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A decision model for cost effective design of biomass based green energy supply chains

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HIGHLIGHTS

- A decision support tool is developed to design economic green energy supply chains.
- Anaerobic digestion systems are modeled as component of the bioenergy supply chain.
- Fuzzy goal programming approach is applied to the model.
- Multiple economic objectives are optimized considering uncertain parameters.
- The effects of different conditions on supply chain are observed.

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ABSTRACT

The core driver of this study is to deal with the design of anaerobic digestion based biomass to energy supply chains in a cost effective manner. In this concern, a decision model is developed. The model is based on fuzzy multi objective decision making in order to simultaneously optimize multiple economic objectives and tackle the inherent uncertainties in the parameters and decision makers' aspiration levels for the goals. The viability of the decision model is explored with computational experiments on a real-world biomass to energy supply chain and further analyses are performed to observe the effects of different conditions. To this aim, scenario analyses are conducted to investigate the effects of energy crop utilization and operational costs on supply chain structure and performance measures.

1. Introduction

An efficient supply chain has to be designed to perform the major activities in a biomass to energy supply chain from biomass cultivation to energy conversion. This includes the transportation network design, selection of locations and capacities of conversion plants, procurement of feedstock, handling and distribution of process residue and tactical operation schedules. Many decisions in biomass to energy supply chains involve complex tradeoffs among conflicting objectives. Therefore, various competing supply chain decisions that affect the supply chain design cannot be made independently.

Today's global and highly competitive markets with continuously changing conditions enforce supply chains to operate in a somehow uncertain environment. These uncertainties increase with the level of decision to be made, i.e. uncertainties encountered in strategic level decision-making impact the performance of supply chains more than those in tactical/operational level decision-making do.

Although there exist a vast literature and a number of models on supply chain design and management for industrial products, the nature of biomass to energy supply chains do not allow the application of these models directly to this type of supply chains. Modeling biomass to energy supply chains requires various problem specific parameters, constraints and objectives related to technical, economic, environmental and energetic characteristics of biomass sources and bioenergy systems.

Decision models for biomass to energy supply chain network design of increasing scope and sophistication have been devised recently. However, it is necessary to develop models that incorporate inherent uncertainties. In addition, these models should incorporate multiple objectives/criteria considering economic, technical, environmental and social aspects to provide more effective solutions to real life problems. Ayoub et al. (2009) developed a methodology and use a multiobjective MILP model to design and evaluate

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biomass utilization networks in local areas. Dal Mas et al. (2011) developed a MILP model for the design and planning of multi-echelon biofuels supply chain under uncertain market conditions. The model determines supply chain design variables as well as biofuel market demand satisfaction rate, supply chain profit and financial risk. Giarola et al. (2011) presented a multi-period, multi-echelon MILP framework to optimize the environmental and financial performances of corn grain and stover based bioethanol supply chains simultaneously. Sharma et al. (2013) developed a LP model to make strategic, tactical and operational decisions related to biomass supply chains considering weather uncertainty. A scenario optimization model is formulated to address the changes in the weather conditions over a one-year planning period. You et al. (2012) developed a multiobjective MILP model to address the optimal design and planning of cellulosic ethanol supply chains under economic, environmental, and social objectives. The economic objective is measured by the total annual cost, the environmental objective is measured by the life cycle greenhouse gas emissions, and the social objective is measured by the number of accrued local jobs. Akgül et al. (2012) presented a multiobjective static modeling framework for the optimization of biofuel supply chains considering economic and environmental objectives. Pérez-Fortes et al. (2012) developed a multiobjective MILP model to support designing and planning of biomass-based supply chains. The model determines the most suitable pre-processing technologies with their capacities and locations, connections between the units of the supply chain, biomass storage periods, matter transportation flows and the electricity network among the different communities. Giarola et al. (2013) proposed a multi-period, multi-echelon life cycle analysis integrated with a MILP modeling framework to support strategic design and planning decisions for bioethanol supply chains. The model is a two-stage stochastic decision making tool including economic and environmental models. Kanzian et al. (2013) developed a multiobjective optimization model for designing of forest biomass supply chains. Network layout decisions such as locations of plants are made as well as decisions about transportation mode, production volumes and usage of terminals. Cambero et al. (2014) presented a multi-period MILP model to optimize the supply chain of forest residues for the production of bioenergy and biofuels simultaneously. The model determines the location, type and size of the technologies, the mix of biofuel and bioenergy products to be generated, the type and amount of forest residues, the amount of forest residues to be transported from sources to facilities and the amount of product to be transported from facilities to markets. The model maximizes the net present value of the supply chain over a 20-year planning horizon. Osmani and Zhang (2014) proposed a two-stage stochastic MILP to maximize the expected profit while minimizing environmental impact of a lignocellulosic bioethanol supply chain under biomass supply, bioethanol demand and biomass/bioethanol price uncertainties. Yılmaz Balaman and Selim (2014) developed a multiobjective MILP model for planning the bioenergy supply chains under economic and environmental objectives. They used different FGP approaches to consider inherent uncertainties and compared the results in terms of economic and environmental perspectives. Krukanont and Prasertsan (2004) conducted a study to determine the location and capacity of biomass power plants that uses rubber wood as feedstock. GIS, mathematical modeling and simulation methods are utilized respectively to map the rubber wood area and to pinpoint the suitable locations for biomass power plants, to derive the biomass costs and to determine the appropriate sites and sizes of the power plants. An et al. (2011) proposed a model to design a lignocellulosic biomass to biofuel supply chain that has multiple commodity flows ranging from biomass suppliers to biofuel customers. The model deals with a production/distribution system, and determines facility locations, capacities, technology and material flows while maximizing the profit. López et al. (2008) applied and compared several metaheuristic techniques to optimize the location and biomass supply area of biomass-based power plants. For this purpose, two trajectory (Simulated Annealing and Tabu Search) and two population-based (GA and PSO) methods are applied. A new PSO algorithm is proposed in the study and the results are compared to those of the four methods. Rentizelas and Tatsiopoulos (2010) conducted a study to find the best location of a bioenergy generation facility that optimizes the system-wide operational and investment costs. Since the optimization model is nonlinear, a hybrid solution procedure is employed. Solutions of the hybrid methodology are compared with those of GA and Sequential Quadratic Programming. Velazquez-Marti and Fernandez-Gonzalez (2010) proposed a mathematical calculation methodology to determine the optimal points for bioenergy production facilities supplying energy to a selected set of cities. The cities are grouped in sets by considering two criteria: all the energy produced by the plant must be consumed and the transportation cost of energy must be minimized. Lin et al. (2014) developed a MILP to design a biomass supply chain that includes a farm management module, a logistics planning module, a facility allocation module and an ethanol distribution module. Strategic decisions such as determining the numbers, locations and capacities of plants and biomass/ethanol distribution patterns as well as tactical decisions like determining the biomass production, storage, delivery and operating schedules are made by the model. Vera et al. (2010) developed a methodology to determine the best location, biomass supply area and power plant size that offer the best profitability to the investor. The methodology includes Binary Honey Bee Foraging Approach that base on particles swarm. Results are compared with those of Binary PSO and GA. Gómez-González et al. (2013) developed a hybrid heuristic approach to find the best location and size of biomass fueled electricity generation facilities. To this aim, PSO is used to search a range of location combinations in the distribution network and Optimal Power Flow is utilized to define available capacity for each combination.

Most of the real world problems dealing with the renewable energy supply chain design consider different objectives such as satisfying minimum system costs and minimum level of harmful gas emissions, and a set of technological, economic, environmental, social and energetic constraints. However, our current literature review demonstrates that the number of studies considering multiple objectives is less than those with single objective in the current literature about biomass to energy supply chain design. Although goal programming is one of the most powerful approaches in practical decision making for multi objective problems which aims to minimize unwanted deviations from target values for objectives, our literature review expose that it is employed only by Yılmaz Balaman and Selim (2014) in biomass to energy conversion systems design.

Fuzzy modeling approaches can be more widely utilized to provide the appropriate framework to describe and treat uncertainties in biomass to energy supply chain network design problem. Considering this gap, we use fuzzy mathematical programming to develop a decision model for design and management of biomass to energy supply chains under uncertain decision environment. The main cost components along with total income are considered as objective functions simultaneously in the model. The viability of the decision model is explored with computational experiments on a real-world problem. Further analyses are also conducted to observe the effects different conditions on structure and performance of the supply chain. In this regard, the effects of