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Life cycle cost optimization of biofuel supply chains under uncertainties based on interval linear programming

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HIGHLIGHTS

- A model for biofuel supply chain under uncertainties is developed.
- Many parameters in biofuel supply chain are regarded as interval numbers.
- Life cycle thinking is incorporated in the design of bioethanol supply chain.
- Life cycle cost is used as the objective for optimizing biofuel supply chain.

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ABSTRACT

The aim of this work was to develop a model for optimizing the life cycle cost of biofuel supply chain under uncertainties. Multiple agriculture zones, multiple transportation modes for the transport of grain and biofuel, multiple biofuel plants, and multiple market centers were considered in this model, and the price of the resources, the yield of grain and the market demands were regarded as interval numbers instead of constants. An interval linear programming was developed, and a method for solving interval linear programming was presented. An illustrative case was studied by the proposed model, and the results showed that the proposed model is feasible for designing biofuel supply chain under uncertainties.

1. Introduction

Biofuel has been regarded as a promising alternative to fossil fuel for its significant advantages of renewability and sustainability performances. More and more countries have commercialized biofuel such as corn ethanol in US and sugarcane ethanol in Brazil (Sims et al., 2010). However, there are also some severe problems that need to be solved such as bad economic performance due to the increase of grain price, worse global ecological performance than fossil fuel, arable land scarcity, and "fuel versus food" debate (Liang et al., 2013; Ren et al., 2013a). Among these problems, economic performance is one of the most important issues that needs to be improved due to the high cost of biofuel production, and most of the current biofuel projects need governmental subsidies or tax reduction (Gnansounou, 2010).

Most of the mature biofuel markets used grain as feedstocks, i.e. corn and wheat, and the performance is usually assessed by life cycle tools, such as life cycle energy and CO_2 analysis (Khoo et al., 2013; Khoo et al., 2011), life cycle energy efficiency and environment impact (Wang et al., 2013), life cycle assessment (Singh et al., 2010), and life cycle cost analysis (Luo et al., 2010; Resurreccion et al., 2012; Stoeglehner and Narodoslawsky, 2009). In other words, the total cost of biofuel is usually assessed in life cycle perspective, form the cultivation of grain, grain transport to bioethanol factory, biofuel production, and biofuel distribution to market. In a region, there are usually several different plants using different technologies for biofuel production, several different agriculture zones for feedstocks production such as corn and wheat, multiple transportation modes for the transport of grain and biofuel, and several markets for the sale of biofuels. Thus, the life cycle

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cost of the whole biofuel system involves multiple factors and stages, and the appropriate design of biofuel supply chain is prerequisite for minimizing the life cycle cost and improving the economic performance.

Various models have been developed for designing biofuel supply chains by optimizing the economic performance. An et al. (2011) formulated a model to maximize the total profit of biofuel supply chain ranging from feedstock suppliers to biofuel customers. Judd et al. (2012), Sultana and Kumar (2011), Zhu et al. (2011), and Zhu and Yao (2011) developed different models to minimize the total cost of biofuel supply chains. Besides the economic objective, some other models have been developed with the consideration of ecological performance of bioethanol supply chain, e.g. ecological footprint has been used as the objective to optimize biofuel supply chain (Ren et al., 2013b). All these models are beneficial for designing and planning biofuel supply chains, but it lacks the methods for the optimization of biofuel supply chain under uncertainties. Moreover, it is very important to consider the uncertainties when designing and planning biofuel supply chains, because uncertainty information commonly exists in economic assessment of biofuel supply chains due to the ever-change market, and the variation of resources price and the yields of the grains. Therefore, developing a model for designing and planning biofuel supply chains under uncertainties is of vital importance.

The objective of this work was to develop a single-objective interval linear programming for addressing the uncertainties when minimizing the life cycle cost of biofuel supply chains. The remainder part of this paper was structured as follows: Section 2 presented the model for life cycle cost optimization under uncertainties. The results and discussion were conducted in Section 3. Finally, this study was concluded in Section 4.

2. Method

2.1. Biofuel supply chain

There are two most popular indices for measuring the economic performance of biofuel supply chain: the total cost and the total profit (An et al., 2011; Judd et al., 2012; Sultana and Kumar, 2011; Zhu et al., 2011; Zhu and Yao, 2011). The difference between these two indices is that the total profit of biofuel supply chain incorporates the revenue by selling the product (biofuels) and byproducts (i.e. glycerin in biodiesel production, dried distillers' grain with soluble and biogas in bioethanol production). In order to measure the economic performance of biofuel supply chain in life cycle perspective, life cycle costing method which has the ability to measure the life cycle cost (LCC) which refers to all the costs in system life cycle related to design, construction and production, distribution, operation, maintenance and support, retirement, and material disposal (Utne, 2009) and has the advantage of looking at the economics over the whole life cycle of the product (Leckner and Zmeureanu, 2011), was used to determine the total

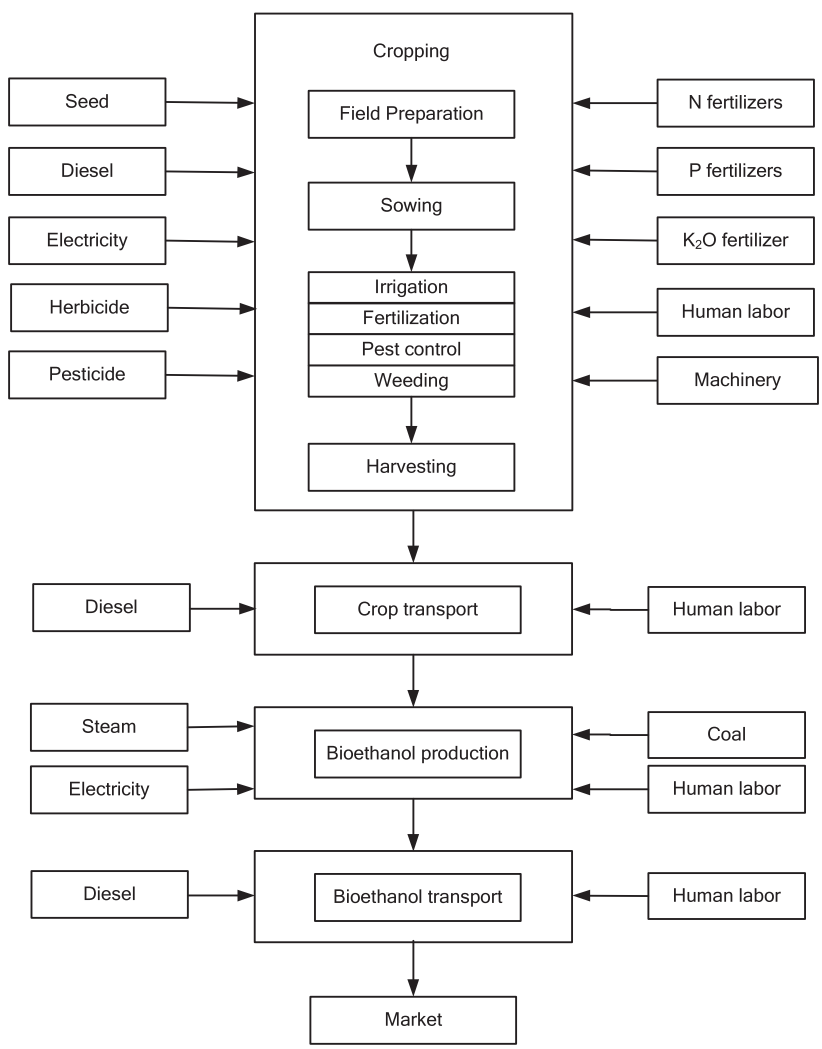

Fig. 1. Life cycle boundary of biofuel and the main inputs of bioethanol system. Source: adapted from Ren et al. (2014).