quad \forall j \tag{8}$$

$$z^{3'}_l + z^3_l \le 1 \quad \forall l \tag{9}$$

$$\sum_{p=1}^{P}\sum_{k=1}^{M}(z^{1'}_{kp} + z^1_{kp}) = k \tag{10}$$

$$\sum_{p=1}^{P}(z^{1'}_{kp} + z^1_{kp}) = 1 \quad \forall k \tag{11}$$

$$\sum_{j=1}^{J}\mathrm{EM}_{kpt} \cdot \alpha \cdot y_{jkpt} \le \mathrm{EMMAX} \quad \forall k, p, t \tag{12}$$

$$\sum_{j=1}^{J}x_{ijt} \le \mathrm{capr}_{it} \quad \forall i, t \tag{13}$$

$$\beta\sum_{t=1}^{T}\sum_{i=1}^{I}x_{ijt} \ge \sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{t=1}^{T}y_{jkpt} \quad \forall j \tag{14}$$

$$I_{jt} \le \mathrm{capb}_{jt} \quad \forall j, t \tag{15}$$

$$\sum_{j=1}^{J}\sum_{t=1}^{T}y_{jkpt} \cdot \alpha \ge \sum_{l=1}^{L}\sum_{t=1}^{T}s_{kplt} \quad \forall k, p \tag{16}$$

$$\sum_{j=1}^{J}y_{jkpt} \le (z_{kp} + z'_{kp}) \cdot M \quad \forall k, p, t \tag{17}$$

$$\mathrm{II}_{lt} \le \mathrm{capw}_{lt} \quad \forall l, t \tag{18}$$

$$I_{j(t-1)} + \sum_{i=1}^{I}x_{ijt} - \sum_{k=1}^{K}\sum_{p=1}^{P}y_{jkpt} - I_{jt} \ge 0 \quad \forall j, t \tag{19}$$

$$
\begin{aligned}
& \mathrm{II}_{l(t-1)} - \mathrm{II}_{lt} + \sum_{w=1}^{W}(B_{lw(t-1)} - B_{lwt} - s'_{lwt}) \\
& + \sum_{k=1}^{K}\sum_{p=1}^{P}s_{kpt} \ge 0 \\
& \forall l, t
\end{aligned} \tag{20}
$$

$$\sum_{l=1}^{L}(s'_{lwt} + B_{lwt} - B_{lw(t-1)}) \ge dd_{wt} \quad \forall w, t \tag{21}$$

$$\sum_{i=1}^{I}x_{ijt} \le \left(z^2_j + z^{2'}_j\right) \cdot M \quad \forall j, t \tag{22}$$

$$\sum_{k=1}^{K}\sum_{p=1}^{P}s_{kplt} \le \left(z^3_l + z^{3'}_l\right) \cdot M \quad \forall l, t \tag{23}$$

$$\sum_{l=1}^{L}s_{kplt} \le \mathrm{capp}_{kpt} \quad \forall k, p, t \tag{24}$$

$$z^{1'}_{kp},\ z^1_{kp},\ z^{2'}_j,\ z^2_j,\ z^{3'}_l,\ z^3_l \in \{0, 1\} \tag{25}$$

Objective function of second model (6) consists of two terms. First one states the present value of revenues and second is the costs. The model also demonstrates the revenue of the supply chain gained by selling the biofuels. The total costs are calculated by the cost of purchasing or renting preprocessing centers, plants and warehouses in *t = 0*, the total cost of biomass (consists of buying, importing from

Table 2 The parameters of the model

Notations	Description	Notations	Description
P'_t	Sale price of biofuel in period t	C_{klt}	Transportation cost for each unit of biofuel between plant k and warehouse l in period t
BC_{kp}	Buy cost for plant k with size p	C_{lwt}	Transportation cost for each unit of biofuel between warehouse l and demand point w in period t
RC_{kp}	Rent cost for plant k with size p	$capr_{it}$	Capacity of resource of biomass i in period t
BC_j	Buy cost for warehouse j	$capb_{jt}$	Capacity of the biomass of preprocessing center j in period t
RC_j	Rental cost for warehouse j	$capw_{lt}$	Capacity of the warehouse j in period t
BC'_l	Buy cost for warehouse l	$capp_{kpt}$	Capacity of plant k with size p in period t
RC'_l	Rental cost for warehouse l	SC'_{lt}	Storage cost of warehouse l for each unit of biofuel in period t
BCB_t	Buy cost for each unit of biomass in period t	PC	Process cost of each unit of biomass
ICB_t	Import cost for each unit of biomass in period t	d'_{wt}	Demand of demand center w in period t
CC_t	Cultivation cost for each unit of biomass in period t	EM_{kpt}	Amount of CO_2 that emission by plant k with size p for each unit of produced biofuel in period t
d_{ijt}	Distance between biomass center i and warehouse j in period t	α	Fraction of biomass conversion to biofuel
d_{jkt}	Distance between warehouse j and plant k in period t	β	Percentage of biomass dry in warehouse
d_{klt}	Distance between plant k and warehouse l in period t	ρ	Penalty cost of shortage in meeting the demands
d_{lw}	Distance between warehouse l and demand point w in period t	EMMAX	Maximum permissible amount of generating the gases in the plant
C_{ijt}	Transportation cost for each unit of biomass between biomass center i and warehouse j in period t	BV_t	The book value of plant in period t
C_{jkt}	Transportation cost for each unit of biomass between warehouse j and plant k in period t	SV_p	The salvage value of plant p

Table 3 The variable of the model

Variables	Descriptions
x_{ijt}	Flow of input biomass i to warehouse j in period t
y_{jkpt}	Flow of biomass from warehouse j to plant k with size p in period t
s_{kplt}	Flow of biofuel from plant k with size p to warehouse l in period t
s'_{lwt}	Flow of biofuel from warehouse l to demand point w in period t
z^1_{kp}	=1 if we purchase the plant k with size p and 0 if we do not purchase the plant k with size p
$z^{1'}_{kp}$	=1 if we rent the plant k with size p and 0 if we do not rent the plant k with size p
z^2_j	=1 if we buy the warehouse j and 0 if we do not buy the warehouse j
$z^{2'}_j$	=1 if we rent the warehouse j and 0 if we do not rent warehouse j
z^3_l	=1 if we buy the warehouse l and 0 if we do not buy the warehouse l
$z^{3'}_l$	=1 if we rent the warehouse l and 0 if we do not rent warehouse l
D_{pt}	Depreciation of plant with size p in period t
I_{jt}	Inventory level of warehouse j at the end of period t
II_{lt}	Inventory level of warehouse l in the period t
B_{lwt}	Backorder of warehouse l in the period t

abroad or harvested one), the total cost of transportation in the whole supply chain, the inventory cost in all periods, the production cost of biofuel, the penalty cost of shortage in meeting the demands and the emission cost of the plants in all periods. As said before, the depreciation costs of installed plants are obtained from the first model.

Table 4 Inputs' capacity in period t

Capacity of inputs (ton)	Period											
	1	2	3	4	5	6	7	8	9	10	11	12
Purchasing	200	120	220	340	200	120	220	340	200	120	220	340
Importing	200	120	220	340	200	120	220	340	200	120	220	340
Harvesting	310	200	200	700	200	120	220	340	200	120	220	340

Constraints (7–9), respectively, represent that the preprocessing center of biomass, plants and the warehouse of biofuels can be purchased or rented. Constraint 10 indicates that k lactation of K candidates is selected to establish the plants. Constraint 11 shows that only one size of plants can be establish in each selected location. Constraint 12 shows the CO_2 emission in every plant should be less than maximum limitation of CO_2 generation. Constraint 13 represents the maximum capacity of the input biomass. Constraint 14 shows that the β percent of biomass dry in warehouse of biomass then is sent to plants. Constraint 14 and 15 state that the inventory level of preprocessing centers of biomass and warehouses of biofuels, respectively, should been less than maximum capacity. Constraint 16 states α percent of the preprocessed biomass transferred to the next stage. Constraints 17, 22 and 23 are logic constraints stating that no biofuel can be produced unless there is a plant operating at this location, no biomass can be utilized unless there is a preprocessing center operating at that location and no biofuel can be sold unless there is a warehouse operating at that location. Constraints 19 and 20 are the inventory constraint in each warehouse. Constraint 21 shows that the demands in place w should be met by supply.

Computational results

In this section, a hypothetical numerical example is presented to state the applicability of the model. The indices and parameters of the example are as follows: the numbers of biomass center, preprocessing centers of biomass, plants, warehouse for products and demand point are three; the preprocessing centers, plants and warehouses have constant capacity which is declared in Table 4.

The outputs of the model indicate the amount of all variables which are used there. The results indicate that all three plants should be made in small sizes. The decision variables about purchasing or renting the warehouses and plants are shown in Table 5. The biomass preprocessing centers which needed to be established are purchased as well as product warehouses. But, for plants two of them are rented and other one is purchased.

Table 5 Either purchasing or renting the warehouses and plants

		Purchase	Rent
Preprocessing centers of biomass	1	1	
	2	1	
	3	1	
Plant	1	1	
	2		1
	3		1
Warehouse for products	1	1	
	2	1	
	3	1	

To solve the second model, it is needed to specify the parameters, such as investment cost and salvage value, which are stated in Table 6. To increase the reality of the example, data are gathered through experts' opinions.

The flows of the biomass and biofuels in the supply chain network are represented in Tables 7, 8, 9 and 10.

The amount of each types of the biomass to each preprocessing centers in each of the months of the year is presented in Table 7.

Amount of biomass sent from warehouses to plants which are calculated through model is stated in Table 8 and depicted in Fig. 2 for clarifying these flows.

Amount of biofuel sent from plants to warehouses which are calculated through model is presented in Table 9.

Amount of biofuel sent from warehouses to demand points which are calculated through model is stated in Table 10.

According to the results, in all periods, there are flows between the echelons in the supply chain network from the biomass centers to demand points. So, twelve diagrams can be depicted related to each period (e.g., the flow of the network in period $t = 1$ is depicted in Fig. 2). Figure 2 is depicted to clarify the amount of flows of Figs. 7, 8, 9 and 10.

Regularly the assets and equipment depreciation are calculated by only one or a combination of DDB, straight line and SOYD. Given the fact that the owner of the facilities tend to pay as little tax as they can in the early years, the combination of these methods is utilized to state depreciation value. It is presumed that in the beginning of each period these three methods would be utilized. The

Table 6 The investment cost and salvages value of each plant and warehouse

		Investment cost (USD)	Salvages value (USD)
Preprocessing centers of biomass	1	10,000	3000
	2	15,000	4500
	3	10,400	3500
Plant	1	100,000	30,000
	2	90,000	20,000
	3	110,000	40,000
Warehouse for products	1	10,300	3000
	2	10,100	3000
	3	13,400	4000

Table 7 Amount of biomass i to preprocessing center j in period t

Biomass	Period											
	1	2	3	4	5	6	7	8	9	10	11	12
Preprocessing center 1												
1	53.7	•	•	256	•	•	•	•	•	•	220	•
2	•	86.3	•	193.8	•	•	•	•	•	•	220	•
3	•	•	•	•	•	•	•	•	•	•	•	•
Preprocessing center 2												
1	146.3	120	220	•	200	•	•	•	200	120	•	106.7
2	•	33.7	220	•	•	•	•	•	•	•	•	340
3	310	200	•	•	•	•	•	340	•	•	•	•
Preprocessing center 3												
1	•	•	•	84	•	120	220	340	•	•	•	233.3
2	•	•	•	•	•	120	•	340	•	•	•	•
3	•	•	80	•	•	120	•	•	200	•	•	•

Table 8 Amount of biomass from warehouse j to plant k with size $p = 1$ in period t

Preprocessing center	Period											
	1	2	3	4	5	6	7	8	9	10	11	12
Plant 1												
1	•	129.5	•	•	•	•	•	•	•	•	116.8	•
2	161	•	•	•	172.6	•	•	137.9	•	175.8	•	208.4
3	•	•	120	65.3	•	141.1	160	•	80.5	•	•	•
Plant 2												
1	161	129.5	•	•	172.6	•	•	•	•	•	116.8	•
2	•	•	•	130.5	.	141.1	160	137.9	•	•	•	208.4
3	•	•	120	•	•	•	•	•	161.1	175.8	•	•
Plant 3												
1	•	•	•	•	172.6	•	•	•	•	•	•	•
2	143	129.5	120	•	•	•	•	•	161.1	175.8	116.8	•
3	•	•	•	130.5	•	141.1	160	137.9	•	•	•	208.4

maximum depreciation value of these methods is chosen in that period. The year that the method of depreciation is switched to another is called the switch point. The depreciation of the installed preprocessing centers of biomass, plant and warehouse for products in each year is indicated in Table 11. Also, the switch points are

Table 9 Flow of biofuel from plant k with size $p = 1$ to warehouse l in period t

Plant	Period											
	1	2	3	4	5	6	7	8	9	10	11	12
Warehouse 1 for products												
1	100	•	•	240	150	•	•	•	•	45.5	140	•
2	•	•	•	•	150	•	•	250	•	•	•	•
3	100	•	•	•	150	90	•	•	•	•	140	•
Warehouse 2 for products												
1	•	•	•	•	•	•	•	•	170	•	•	•
2	100	100	•	•	•	•	60	•	•	•	•	94
3	•	•	•	•	•	•	•	•	170	•	•	•
Warehouse 3 for products												
1	•	100	120	•	•	90	180	250	•	•	•	•
2	•	•	120	240	•	90	120	•	170	90	140	•
3	•	100	120	240	•	•	180	250	•	90	•	77

Table 10 Flow of biofuel from warehouse l to demand point w in period t

Warehouse for products	Period											
	1	2	3	4	5	6	7	8	9	10	11	12
Demand point 1												
1	12	•	•	•	•	•	•	26	19.33	•	40.5	•
2	•	•	•	•	•	•	20	•	1.667	•	93.67	13.33
3	.	13	28	23	26	21	•	•	•	•	311	6.67
Demand point 2												
1	25	•	•	•	•	20	•	•	20	•	31	•
2	•	•	•	•	27	•	•	•	•	•	•	•
3	•	27	19	25	•	•	21	19	•	•	•	19
Demand point 3												
1	22	•	•	•	10	237.67	•	18	.	•	37	•
2	•	•	•	•	•	39.67	•	•	18	•	•	18
3	•	21	34	20	•	149.67	139	•	•	•	•	•

highlighted in Table 11. According to the calculated depreciation in the model 1, the book value of each installed preprocessing centers of biomass, plant and warehouse for products at beginning of year are shown Table 12.

Sensitivity analysis

For more description of book value results, some figures are illustrated in "Appendix".

Lots of parameters exist in the proposed model which can change the objective function level. In this study the rate of return (ROR) of the project is calculated. The result from Fig. 3 shows ROR = 78 %. Unless interest rate is less than 78 % the project is not acceptable. Investment in this project would be done while the interest rate would be less than ROR. Figure 3 shows that while the interest rate is less than 78 % the objective function of the model is positive and the project is reasonable.

Conclusion

The depletion of the fossil fuels and major concerns about the security of energy in the future to produce fuels led to utilizing the renewable energies such as biofuels. This paper presented a general optimization model which enables the selection of preprocessing centers for the biomass, biofuel plants, and warehouses to store the biofuels. Two models are introduced to calculate the benefits of biofuel supply chain. At the first model, the depreciation costs of the installed centers are calculated by means of three methods (straight line, SOYD and DDB). The results of the first model indicated that at the preprocessing center, in the installed plants and the warehouses, method of

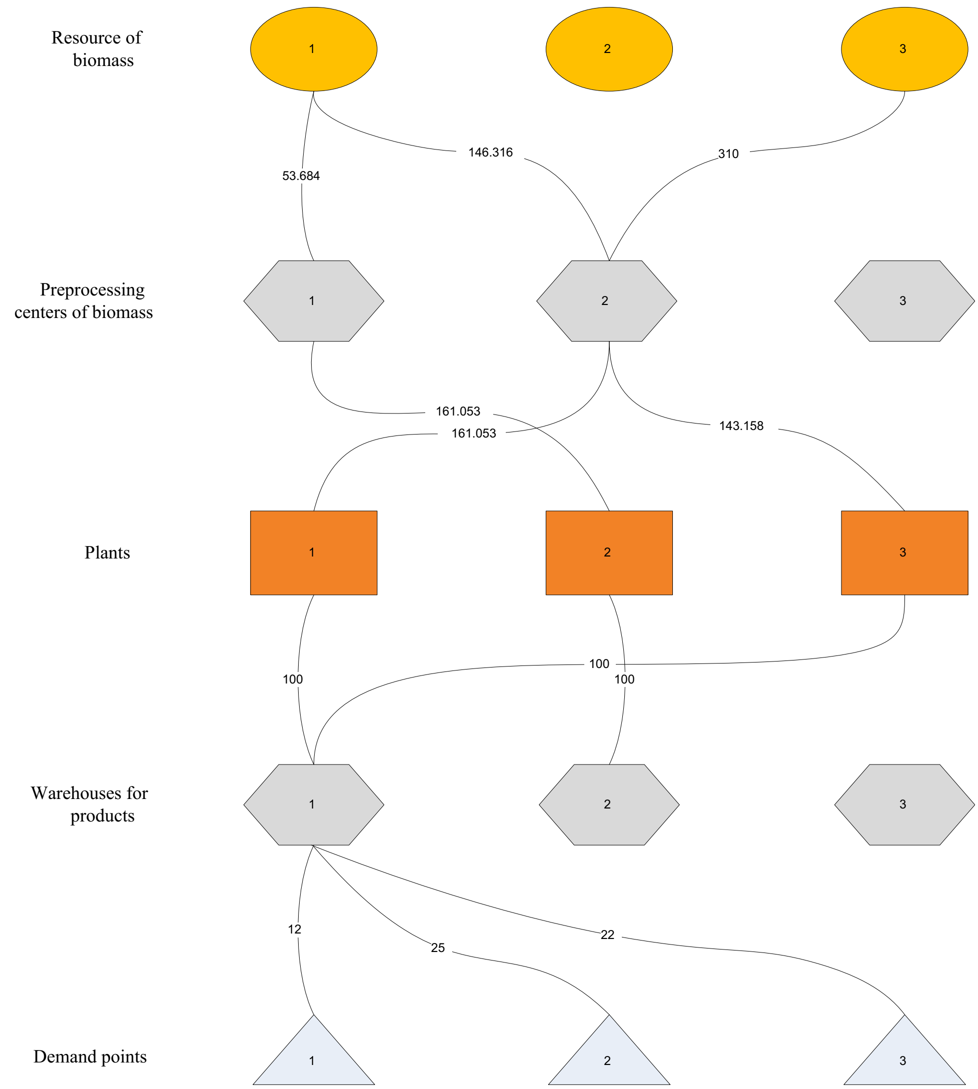

Fig. 2 The flow of biomass and biofuel from resources of biomass to demand points

Table 11 The depreciation of the installed preprocessing centers of biomass, plant and warehouse for production each year

Year	Preprocessing centers of biomass			Plant			Warehouse for products		
	1	2	3	1	2	3	1	2	3
1	1301.8	1952.7	1353.8	13,017.8	11,716.0	14,319.5	1340.8	1314.8	1744.4
2	1101.5	1652.3	1145.6	11,015.0	9913.5	12,116.5	1134.5	1112.5	1476.0
3	932.0	1398.1	969.3	9320.4	8388.4	10252.4	960.0	941.4	1248.9
4	788.6	1183.0	820.2	7886.5	7097.8	8675.1	812.3	796.5	1056.8
5	667.3	1001.0	694.0	6673.2	6005.9	7340.5	687.3	674.0	894.2
6	564.7	847.0	587.2	5646.5	5081.9	6211.2	581.6	570.3	756.6
7	477.8	716.7	496.9	4777.8	**4787.5**	5255.6	492.1	482.6	640.2
8	**411.3**	**617.0**	420.5	**4113.4**	4787.5	4447.1	**438.7**	**420.5**	**554.5**
9	411.3	617.0	**355.8**	4113.4	4787.5	3762.9	438.7	420.5	554.5
10	411.3	617.0	352.6	4113.4	4787.5	3184.0	438.7	420.5	554.5
11	411.3	617.0	352.6	4113.4	4787.5	**2918.2**	438.7	420.5	554.5
12	411.3	617.0	352.6	4113.4	4787.5	2918.2	438.7	420.5	554.5

Table 12 The book value of each installed preprocessing centers of biomass, plant and warehouse for products at beginning of year

	Preprocessing center of biomass			Plant			Warehouse for products		
	1	2	3	1	2	3	1	2	3
Year									
0	10,000	15,000	10,400	100,000	90,000	110,000	10,300	10,100	13,400
1	8898.5	13,347.7	9254.4	88,985.0	80,086.5	97,883.5	9165.5	8987.5	11,924.0
2	7966.5	11,949.7	8285.1	79,664.6	71,698.1	87,631.0	8205.5	8046.1	10,675.1
3	7177.8	10,766.7	7464.9	71,778.1	64,600.3	78,955.9	7393.1	7249.6	9618.3
4	6510.5	9765.7	6770.9	65,104.9	58,594.4	71,615.4	6705.8	6575.6	8724.1
5	5945.8	8918.8	6183.7	59,458.4	53,512.5	65,404.2	6124.2	6005.3	7967.4
6	5468.1	8202.1	5686.8	54,680.5	48,725.0	60,148.6	5632.1	5522.7	7327.2
7	5056.7	7585.1	5266.3	50,567.1	43,937.5	55,701.5	5193.4	5102.3	6772.7
8	4645.4	6968.1	4910.6	46,453.7	39,150.0	51,938.6	4754.7	4681.8	6218.1
9	4234.0	6351.0	4557.9	42,340.3	34,362.5	48,754.6	4316.0	4261.4	5663.6
10	3822.7	5734.0	4205.3	38,226.8	29,575.0	45,836.4	3877.4	3840.9	5109.1
11	3411.3	5117.0	3852.6	34,113.4	24,787.5	42,918.2	3438.7	3420.5	4554.5

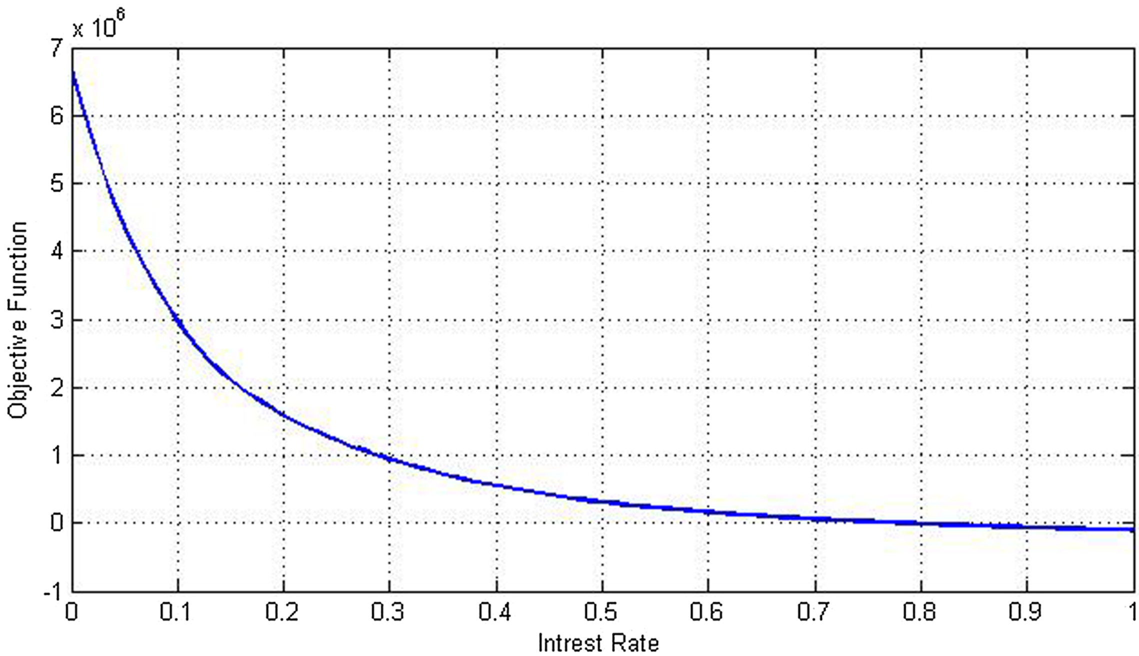

Fig. 3 Interest rate with objective function

calculating the depreciation changed from DDB to straight line in period ($t = 7$, $t = 7$, $t = 8$), ($t = 7$, $t = 6$, $t = 10$) and ($t = 7$, $t = 7$, $t = 7$), respectively. Therefore, for the installed centers the depreciation is utilized by the results of the first model. The results of the second model indicate that the small-size plants are purchased. Three preprocessing centers are purchased. One of the plants is rented and two are purchased and all of the warehouses of the biofuel are purchased. Also the results of the supply chain flows are indicated in the tables. Depreciation cost could be considered in designing all supply chains, such as automobile and oil. This new concept helps top managers decide well in designing supply chains and establishing plants and warehouses. Parameters in the model could be considered uncertain, for example, demand in the biofuel supply chain can be considered fuzzy.

Appendix

Switching point shows that the strategy of selecting depreciation method is changed from one to another. According to the fact that each organization desires to select the best depreciation method to reduce their cost, this model facilitates selecting depreciation cost by which they could be able to choose the best one with regards to the net present value of depreciation in each year. Switching points for each preprocessing centers, plants and warehouses are presented in Figs. 4, 5, 6, 7, 8, 9, 10, 11 and 12.

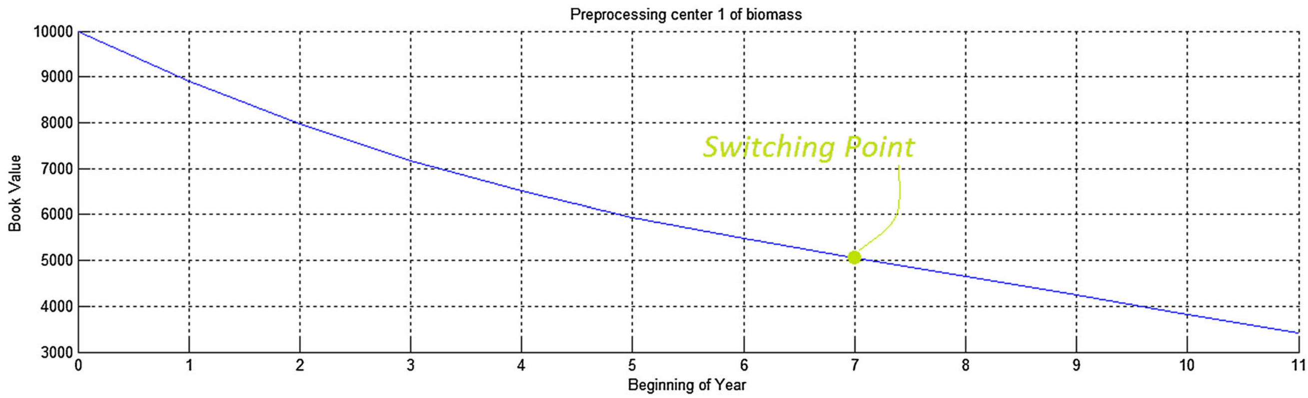

Fig. 4 Book value of preprocessing center 1 with regards to year

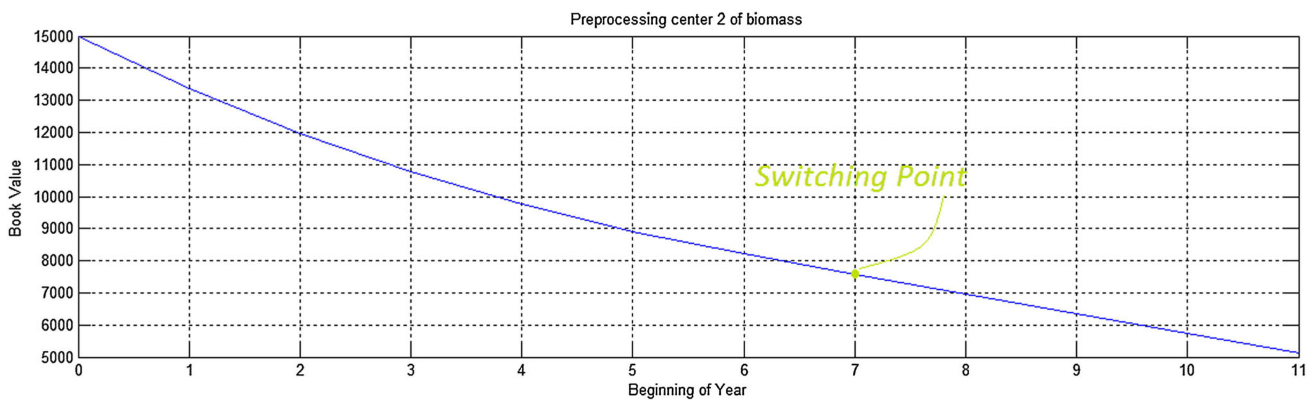

Fig. 5 Book value of preprocessing center 2 with regards to year

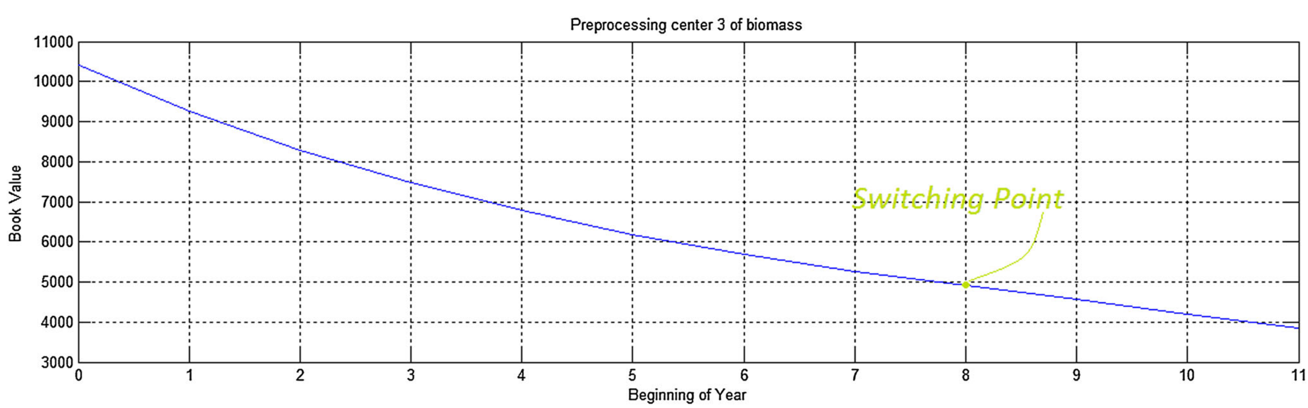

Fig. 6 Book value of preprocessing center 3 with regards to year

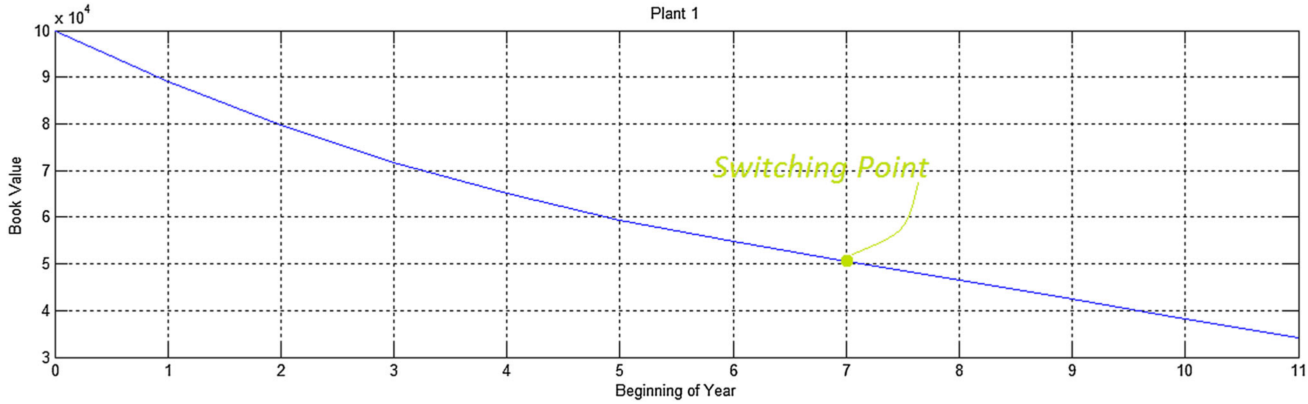

Fig. 7 Book value of plant 1 with regards to year

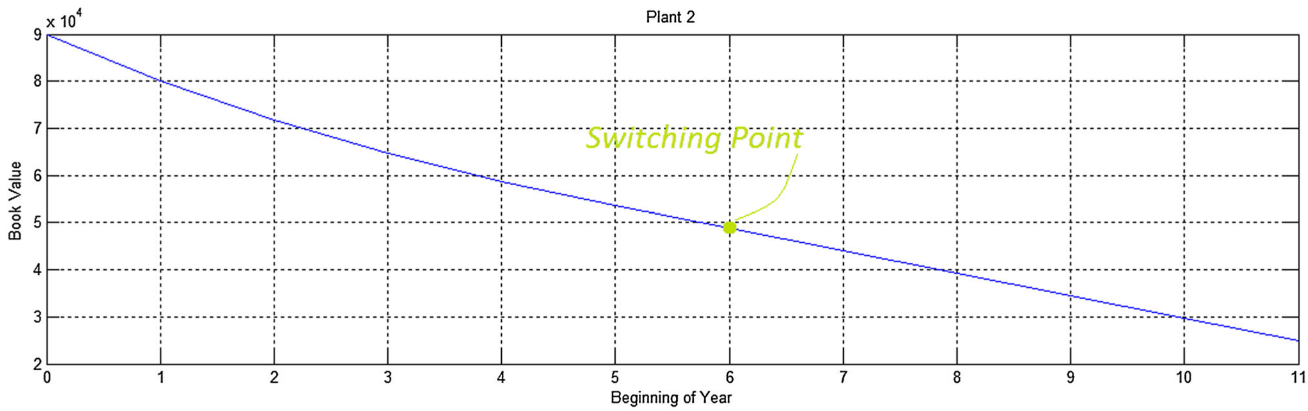

Fig. 8 Book value of plant 2 with regards to year

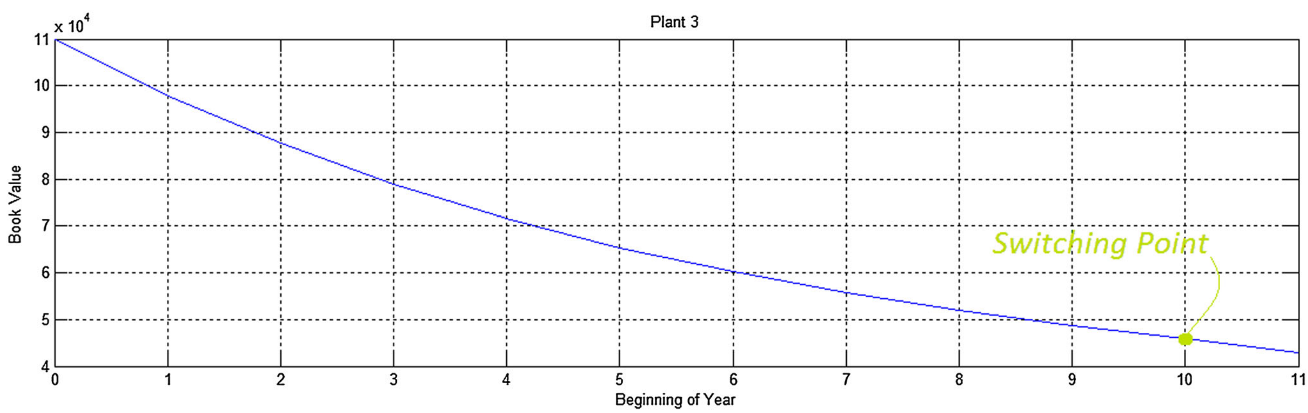

Fig. 9 Book value of plant 3 with regards to year

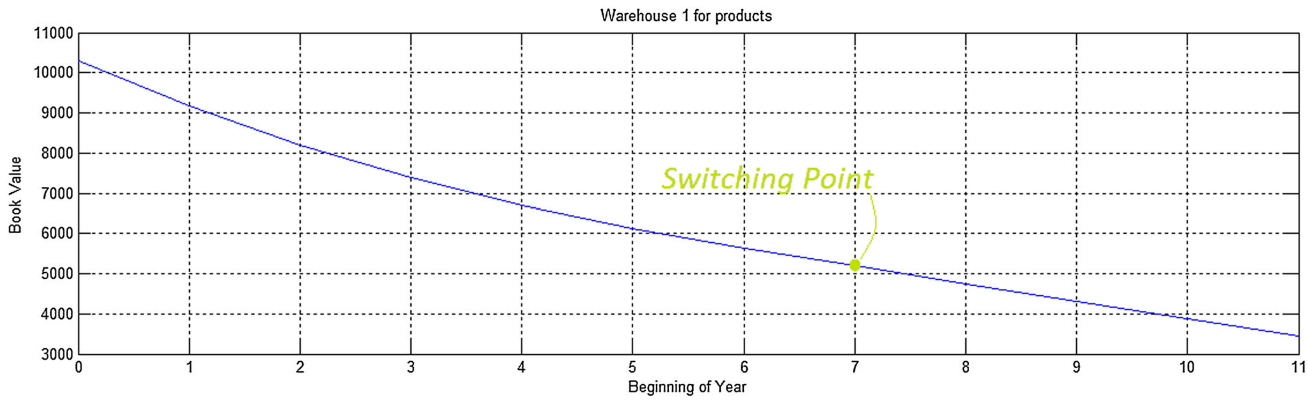

Fig. 10 Book value of warehouse 1 with regards to year

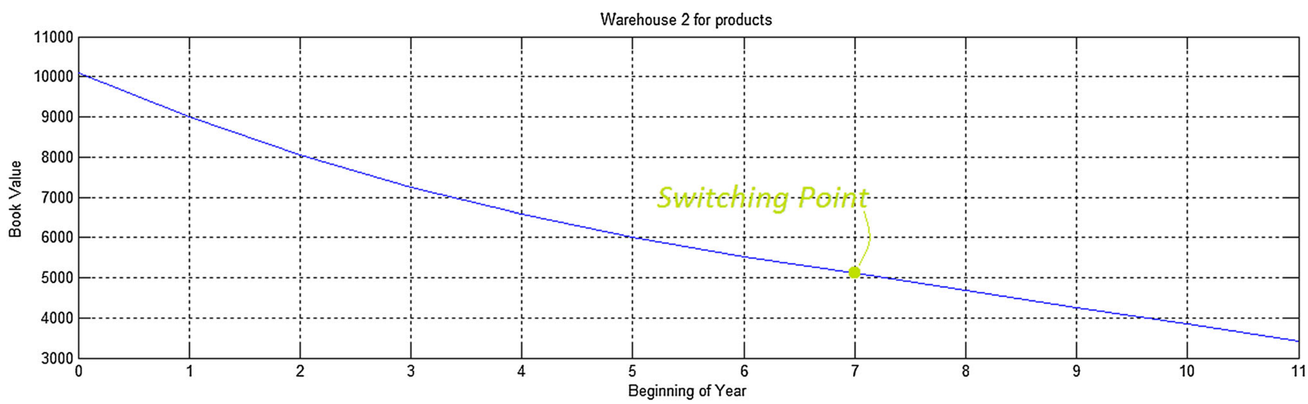

Fig. 11 Book value of warehouse 2 with regards to year

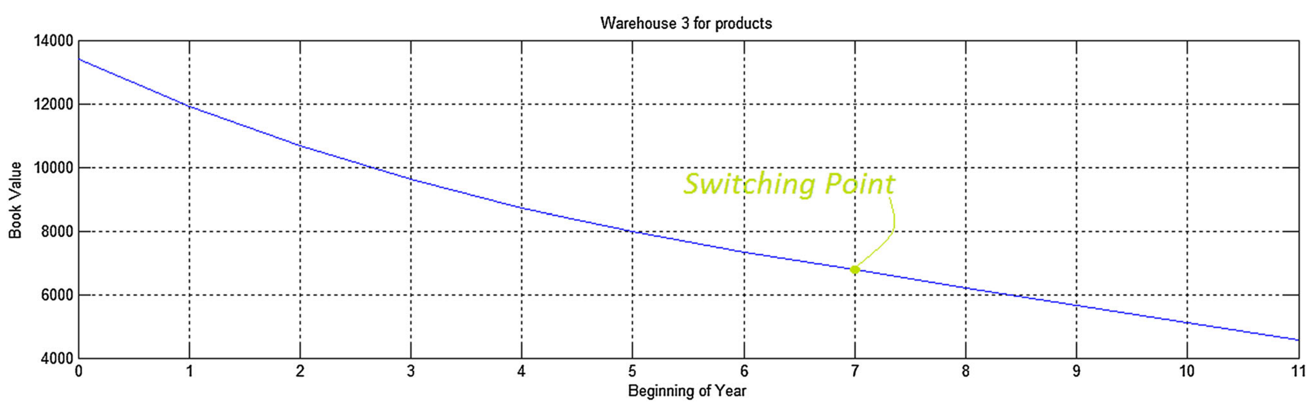

Fig. 12 Book value of warehouse 3 with regards to year

References

Akgul O, Zamboni A, Bezzo F, Shah N, Papageorgiou LG (2011) Optimization-based approaches for bioethanol supply chains. Ind Eng Chem Res 50(9):4927–4938. doi:10.1021/ie101392y

Akgul O, Shah N, Papageorgiou LG (2012) Economic optimisation of a UK advanced biofuel supply chain. Biomass Bioenergy 41:57–72. doi:10.1016/j.biombioe.2012.01.040

Alimardani M, Jolai F, Rafiei H (2013) Bi-product inventory planning in a three-echelon supply chain with backordering, Poisson demand, and limited warehouse space. J Ind Eng Int 9(1):1–13. doi:10.1186/2251-712X-9-22
AriaNezhad MG, Makuie A, Khayatmoghadam S (2013) Developing and solving two-echelon inventory system for perishable items in a supply chain: case study (Mashhad Behrouz Company). J Ind Eng Int 9(1):1–10. doi:10.1186/2251-712X-9-39
Ayoub N, Yuji N (2012) Demand-driven optimization approach for biomass utilization networks. Comput Chem Eng 36:129–139. doi:10.1016/j.compchemeng.2011.09.005
Ayoub N, Martins R, Wang K, Seki H, Naka Y (2007) Two levels decision system for efficient planning and implementation of bioenergy production. Energy Convers Manage 48(3):709–723. doi:10.1016/j.enconman.2006.09.012
Ayoub N, Elmoshi E, Seki H, Naka Y (2009) Evolutionary algorithms approach for integrated bioenergy supply chains optimization. Energy Convers Manag 50(12):2944–2955. doi:10.1016/j.enconman.2009.07.010
Chen C-W, Fan Y (2012) Bioethanol supply chain system planning under supply and demand uncertainties. Transp Res Part E Logist Transp Rev 48(1):150–164. doi:10.1016/j.tre.2011.08.004
Čuček L, Varbanov PS, Klemeš JJ, Kravanja Z (2012) Total footprints-based multi-criteria optimisation of regional biomass energy supply chains. Energy 44(1):135–145. doi:10.1016/j.energy.2012.01.040
Fazlollahi S, Maréchal F (2013) Multi-objective, multi-period optimization of biomass conversion technologies using evolutionary algorithms and mixed integer linear programming (MILP). Appl Therm Eng 50(2):1504–1513. doi:10.1016/j.applthermaleng.2011.11.035
Jackson SB, Liu XK, Cecchini M (2009) Economic consequences of firms' depreciation method choice: evidence from capital investments. J Acc Econ 48(1):54–68. doi:10.1016/j.jacceco.2009.06.001
Judd JD, Sarin SC, Cundiff JS (2012) Design, modeling, and analysis of a feedstock logistics system. Bioresour Technol 103(1):209–218. doi:10.1016/j.biortech.2011.09.111
Keirstead J, Samsatli N, Pantaleo AM, Shah N (2012) Evaluating biomass energy strategies for a UK eco-town with an MILP optimization model. Biomass Bioenergy 39:306–316. doi:10.1016/j.biombioe.2012.01.022
Kim J, Realff MJ, Lee JH, Whittaker C, Furtner L (2011) Design of biomass processing network for biofuel production using an MILP model. Biomass Bioenergy 35(2):853–871. doi:10.1016/j.biombioe.2010.11.008
Kostin AM, Guillén-Gosálbez G, Mele FD, Bagajewicz MJ, Jiménez L (2012) Design and planning of infrastructures for bioethanol and sugar production under demand uncertainty. Chem Eng Res Design 90(3):359–376. doi:10.1016/j.cherd.2011.07.013
Kumar R, Sharma AK, Tewari PC (2015) Cost analysis of a coal-fired power plant using the NPV method. J Ind Eng Int 11(4):495–504. doi:10.1007/s40092-015-0116-8
Leão RRDCC, Hamacher S, Oliveira F (2011) Optimization of biodiesel supply chains based on small farmers: a case study in Brazil. Bioresour Technol 102(19):8958–8963. doi:10.1016/j.biortech.2011.07.002
Leduc S, Schwab D, Dotzauer E, Schmid E, Obersteiner M (2008) Optimal location of wood gasification plants for methanol production with heat recovery. Int J Energy Res 32(12):1080–1091. doi:10.1002/er.1446
Mahmoudi R, Hafezalkotob A, Makui A (2014) Source selection problem of competitive power plants under government intervention: a game theory approach. J Ind Eng Int 10(3):59. doi:10.1007/s40092-014-0059-5
Meier A, Gremaud N, Steinfeld A (2005) Economic evaluation of the industrial solar production of lime. Energy Convers Manag 46(6):905–926. doi:10.1016/j.enconman.2004.06.005
Mele FD, Guillén-Gosálbez G, Jiménez L (2009) Optimal planning of supply chains for bioethanol and sugar production with economic and environmental concerns. Comput Aided Chem Eng 26:997–1002. doi:10.1016/S1570-7946(09)70166-X
Mobini M, Sowlati T, Sokhansanj S (2011) Forest biomass supply logistics for a power plant using the discrete-event simulation approach. Appl Energy 88(4):1241–1250. doi:10.1016/j.apenergy.2010.10.016
Mousavi SH, Nazemi A, Hafezalkotob A (2014) Using and comparing metaheuristic algorithms for optimizing bidding strategy viewpoint of profit maximization of generators. J Ind Eng Int 11(1):59–72. doi:10.1007/s40092-014-0094-2
Pérez-Fortes M, Laínez-Aguirre JM, Arranz-Piera P, Velo E, Puigjaner L (2012) Design of regional and sustainable bio-based networks for electricity generation using a multi-objective MILP approach. Energy 44(1):79–95. doi:10.1016/j.energy.2012.01.033
Petroleum B (2015) BP statistical review of world energy. British Petroleum, London. Available at http://www.bp.com/statisticalreview
Rentizelas AA, Tatsiopoulos IP (2010) Locating a bioenergy facility using a hybrid optimization method. Int J Prod Econ 123(1):196–209. doi:10.1016/j.ijpe.2009.08.013
Seifbarghy M, Kalani MM, Hemmati M (2015) A discrete particle swarm optimization algorithm with local search for a production-based two-echelon single-vendor multiple-buyer supply chain. J Ind Eng Int. doi:10.1007/s40092-015-0126-6
Tumuluru JS, Sokhansanj S, Wright CT, Boardman RD, Yancey NA (2011) A review on biomass classification and composition, co-firing issues and pretreatment methods. In: Proceedings of the American society of agricultural and biological engineers annual international meeting, pp 2053–2083. doi:10.13031/2013.37191
Velazquez-Marti B, Fernandez-Gonzalez E (2010) Mathematical algorithms to locate factories to transform biomass in bioenergy focused on logistic network construction. Renew Energy 35(9):2136–2142. doi:10.1016/j.renene.2010.02.011
Zamboni A, Bezzo F, Shah N (2009) Supply chain optimization for bioethanol production system in Northern Italy: environmentally conscious strategic design. Comput Aided Chem Eng 27:2037–2042. doi:10.1016/S1570-7946(09)70730-8
Zhang J, Osmani A, Awudu I, Gonela V (2013) An integrated optimization model for switchgrass-based bioethanol supply chain. Appl Energy 102:1205–1217. doi:10.1016/j.apenergy.2012.06.054
Zhu X, Yao Q (2011) Logistics system design for biomass-to-bioenergy industry with multiple types of feedstocks. Bioresour Technol 102(23):10936–10945. doi:10.1016/j.biortech.2011.08.121