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Biomass supply chain network design: An optimization-oriented review and analysis

Hamid Ghaderi, Mir Saman Pishvaee, Alireza Moini*

School of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran

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ABSTRACT

Optimal network design is a key factor in the enhancement of the economic, environmental, and social performance and efficiency of the biomass supply chain (BSC), and this is why it has become quite popular with the academia and practitioners. The great number of the related papers published in the scientific journals in recent years is the proof of the claim; therefore, to make a framework of the past works and specify the future directions, a comprehensive review of the state-of-the-art papers deems necessary. The objective of this paper is to review the papers regarding the biomass supply chain network design (BSCND) models published in the scientific journals. A total number of 146 papers, published from Jan. 1997 to Jul. 2016 are reviewed, analyzed and classified based on their modeling approaches, decisions, uncertainties, solution methodologies, sustainability, model features, entities, data, and regions of the case studies. To determine the research opportunities and future directions, the gaps existing in the present literature have been clearly explained as well.

Contents

Abbreviations: BSC, Biomass Supply Chain; BSCND, Biomass Supply Chain Network Design; GIS, Geographical Information Systems; EDSS, Environmental Decision Support System; LP, Linear Programming; NLP, Non-linear Programming; MINLP, Mixed Integer Non-linear Programming; MCDM, Multi-Criteria Decision Making; MADM, Multi-Attribute Decision Making; MODM, Multi-Objective Decision Making; BHBF, Binary Honey Bee Foraging; GA, Genetic Algorithm; PSO, Particle Swarm Optimization; SAA, Sample Average Approximation; LA, Lagrangian Relaxation; CA, Continuum Approximation; CS, Commercial Solver; EA, Exact Algorithm; HMA, Heuristic, Meta-heuristic and Approximation algorithms.

* Corresponding author.
E-mail addresses: moini@iust.ac.ir, moiniam@gmail.com (A. Moini).

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1. Introduction

The population growth, changes in the life style, and the rise in the man's living standards have all led to an increase in the energy consumption in the world, specifically, in the industrial countries. Bioenergy production systems, as a part of the solution to this problem, have attracted much attention in recent years because they can be appropriate substitutes for the traditional energy production systems which are, in addition to being finite and nonrenewable, associated with environmental problems (Sathre, 2014) as well. According to the European Union, biomass is defined as the biodegradable elements of the products, urban and industrial waste, agricultural residues, forests and the related industries which are used as the feedstock for producing biofuels and generating heat and power in the bioenergy production systems.

The biomass feedstock, biofuels, and the related production processes can be classified into three generations. To produce the first generation biofuel, use is made of sugars and vegetable oils which are capable of being turned into biofuel through ordinary technologies. Most of the feedstock used in this process can be used as food too (Banerjee et al., 2010) and endanger the safety of the food supply. Therefore, the trend has changed to using non-food feedstock. On the other hand, the use of the latter is associated with many challenges, from biomass cultivation to biofuel production technology (Rentizelas et al., 2009b). The second generation biofuels are produced from such non-food feedstock as lignocellulosic biomass, woody crops, and agricultural residues or waste which make the fuel production process more difficult. The third generation biofuel, recently joined the main classification, is the one produced from algae. The main obstacle to the commercialization of the second and third generation biofuels is their difficult and complicated production processes. The biofuel production necessitates the flow of the biomass feedstock from the supply sites to the demand centers. Along this route, the biomass passes through some facilities and undergoes various processes called the biomass supply chain. Each part of the supply chain needs specific knowledge, technology and activities including growing, harvesting, transporting, integrating, storing, converting, distributing, and consuming. In addition, depending on the type of biomass, final product, and the conversion technology, it may be necessary to add some pretreatment, intermediate, and blending sites in the supply chain.

The optimal design is an important factor in the enhancement of the economic, environmental, and social performance and efficiency of the BSC. In recent years, the growing interest towards using renewable energy resources has increased the decisions made on the design of BSC (Balaman and Selim, 2014), but no efforts have been made to systematically review, analyze and classify related papers and specify the potential research opportunities and the future directions. Effort has been made in this paper to show the gap in the present literature through a review of 146 papers published from Jan. 1997 to Jul. 2016. It has been so organized as to discuss two previous review papers on the BSCND in Section 2, explain the research methodology in Section 3, classify, analyze, and present the future research opportunities in Section 4 and, finally, conclude and propose the future directions in Section 5.

2. Research motivation

In this section, some review papers have been evaluated in order to show their shortcomings and specify the importance of the present review. So far, no review has been done that specifically studies the BSCND problem; however, the works by (Sharma et al., 2013a) and (De Meyer et al., 2014) are among the reviews which have considered BSCND models. The former work covers the papers of up to 2011, and the latter one those of up to 2012. Sharma et al. (2013a) studied 32 papers out of which 30 were about BSCND. In their work, they firstly describe energy trends, renewable energy targets, biomass feedstock needed for biofuel production, and the conversion process in the BSC. Then, they present a comprehensive review of some selected papers in order to analyze the mathematical programming models developed for the BSC and identify the future works and challenges. They consider different strategic decisions related to each facility (including location and capacity) in an integrated form, but do not study the approaches and factors related to uncertainty, dynamism and solution methods. De Meyer et al. (2014) reviewed 71 papers selected in the area of biomass-for-bioenergy supply chains in which 68 are related to BSCND problem. The focus of this review is mainly on the optimization methods used in the design and management of BSCs. They firstly give a general definition of the BSC and the decisions made in its design and management. Then, a classification of the selected papers is done based on: (1) mathematical optimization approaches, (2) decision level and decision variables, and (3) objective functions. Similar to the review done by Sharma et al. (2013a), the factors related to uncertainties and dynamism as well as solution methods used to solve the models are neglected in (De Meyer et al., 2014). Moreover, the biomass feedstock, the final product, and entities in the supply chain are not considered in this review.

According to the huge number of papers published in the area of BSC and the lack of systemic review in this context, this research aims to provide a comprehensive structured review on BSCND problem. This review provides a complete but systemic analysis on 146 papers published in the area of BSCND from 1997 to 2016. Some important factors neglected in the previous reviews such as uncertainty of parameters, dynamism and solution methods are considered in this research in order to provide an appropriate and comprehensive view for the readers.

3. Research methodology

The research methodology used in this paper is inspired by the methodology proposed by (Mayring, 2011) and includes four main