Journal of Industrial and Systems Engineering
Vol. 15, No. 2, pp. 94-108
Spring (April) 2023

An overview of the second-generation biomass supply chain based on non-edible Jatropha and Paulownia plants and providing directions for future studies

Seyed Alireza Hosseinitabar[1], Ehsan Torshizi[1], Fatemeh Sabouhi[1*], Ali Bozorgi-Amiri[1]

[1]*School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran*

s.a.hoseinitabar@ut.ac.ir, ehsantorshizi@ut.ac.ir, fatemehsabouhi@ut.ac.ir, alibozorgi@ut.ac.ir

Abstract

Environmental pollution, the depletion of fossil fuels, the swelling population, and the subsequent surge in energy consumption worldwide have prompted numerous industrialists, scientists, and researchers to embrace biomass products as an alternative to fossil fuels. Biomass-based products, such as biofuels, have emerged as viable sources of energy in light of economic and ecological considerations. Among the various generations of biomass, the second generation stands out for its particularly favorable attributes. In particular, Jatropha and Paulownia have garnered significant attention as extremely useful second-generation biomass plants, specifically for biofuel production. This study undertakes a comprehensive literature review and classification of the Jatropha and Paulownia supply chain network design, shedding light on their significance and potential. Furthermore, various scientific analyses are conducted to examine the works published in this field. These articles are classified based on the principles of sustainability, product type, biomass type, limitations, type of uncertainty, and solution approach, among others. Additionally, the studies in this field are reviewed, a number of research gaps are outlined, and areas are suggested for future research based on the findings of this study.

Keywords: Biomass supply chain, second generation biomass, Jatropha, Paulownia

1- Introduction

Energy is an essential prerequisite for social and economic progress, and there has been a correspondingly significant increase in energy consumption across the world, particularly in developing countries (Sheikhalishahi et al., 2022). Industries worldwide have undergone significant growth, leading to increased reliance on natural resources for energy production (Ellabban et al., 2014). However, this has also resulted in environmental pollution, fossil fuel depletion, and climate change, posing serious challenges to sustainable energy production. Fossil fuel reserves are limited, and excessive extraction threatens their depletion in the near future. Moreover, the use of fossil fuels has an adverse impact on sustainable development, contributing to air pollution and climate change, particularly in major cities (Jafarnejad et al., 2020). To address these concerns and mitigate the risks associated with excessive fossil fuel consumption, renewable energy sources like biofuels offer a promising alternative (Gafti et al., 2023). It has been projected that by 2040, the consumption of fossil fuels and renewable energy sources will be equal. Current projections further indicate that by 2070, approximately 60% of the world's total energy demand will be met through renewable energies (Osman et al., 2023).

*Corresponding author
ISSN: 1735-8272,

Biofuels, being carbon-free and renewable, have garnered considerable attention in recent years (Ghelichi et al., 2018). Several developed countries have initiated biofuel development programs, aiming to replace around half of their fossil fuel consumption with biofuels. Derived from photosynthesis where solar energy, water, and carbon dioxide are converted into organic materials, biomass serves as the primary source for biofuel production (Farrokhi-Asl et al., 2020). Biomass encompasses renewable organic materials sourced from plants or animals and offers the added benefit of absorbing carbon dioxide, thereby reducing atmospheric pollutant emissions (Rafie and Sahebi, 2022). While the term biomass is used interchangeably with biofuel, it is important to note that biomass refers to plant material, such as wood logs, that can be directly used as fuel. Biofuel, on the other hand, refers to liquid or gaseous fuels that are derived from biomass and utilized for transportation (Taghizadeh-Alisaraei et al., 2017). Biomass, as a source with minimal pollution, holds great potential for global fuel and energy production. As one of the most abundant renewable energy sources, biofuel carries few negative environmental consequences (Bayatloo et al., 2017). It not only has the capacity to meet the increasing demand for electricity and liquid fuel but also contributes to agricultural development, rural growth, and overall economic progress. The transportation sector has witnessed a significant surge in demand for biofuels, driven by the energy crisis and environmental concerns (Mohtashami et al., 2021). Biomass is recognized as the fourth major source of energy, accounting for approximately 14% of the world's energy requirements. In developing countries, this share can reach up to 40% (Antar et al., 2021). Biofuels can be derived from various types of biomass, which are categorized into four generations. The first generation involves the production of vegetable oils and sugars from food crops like wheat, soy, and corn. The second generation utilizes biomass from forest residues, agricultural waste, and non-edible plants like Miscanthus, Paulownia, and Jatropha. The third generation focuses on algae, capable of producing crude oil as a substitute for diesel. Lastly, the fourth generation involves the use of genetically engineered microalgae and microbes for biomass production (Razm et al., 2019, Pishvaee et al., 2020).

Second-generation biomass overcomes many of the shortcomings associated with the first generation, while providing advantages such as reduced competition with the food industry, comparatively lower cultivation costs, widespread availability, and little environmental pollution (Abdullah et al., 2019). Notable examples of second-generation biomass include Jatropha and Paulownia. A plant known for its resilience to hot and dry climates, Jatropha requires irrigation only during its initial three years and has a lifespan of approximately 50 years. Cultivating Jatropha also contributes to greenhouse gas reduction (Singh et al., 2021). While the plant's seeds are poisonous, their seed cores have a rich oil content, which can be extracted through various chemical procedures for use as biofuel in various industries. Additionally, the waste generated by Jatropha can be utilized in the production of agricultural pesticides (Uddin II et al., 2017). Paulownia, a native plant of China, has gained attention due to its rapid growth and valuable wood, leading to extensive cultivation worldwide (Ellabban et al., 2014). It serves as an excellent choice for renewable energy production, possessing advantages such as weather resistance, suitability for paper production, fast growth, and application in pharmaceutical industries. Paulownia wood is used in biofuel and composite production, while its pulp finds use as cattle feed (Abbasi et al., 2020, del Río et al., 2020).

Second-generation biomass is a suitable renewable fuel for providing energy based on sustainable development goals. However, the stages of planting and pre-processing of biomass to the production and distribution of biological products will have economic, environmental, and social consequences; For this reason, the design of the second-generation biomass supply chain considering sustainability considerations is of particular importance (Hong et al., 2016).

Owing to its alignment with sustainable development goals, second-generation biomass represents a suitable renewable fuel source. However, the various stages involved, from biomass planting and pre-processing to the production and distribution of bio-products, have economic, environmental, and social consequences. Consequently, it is crucial to design second-generation biomass supply chains that incorporate the principles of sustainability (Hong et al., 2016).

The biomass supply chain encompasses multiple distinct processes, including the harvest, collection, storage, preprocessing, and transportation of biomass (Mahjoub and Sahebi, 2020). Studies have identified various facilities in biomass supply chains; however, the key facilities and institutions remain biomass supply sites, collection centers, preprocessing facilities, biorefineries, distribution centers, and demand points (Rasekh et al., 2023). Since biomass is typically obtained from fields and forests, ground transportation remains the primary method for material collection and inter-facility transportation (Sharma et al., 2013).

This article aims to examine and review studies conducted on second-generation biomass supply chains, with a particular focus on Jatropha and Paulownia.

2- Scientometrics

Based on prevailing definitions in the field of scientometrics, scientometrics can be understood as the systematic measurement and analysis of scientific literature. Its purpose is to inform planning, policy-making, awareness, and foresight in various dimensions, including individual, group, organizational, and international contexts. The pioneers and experts of scientometrics have established its scope, emphasizing its role in serving science policy, which forms the core philosophy underlying its existence. Scientometrics stands as one of the most widely employed approaches for evaluating scientific activities and managing research. It indirectly assesses scientific communication and the methods involved in the production, dissemination, and utilization of scientific information by examining their sources. Prominent citation databases, such as Clarivate Analytics' Journal Citation Report (JCR), InCites, and Web of Science, offer valuable platforms for scientifically comparing authors, institutions, journals, articles, and countries based on reliable citation profiles. Additionally, Elsevier Institute's citation databases, including SciVal, Scopus, and Google Scholar, are recognized as scientific tools that contribute to this endeavor.

2-1- Scientometric analysis

To initiate scientific research on the biofuel and biomass supply chains, the logical first step was to study relevant issues at both the domestic and global levels. By thoroughly examining reliable research sources, key topics were identified and research keywords were determined. The keywords were then used as the basis of searches on reputable platforms such as Google Scholar, Scopus, and Web of Science, without applying any historical filters and spanning all available years. The research process also incorporated the use of the Google search engine and Publish or Perish search software.

To gain a comprehensive understanding of the relationships between keywords, countries, and articles, the scientometric software Vos Viewer was executed. This application effectively identifies and illustrates the co-occurrence of keywords, providing valuable insights for the research. Figure 1 displays the number of articles published in the field of biomass, categorized by the year of publication. As depicted in figure 1, there has been a notable increase in the number of articles published on biomass supply chains in recent years. This surge can be attributed to the growing energy consumption, heightened focus on sustainable development, and the increasing preference for cleaner fuels that generate less pollution compared to fossil fuels.

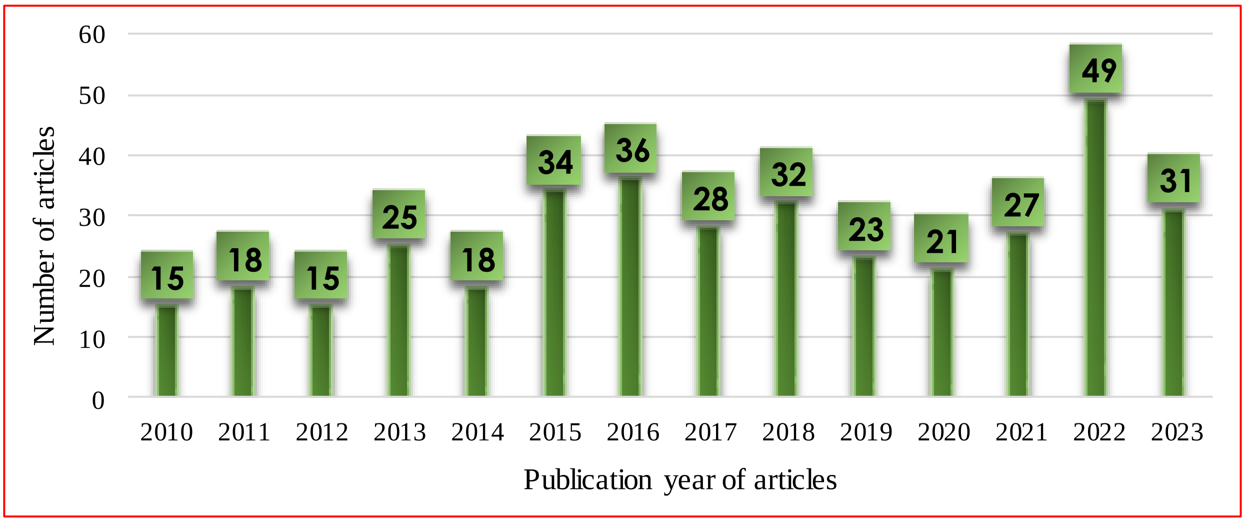

Fig 1. Number of articles published in the field of second-generation biomass supply chain keywords analysis

In figure 2, the interrelationship and co-occurrence of keywords are graphically illustrated. Each line connecting two keywords represents the simultaneous presence of these words in a significant number of references. The size of each node in figure 2 corresponds to the frequency of its occurrence in references, where larger nodes indicate that the keyword has been used in a greater number of references, while a higher number of connecting edges signifies its association with a larger set of keywords. It is evident in figure 2 that certain terms, such as optimization, biomass, management, design, model, and biomass supply chain, have been utilized extensively as keywords in numerous articles. The width of the connecting lines signifies the strength of the connection between each pair of keywords. Furthermore, the shorter the lines between two keywords, the greater their similarity. Table 1 provides an overview of several frequently-used keywords extracted from the collected references. These keywords reflect the prevalent themes and topics explored in the research. Based on the analysis of keywords in related articles, it can be concluded that key terms such as resilience, disruption, routing, and decision-making have not received sufficient attention in the body of research on second-generation biomass supply chain design.

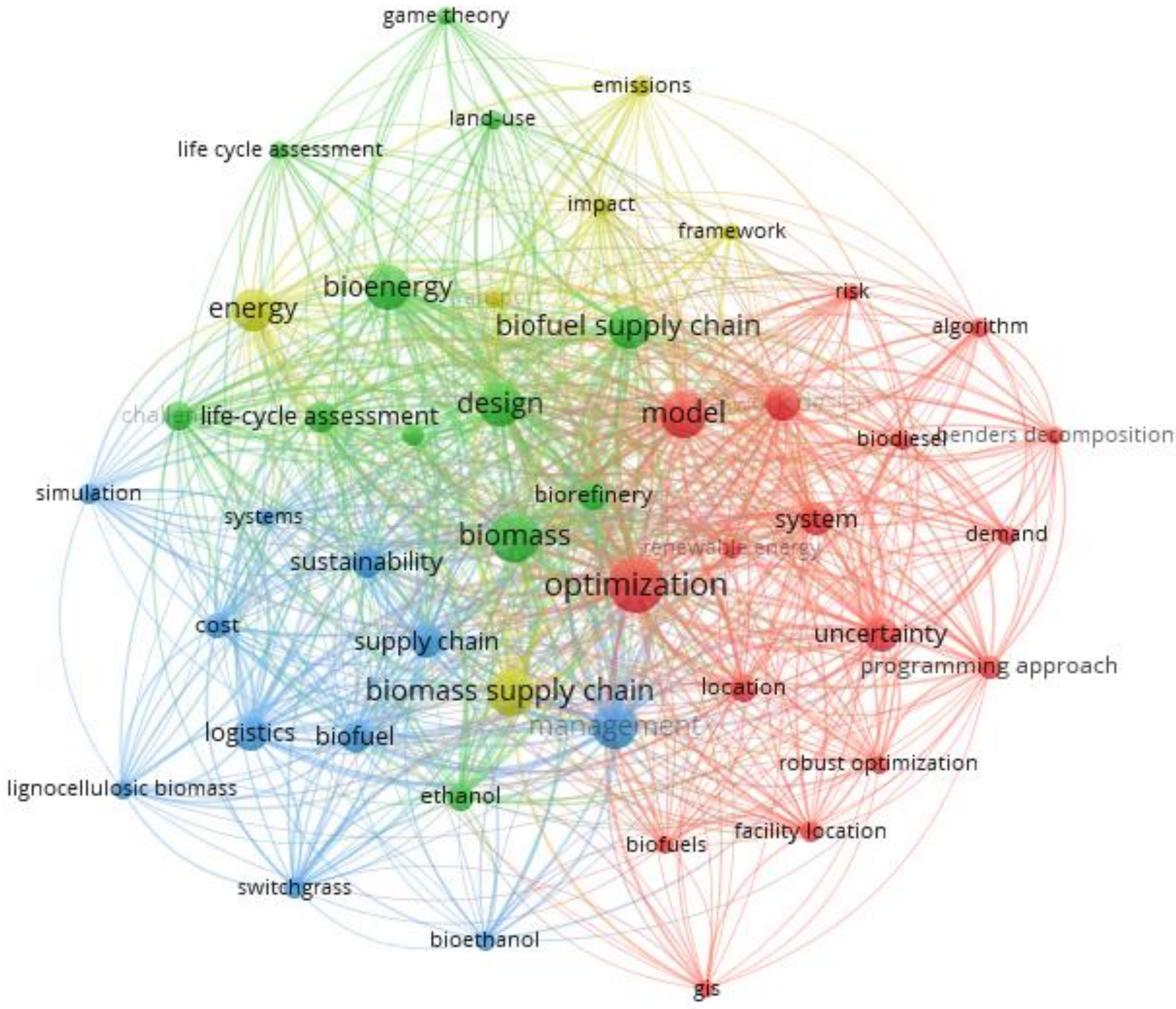

Fig 2. Co-occurrence of keywords in biomass supply chain design

Table 1. Frequent research keywords in biomass supply chain design

Keywords	Number of applications in research review
Optimization	72
Biomass	60
Model	51
Biofuel Supply Chain	51
Management	48
Design	48
Bioenergy	45
Biomass Supply Chain	44
Energy	41
Uncertainty	30
Network Design	28
Supply Chain	27

2-1-1- Analysis by country

Figure 3 illustrates the collaborative relationships among countries in the field of biomass supply chain design, encompassing author collaboration, publication collaboration, collaboration between scientific centers and organizations, and government-level collaboration. The size of each node in figure 3 corresponds to the level of activity and publication output by the respective countries in this field. Notably, the United States, Iran, China, Canada, and Malaysia emerged as the most prolific contributors, having published a significant number of articles about the design of biomass supply chains.

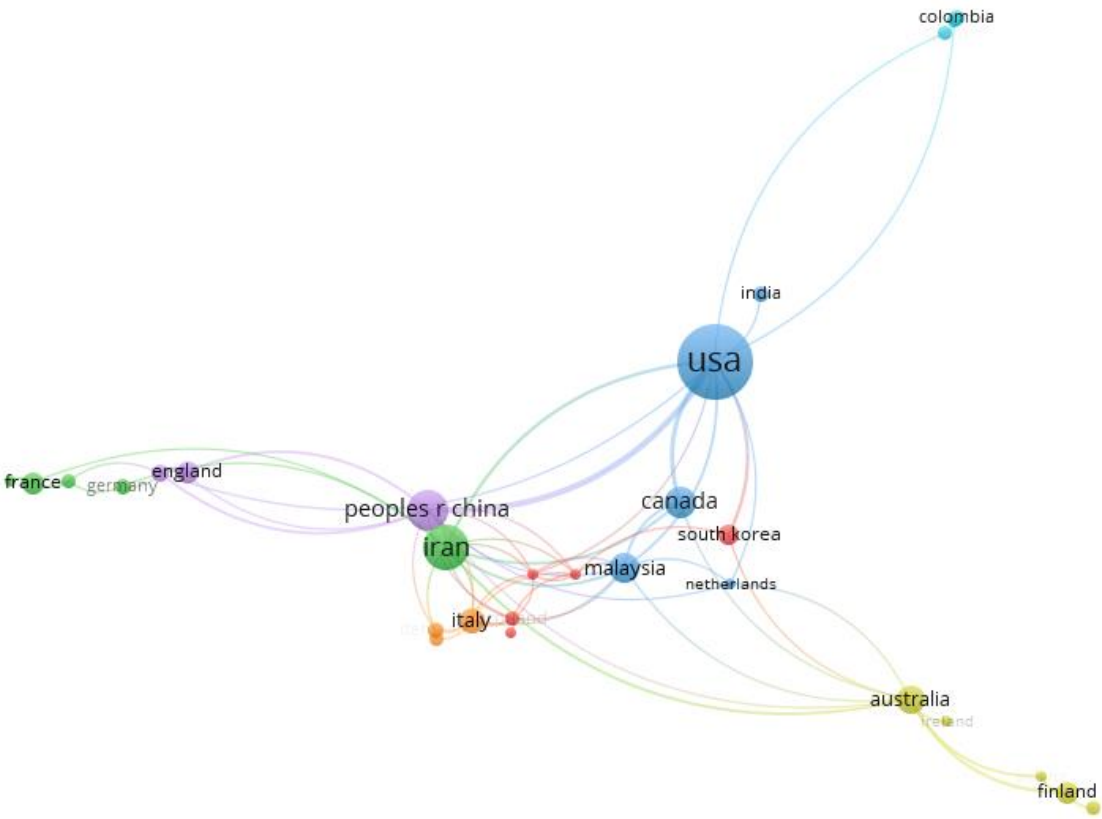

Fig 3. Collaborative relationships among countries for articles in field of biomass supply chain design

2-1-2- Analysis based on citing articles

Figure 4 presents an analysis based on article citations, where the size of each node indicates the number of citations received by the corresponding articles. The arcs between nodes represent the citation relationships between articles. Notably, the articles authored by You et al. (2012), Yue et al. (2014), and Kim et al. (2011) have garnered the highest number of citations in the field of biomass supply chain design.

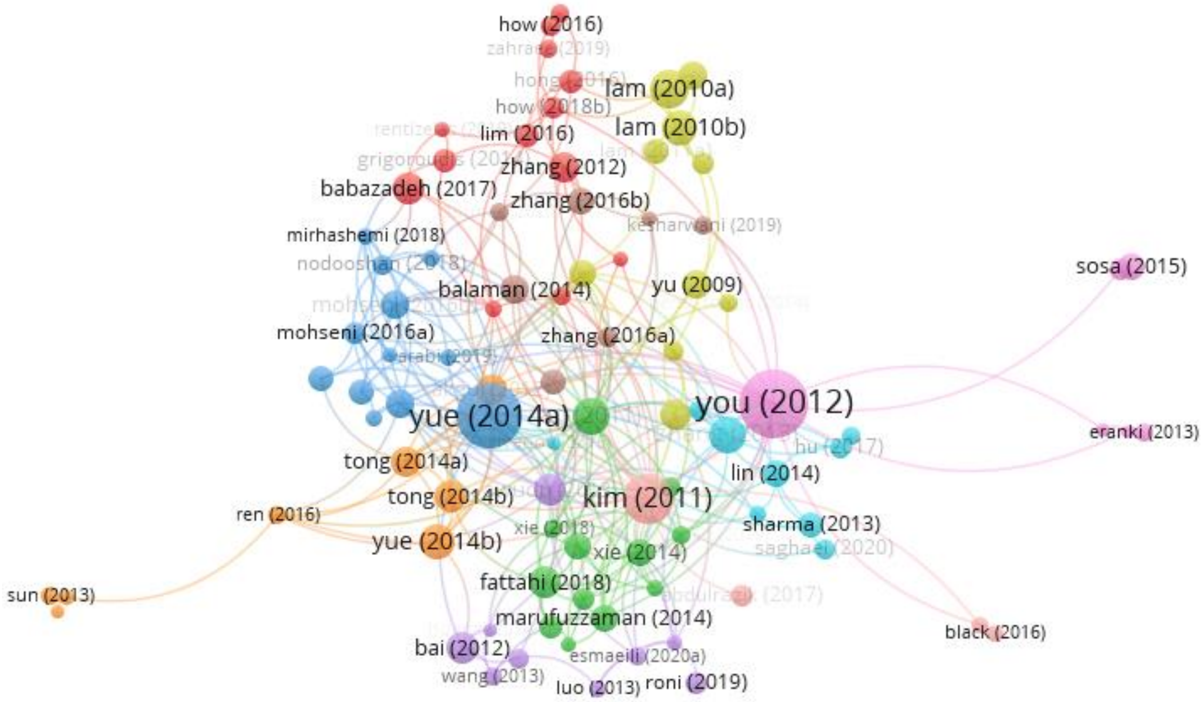

Fig 4. Citation relationship between articles published on biomass supply chain design literature review

3- Literature review

3-1- Design of second-generation biomass supply chain based on non-edible plants

In recent years, the field of biomass supply chain design has undergone substantial growth in the number of published articles. For instance, Esmaeili et al. (2023) proposed a two-stage supply chain modeling approach for the establishment of biorefineries in North Dakota state. The initial stage involved utilizing geographic information system (GIS) analysis to determine suitable locations for biorefinery placement. In the subsequent step, an optimization model was applied to maximize the profit of the bioethanol supply chain, focusing on switchgrass as the primary feedstock. Mahjoub et al. (2020) introduced a multi-objective mathematical programming model for a diverse biomass supply chain network. This model incorporated various sources of second-generation biomass, such as Jatropha, agricultural residues, and animal manure, as well as third-generation biomass, including microalgae, for energy production. Bambara et al. (2019) presented a mathematical programming model specifically designed for biomass supply chain design. The objective of this model was to minimize overall supply chain costs, incorporating the utilization of wild biomass as a feedstock.

Babazadeh and Shamsi (2019) combined two mathematical programming techniques, data envelopment analysis (DEA) and mixed-integer linear programming (MILP). They utilized DEA to optimize the cultivation locations of raw materials for biofuel production, and MILP to optimize the different levels of the supply chain. The researchers also conducted a case study in Iran, utilizing real-world data to evaluate the performance of their mathematical programming models. Andersen et al., 2012) proposed a multi-period, single-objective, single-product MILP model for the design and optimization of the biodiesel supply chain in Argentina. In this model, the authors used various biomass sources, including Jatropha seeds, sunflower seeds, and soybeans, to produce biodiesel. The primary objective of this model was to maximize the Net Present Value of the biodiesel supply chain. Cao et al. (2021) integrated the facility location and vehicle routing problems for the biomass supply chain. They proposed a mixed-integer programming model that could achieve optimal decisions for small-scale instances. Given the computational complexity of the problem, the authors developed a hierarchical Tabu search-based heuristic algorithm to solve the problem.

3-2- Design of second-generation biomass supply chain based on non-edible plants under uncertainty

Uncertainties form an inseparable part of the real world, and biomass supply chain problems are no exception to this rule as they often involve inherent uncertainties (Nasiri Kashani et al., 2023). Uncertain parameters can pose significant challenges for decision-makers in a biomass supply chain problem. Therefore, researchers have often examined the impact of uncertainty in their research. For instance, Zarei et al. (2021) created a MILP model under uncertainty to simultaneously incorporate three types of biomass feedstocks for designing second and third-generation biomass supply chains. Their objective was to minimize annual costs by selecting raw materials, locating production and storage facilities, identifying optimal material flows, and defining a specific route for each raw material. Nur et al. (2021) developed a stochastic programming model that used vehicle routing to minimize supply chain costs. Their model incorporated switchgrass and corn waste as the chain's biomass sources and utilized a hybrid decomposition algorithm for optimization. Sarker et al. (2019) proposed a mixed-integer mathematical model to locate hubs and power plants in the renewable energy supply chain, aiming to minimize overall operational costs. They employed a genetic algorithm to obtain optimal solutions, considered environmental and economic criteria, and also performed several numerical experiments to validate the performance of the model.

Ghelichi et al. (2018) presented a stochastic programming model for biodiesel production from Jatropha. Their eco-friendly multi-period MILP model considered the entire supply chain. Babazadeh et al. (2019) introduced a feasibility planning model for second-generation biodiesel supply chain design, emphasizing glycerin and biodiesel production from Jatropha plants and waste cooking oil. Their solution approach utilized Benders' decomposition algorithm. Babazadeh et al. (2017) proposed a two-stage approach to design a biodiesel supply chain using DEA and mathematical programming techniques in Iran. The proposed approach involved evaluating various biomass cultivation areas based on climatic and social criteria using an integrated data coverage analysis model. The areas that would receive favorable efficiency scores were identified as potential candidate areas for biomass cultivation in the biodiesel supply chain. The objective of the proposed model, in which Jatropha and waste cooking oil were utilized as biomass sources, was to minimize the overall cost of the supply chain. Lastly, Maheshwari et al. (2017) developed a stochastic programming model for biomass supply chain design focusing on second-generation biomass. They accounted for risks such as drought, pest attacks, and equipment damage.

3-3- Design of sustainable second-generation biomass supply chain based on non-edible plants

In recent years, governments have implemented stringent environmental regulations, and environmental non-governmental organizations (ENGOs) have gained enormous influence in safeguarding the environment and restoring natural resources. From another perspective, addressing social and human challenges while pursuing economic objectives has heightened the significance of sustainability dimensions (Moini et al., 2023). Studies on second-generation biomass supply chains, which primarily focus on non-edible plants, have tackled these issues. For instance, Huang et al. (2019) presented a multi-objective supply chain for jet fuel production utilizing corn waste as the feedstock. Their study incorporated environmental considerations, specifically greenhouse gas emissions, and employed geographic information systems (GIS) to determine optimal facility locations. Petridis et al. (2018) devised an integrated mathematical framework for biomass production, storage, and transportation, aiming to design an efficient supply chain. They developed a weighted MILP model that optimized environmental, economic, and social criteria.

Furthermore, Pérez-Fortes et al. (2014) explored the utilization of biomass waste in coal combustion power plants to mitigate adverse environmental impacts. They conducted an analysis of biomass storage, changes in properties, and transport while considering various pretreatment methods. The authors formulated an optimization problem as a mixed-integer linear program, assessing the net present value and environmental impact through life cycle assessment. They also reviewed the results of their optimization and pretreatment technology selection for different scenarios, considering biomass distribution and availability in a case study based in Spain. You and Wang (2011) designed a biomass-to-liquid supply chain with a focus on economic and environmental criteria. The researchers aimed to minimize the total annual cost and greenhouse gas emissions. They proposed a multi-objective and multi-period linear programming model that incorporated geographical diversity, infrastructure, demand fulfillment, technology application, and government assistance. This model determined key decisions on facility location, technology type, investment scope, production rate, inventory level, and logistics.

3-4- Design of the sustainable second-generation biomass supply chain based on non-edible plants under uncertainty

In realm of sustainable biomass supply chains, several articles have addressed the challenge of uncertainty. For instance, Rasekh et al. (2023) presented a multi-period and multi-objective model for designing a sustainable supply chain network for second and third-generation biomass. Their objectives included maximizing total energy production and job creation while minimizing water consumption, carbon emissions, and overall costs. The case study demonstrated the model's performance using the MINMAX planning approach. On a similar note, Afkhami and Zarrinpoor (2021) developed a multi-purpose and multi-product global biodiesel supply chain that incorporated sustainability dimensions. Their proposed model aimed to maximize social benefits and profitability while minimizing adverse environmental impacts. Mohtashami et al. (2021) designed a multi-objective biodiesel supply chain based on Jatropha as its feedstock. The study initially employed DEA to identify suitable sites for biomass cultivation, followed by strategic and tactical decision-making through a mathematical model. The primary focus of the model was to maximize social benefits and income while reducing adverse environmental impacts. In another study, Mahjoub and Sahebi (2020) introduced a multi-objective sustainable optimization model to develop a bioenergy supply chain by integrating second and third-generation biomass. The objectives of this model were to minimize adverse environmental impacts, costs, and water consumption while maximizing energy production. A GIS was used to identify suitable locations for biomass cultivation.

Additionally, Ghaderi et al. (2018) proposed a multi-objective, multi-period robust possibilistic programming model for designing a biomass supply chain based on switchgrass. The model considered economic, social, and environmental sustainability under uncertainty. The objectives included minimizing total supply chain cost and environmental impacts and maximizing social benefits. The validity of the model was verified through a case study conducted in Iran. Lastly, Bairamzadeh et al. (2016) presented a multi-objective MILP model for designing and optimizing the lignocellulosic biomass supply chain, considering uncertainty and economic, environmental, and social sustainability. The model aimed to maximize total supply chain profit and social benefits, while minimizing adverse environmental impacts. The proposed model incorporated strategic decisions on biomass sourcing, location, allocation, and capacity levels, in addition to tactical decisions on inventory levels, production rates, and shipping quantities. The performance of the model was assessed through a case study conducted in Iran.

Tables 2 and 3 provide an overview of the characteristics of studies on second-generation biomass supply chain design.

Table 2. Second-generation biomass supply chain studies based on decision criteria and constraints

Authors	Decision criteria			Network decisions				Constraints					Uncertainty dealing method			Solution approach	
	Economic	Environmental	Social	Location	Production	Holding	Shortage	Production capacity	Vehicle capacity	Storage capacity	Number of facilities	Number of vehicles	Fuzzy	Robust	Stochastic	Exact	Heuristic
Rasekh et al. (2023)	✓	✓	✓	✓	✓	✓		✓		✓						CPLEX	
Esmaeili et al. (2023)	✓			✓	✓			✓								CPLEX	
Cao et al. (2021)	✓			✓	✓			✓	✓			✓					Hybrid tabu search algorithm
Afkhami and Zarrinpoor (2021)	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓				CPLEX	
Nur et al. (2021)	✓			✓	✓	✓	✓	✓	✓	✓					✓		Combining SAA with an enhanced PHA algorithm
Mohtashami 1)	✓	✓	✓	✓	✓	✓		✓		✓						CPLEX	
Zarei et al. (2021)	✓			✓	✓	✓		✓	✓	✓		✓			✓	CPLEX	
Mahjoub et al. (2020)	✓			✓	✓	✓		✓		✓						CPLEX	
Mahjoub and Sahebi (2020)	✓	✓		✓	✓	✓		✓	✓	✓						CPLEX	
Sarker et al. (2019)	✓			✓	✓	✓							✓				Genetic algorithm
Babazadeh and Shamsi (2019)	✓			✓	✓	✓		✓		✓						CPLEX	
Huang et al. (2019)	✓	✓		✓	✓	✓		✓		✓						CPLEX	
Ghelichi et al. (2018)	✓			✓	✓	✓		✓	✓	✓		✓			✓	CPLEX	
Petridis et al. (2018)	✓	✓	✓		✓	✓	✓			✓					✓	CPLEX	
Ghaderi et al. (2018)	✓	✓	✓	✓	✓	✓		✓		✓			✓	✓		TH method	
Babazadeh et al. (2017)	✓			✓	✓			✓			✓		✓			CPLEX	
Bairamzadeh et al. (2016)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓		CPLEX	
Pérez-Fortes et al. (2014)	✓	✓			✓	✓		✓								CPLEX	
Andersen et al. (2012)	✓			✓	✓	✓		✓		✓						CPLEX	
You and Wang (2011)	✓	✓		✓	✓	✓		✓	✓	✓					✓	CPLEX	

PHA:Progressive Hedging Algorithm, SAA: Sample Average Approximation, TH: Torabi and Hassini

Table 3. Second-generation biomass supply chain studies based on network facilities, products, and raw materials

Authors	Network centers	Product	Biomass
Rasekh et al. (2023)	Jatropha farm, Jatropha supplier, Oil extraction center, Biorefinery, Distribution center, Biodiesel demand center, Glycerin demand center	Biodiesel, Glycerin	Jatropha, Oil waste
Esmaeili et al. (2023)	Switchgrass supplier, Biorefinery, Bioethanol demand center	Bioethanol	Switchgrass
Cao et al. (2021)	Farm, Collection center, Biorefinery	Biodiesel, Bioethanol Biogas, Methane, C-Ethanol	Oil plants, Corn, Sugar beet, Animal waste, lignocellulosic
Afkhami and Zarrinpoor (2021)	Jatropha farm, Jatropha supplier, Oil extraction center, Biorefinery, Distribution center, Biodiesel demand center, Glycerin demand center, Fertilizer demand center	Biodiesel, Glycerin	Jatropha
Nur et al. (2021)	Switchgrass farm, Corn farm, Warehouse, Biorefinery	Biodiesel	Switchgrass, Corn stover
Mohtashami et al. (2021)	Jatropha farm, Oil extraction center, Biorefinery, Distribution center, Biodiesel demand center, Electricity demand center, Fertilizer demand center	Biodiesel, Electricity	Jatropha
Zarei et al. (2021)	Farm, Warehouse, Biorefinery, Distribution center, Biofuel demand center	Biofuel	Wood residue, Microalgae
Mahjoub et al. (2020)	Jatropha farm, Microalgae production center, Warehouse, Biorefinery, Distribution center, Biodiesel demand center, Electricity demand center, Fertilizer demand center	Biodiesel, Electricity	Jatropha, Microalgae, Livestock waste
Mahjoub and Sahebi (2020)	Jatropha farm, Microalgae production center, Warehouse, Biorefinery, Distribution center, Biodiesel demand center, Electricity demand center, Fertilizer demand center	Biodiesel, Electricity	Jatropha, Microalgae, Livestock waste
Sarker et al. (2019)	Farm, Preprocessing center, Biorefinery, Distribution center	Biogas	Crops, Grass, Wood residue, and Livestock waste
Babazadeh and Shamsi (2019)	Supplier, Biorefinery, Distribution center	Biodiesel, Electricity	Jatropha, Agricultural waste, Animal waste, Microalgae
Huang et al. (2019)	Corn farm, Corn stalk production center, Biorefinery, Airport	Jet fuel	Corn stover
Ghelichi et al. (2018)	Jatropha farm, Jatropha supplier, Oil waste center, Oil extraction center, Biorefinery, Biodiesel demand center, Glycerin demand center	Biodiesel, Glycerin	Jatropha, Oil waste
Petridis et al. (2018)	Jatropha farm, Jatropha supplier, Collection center, Oil extraction center, Biorefinery, Distribution center, Biodiesel demand center, Glycerin demand center, Fertilizer demand center	Biodiesel, Glycerin	Jatropha
Ghaderi et al. (2018)	Farm, Collection center, Biorefinery	Biofuel	Forest waste
Babazadeh et al. (2017)	Switchgrass supply center, Preprocessing center, Biorefinery, Distribution center, Bioethanol demand center	Bioethanol	Switchgrass
Bairamzadeh et al. (2016)	Biomass supply zone, Biorefinery, Bioethanol demand zone	Bioethanol	lignocellulosic
Pérez-Fortes et al. (2014)	Farm, Collection center, Preprocessing center, Biorefinery, Distribution center, Electricity demand zones	Electricity	Agricultural waste
Andersen et al. (2012)	Biomass supply center, Storage center, Biorefinery	Biodiesel	Soybean, Sunflower, Jatropha
You and Wang (2011)	Farm, Preprocessing center, Biorefinery, Distribution center, Biodiesel demand center	Biodiesel	Forest waste and primary mills, Secondary mills, Urban wood waste

4- Research gap

Examining the studies in this field revealed several research gaps, some of which are described below:

- No extensive study has been conducted thus far to examine and classify studies on second-generation biomass supply chains based on non-edible plants.

- No comprehensive study has been published to classify the extensive, diverse research conducted thus far on the supply chains of Jatropha and Paulownia, which are considered the most important non-edible plants used as second-generation biomass.

- Many articles have utilized mathematical optimization models to design second-generation biomass supply chains; however, very few studies have integrated decision-making and optimization approaches.

- The idea to integrate data-driven, system dynamics, and simulation-based approaches with an optimization perspective has not received much scholarly attention in second-generation biomass supply chain design.

- While researchers have used various sources of second-generation biomass for biofuel production, few studies have explored the combination of different generations of biomass.

- Some studies have considered uncertainty in parameters such as biofuel demand in the design of the biomass supply chain. However, uncertainty in production parameters, facility capacity, and land productivity based on weather conditions has been neglected in the literature.

- In studies on the second-generation biomass supply chain, insufficient work has been done on by-products and the utilization of biomass residues in conversion processes for biofuel production.

- Few studies have been conducted on the biomass supply chain design involving the water-energy nexus, or similar integrated approaches such as the energy-land nexus and the food-energy nexus.

- The occurrence of partial and complete disruptions in biomass supply chain design, and developing suitable resilience strategies to cope with them, are issues that require further investigation.

- Strategic and tactical decisions have been examined in the design of the second-generation biomass supply chain to some extent; however, operational decisions such as routing and scheduling have not been given sufficient attention in this field.

- It has been shown that using biofuels not only has positive environmental impacts but also various social benefits. Therefore, it is arguably essential to place more emphasis on components of social sustainability, such as job creation and gender equality, in the field of second-generation supply chain design.

- A stark lack of attention to closed-loop supply chains and the utilization of waste and by-products is evident among the studies conducted on second-generation biomass supply chains.

- No scientometric analysis has been performed thus far to have encompassed various dimensions and fields, including keyword analysis, country-based analysis, case studies, and citation analysis.

5-Conclusion and future directions

The growing concern over environmental pollution and the need to reduce reliance on fossil fuels have prompted governments to prioritize the utilization of renewable energies. Biomass plays a significant role in the production of various renewable energies, with biofuels considered one of the most widely-adopted options in today's energy landscape. Biofuels are categorized based on the type of biomass employed in their production, among which second-generation biomass particularly stands out due to its favorable economic and environmental advantages. Notably, Paulownia, Miscanthus, and Jatropha, among other non-edible second-generation biomass plants, have gained prominence as widely-utilized options worldwide. Deriving biofuels from Jatropha and Paulownia necessitates that specific processes should be carried out in specialized facilities. Consequently, designing an efficient supply chain is a vital prerequisite for transporting biomass from cultivation fields to operational centers for processing, production of biofuel in biorefineries, and distributing the end-product to consumption centers. Against this backdrop, the present study article undertook a comprehensive review of the literature on biomass supply chain design, with a particular emphasis on supply chains involving Jatropha and Paulownia as biomass feedstocks.

This study aimed to provide a systematic review based on scientometrics and examine the studies conducted in the field of second-generation biomass supply chain design in which non-edible plants are used as feedstock. Additionally, conducting a comprehensive review of recent studies in this field, this study strives to identify and analyze the prominent research gaps in the literature. Based on this review, the following directions are proposed for future research in this field:

- Managers should strive to achieve the right balance between demand estimation and costs of energy supply chains. It is thus crucial to consider factors such as fluctuating demand and the challenges of supplying biomass plants due to weather and environmental conditions.
- A notable challenge in providing renewable energy for industries lies in determining the optimal location of supply chain facilities. Managers must meticulously assess sustainability criteria to evaluate different locations for constructing facilities, taking into account the environmental, economic, social, and legal implications of their decisions for humanity at large.
- The biomass supply chain is susceptible to disruptions such as natural disasters and pandemics. Hence, decision-makers and managers must evaluate the likelihood of these disruptions and devise suitable resilience strategies to mitigate their impact.
- Production and maintenance centers need to exhibit the necessary flexibility to accommodate occasional spikes in demand and have sufficient capacity to meet the required production or maintenance levels.
- Weather conditions, including temperature and rainfall, are inherently unpredictable. Thus, cultivating biomass plants necessitates a comprehensive consideration of all relevant conditions.
- Given the significant turnover and production volume of this type of supply chain, an accurate assessment of income and cost trends is imperative when considering the financial parameters involved.
- Expanding the target market offers the potential to globalize the supply chain. By exporting final products like biofuel, glycerin, bioplastic, biohydrogen, and bioactive substances, the supply chain can effectively achieve globalization.
- A significant challenge facing the biomass supply chain is the management of waste generated by refineries and other production centers. Establishing a well-structured network to dispose of the resulting waste materials is crucial to prevent environmental harm. Consequently, the design of a reverse network within the supply chain appears necessary.

References

Abbasi, M., Pishvaee, M. S. & Bairamzadeh, S. (2020). Land suitability assessment for Paulownia cultivation using combined GIS and Z-number DEA: A case study. Computers and Electronics in Agriculture, 176, 105666.

Abdullah, B., Syed Muhammad, S. a. F. A., Shokravi, Z., Ismail, S., Kassim, K. A., Mahmood, A. N. & Aziz, M. M. A. (2019). Fourth generation biofuel: A review on risks and mitigation strategies. Renewable and Sustainable Energy Reviews, 107, 37-50.

Afkhami, P. & Zarrinpoor, N. (2021). Optimization Design of a Supply Chain for Jatropha-Based Biofuel from a Sustainable Development Perspective Considering International Resources and Demand: A Case Study. Industrial & Engineering Chemistry Research, 60, 6188-6207.

Andersen, F., Iturmendi, F., Espinosa, S. & Diaz, M. S. (2012). Optimal design and planning of biodiesel supply chain with land competition. Computers & Chemical Engineering, 47, 170-182.

Antar, M., Lyu, D., Nazari, M., Shah, A., Zhou, X. & Smith, D. L. (2021). Biomass for a sustainable bioeconomy: An overview of world biomass production and utilization. Renewable and Sustainable Energy Reviews, 139, 110691.

Babazadeh, R., Ghaderi, H. & Pishvaee, M. S. (2019). A benders-local branching algorithm for second-generation biodiesel supply chain network design under epistemic uncertainty. Computers & Chemical Engineering, 124, 364-380.

Babazadeh, R., Razmi, J., Rabbani, M. & Pishvaee, M. S. (2017). An integrated data envelopment analysis–mathematical programming approach to strategic biodiesel supply chain network design problem. Journal of Cleaner Production, 147, 694-707.

Babazadeh, R. & Shamsi, M. (2019). Biofuel supply chain optimization: mathematical programming approaches. Advanced Biofuels. Elsevier.

Bairamzadeh, S., Pishvaee, M. S. & Saidi-Mehrabad, M. (2016). Multiobjective Robust Possibilistic Programming Approach to Sustainable Bioethanol Supply Chain Design under Multiple Uncertainties. Industrial & Engineering Chemistry Research, 55, 237-256.

Bambara, L. D. F., Sawadogo, M., Roy, D., Blin, J., Anciaux, D. & Ouiminga, S. K. (2019). Wild and cultivated biomass supply chain for biofuel production. A comparative study in West Africa. Energy for Sustainable Development, 53, 1-14.

Bayatloo, F., Bozorgi-Amiri, A. & Sabouhi, F. (2017). Optimal energy distribution and storage in a wind-based renewable electricity supply chain. Journal of Industrial and Systems Engineering, 10, 110-122.

Cao, J. X., Zhang, Z. & Zhou, Y. (2021). A location-routing problem for biomass supply chains. Computers & Industrial Engineering, 152, 107017.

Del Río, P. G., Domínguez, V. D., Domínguez, E., Gullón, P., Gullón, B., Garrote, G. & Romaní, A. (2020). Comparative study of biorefinery processes for the valorization of fast-growing Paulownia wood. Bioresource Technology, 314, 123722.

Ellabban, O., Abu-Rub, H. & Blaabjerg, F. (2014). Renewable energy resources: Current status, future prospects and their enabling technology. Renewable and Sustainable Energy Reviews, 39, 748-764.

Esmaeili, S. a. H., Sobhani, A., Ebrahimi, S., Szmerekovsky, J., Dybing, A. & Keramati, A. (2023). Location Allocation of Biorefineries for a Switchgrass-Based Bioethanol Supply Chain Using Energy Consumption and Emissions. Logistics, 7, 5.

Farrokhi-Asl, H., Makui, A., Jabbarzadeh, A. & Barzinpour, F. (2020). Solving a multi-objective sustainable waste collection problem considering a new collection network. Operational Research, 20, 1977-2015.

Gafti, M., Sabouhi, F., Bozorgi-Amiri, A. & Jamili, A. (2023). A multi-period location-routing model for waste-to-energy supply chain: A case study. Applied Energy, 337, 120802.

Ghaderi, H., Moini, A. & Pishvaee, M. S. (2018). A multi-objective robust possibilistic programming approach to sustainable switchgrass-based bioethanol supply chain network design. Journal of Cleaner Production, 179, 368-406.

Ghelichi, Z., Saidi-Mehrabad, M. & Pishvaee, M. S. (2018). A stochastic programming approach toward optimal design and planning of an integrated green biodiesel supply chain network under uncertainty: A case study. Energy, 156, 661-687.

Hong, B. H., How, B. S. & Lam, H. L. (2016). Overview of sustainable biomass supply chain: from concept to modelling. Clean Technologies and Environmental Policy, 18, 2173-2194.

Huang, E., Zhang, X., Rodriguez, L., Khanna, M., De Jong, S., Ting, K. C., Ying, Y. & Lin, T. (2019). Multi-objective optimization for sustainable renewable jet fuel production: A case study of corn stover based supply chain system in Midwestern U.S. Renewable and Sustainable Energy Reviews, 115, 109403.

Jafarnejad, E., Makui, A., Hafezalkotob, A. & Mohammaditabar, D. (2020). A Robust Approach for Cooperation and Coopetition of Bio-Refineries Under Government Interventions by Considering Sustainability Factors. IEEE Access, 8, 155873-155890.

Kim, J., Realff, M. J. & Lee, J. H. (2011). Optimal design and global sensitivity analysis of biomass supply chain networks for biofuels under uncertainty. Computers & Chemical Engineering, 35, 1738-1751.

Maheshwari, P., Singla, S. & Shastri, Y. (2017). Resiliency optimization of biomass to biofuel supply chain incorporating regional biomass pre-processing depots. Biomass and bioenergy, 97, 116-131.

Mahjoub, N. & Sahebi, H. (2020). The water- energy nexus at the hybrid bioenergy supply chain: A sustainable network design model. Ecological Indicators, 119, 106799.

Mahjoub, N., Sahebi, H., Mazdeh, M. & Teymouri, A. (2020). Optimal design of the second and third generation biofuel supply network by a multi-objective model. Journal of Cleaner Production, 256, 120355.

Mohtashami, Z., Bozorgi-Amiri, A. & Tavakkoli-Moghaddam, R. (2021). A two-stage multi-objective second generation biodiesel supply chain design considering social sustainability: A case study. Energy, 233, 121020.

Moini, G., Teimoury, E., Seyedhosseini, S. M., Radfar, R. & Alborzi, M. (2023). Analyzing the impact of sustainability on the network design and planning decisions in a spare part supply chain: an empirical investigation. Journal of Industrial and Systems Engineering, 15, 1-25.

Nasiri Kashani, K., Pishvaee, M. S., Seyedhosseini, S. M. & Rasouli, M. R. (2023). Optimization model for designing disruption-oriented network of laboratory services and managing procurement of health items under uncertainty: A real-world case study. Journal of Industrial and Systems Engineering, 15, 159-178.

Nur, F., Aboytes-Ojeda, M., Castillo-Villar, K. K. & Marufuzzaman, M. (2021). A two-stage stochastic programming model for biofuel supply chain network design with biomass quality implications. IISE Transactions, 53, 845-868.

Osman, A. I., Chen, L., Yang, M., Msigwa, G., Farghali, M., Fawzy, S., Rooney, D. W. & Yap, P.-S. (2023). Cost, environmental impact, and resilience of renewable energy under a changing climate: a review. Environmental Chemistry Letters, 21, 741-764.

Pérez-Fortes, M., Laínez-Aguirre, J. M., Bojarski, A. D. & Puigjaner, L. (2014). Optimization of pre-treatment selection for the use of woody waste in co-combustion plants. Chemical Engineering Research and Design, 92, 1539-1562.

Petridis, K., Grigoroudis, E. & Arabatzis, G. (2018). A goal programming model for a sustainable biomass supply chain network. International Journal of Energy Sector Management, 12, 79-102.

Pishvaee, M. S., Mohseni, S. & Bairamzadeh, S. (2020). Biomass to Biofuel Supply Chain Design and Planning Under Uncertainty: Concepts and Quantitative Methods.

Rafie, S. M. & Sahebi, H. (2022). Sustainable fuel supply network design by integrating gas oil and biodiesel supply chains under uncertainty. Journal of Industrial and Systems Engineering, 14, 238-262.

Rasekh, A., Hamidzadeh, F., Sahebi, H. & Pishvaee, M. S. (2023). A sustainable network design of a hybrid biomass supply chain by considering the water–energy–carbon nexus. Energy Science & Engineering, 11, 1107-1132.

Razm, S., Nickel, S., Saidi-Mehrabad, M. & Sahebi, H. (2019). A global bioenergy supply network redesign through integrating transfer pricing under uncertain condition. Journal of Cleaner Production, 208, 1081-1095.

Sarker, B. R., Wu, B. & Paudel, K. P. (2019). Modeling and optimization of a supply chain of renewable biomass and biogas: Processing plant location. Applied Energy, 239, 343-355.

Sharma, B., Ingalls, R. G., Jones, C. L. & Khanchi, A. (2013). Biomass supply chain design and analysis: Basis, overview, modeling, challenges, and future. Renewable and Sustainable Energy Reviews, 24, 608-627.

Sheikhalishahi, M., Hakimi, A. & Hakimi, M. (2022). An integrated fuzzy AHP- fuzzy DEA approach for location optimization of renewable energy plants. Journal of Industrial and Systems Engineering, 14, 11-18.

Singh, D., Sharma, D., Soni, S. L., Inda, C. S., Sharma, S., Sharma, P. K. & Jhalani, A. (2021). A comprehensive review of physicochemical properties, production process, performance and emissions characteristics of 2nd generation biodiesel feedstock: Jatropha curcas. Fuel, 285, 119110.

Taghizadeh-Alisaraei, A., Assar, H. A., Ghobadian, B. & Motevali, A. (2017). Potential of biofuel production from pistachio waste in Iran. Renewable and Sustainable Energy Reviews, 72, 510-522.

Uddin Ii, R., Azeez, K. & Lawal, A. (2017). Potentials of two bio-pesticides in the control of some field insect pests of bambara groundnut in Ilorin. Ethiopian Journal of Environmental Studies and Management, 10, 443-450.

You, F., Tao, L., Graziano, D. J. & Snyder, S. W. (2012). Optimal design of sustainable cellulosic biofuel supply chains: multiobjective optimization coupled with life cycle assessment and input–output analysis. AIChE Journal, 58, 1157-1180.

You, F. & Wang, B. (2011). Life Cycle Optimization of Biomass-to-Liquid Supply Chains with Distributed–Centralized Processing Networks. Industrial & Engineering Chemistry Research, 50, 10102-10127.

Yue, D., You, F. & Snyder, S. W. (2014). Biomass-to-bioenergy and biofuel supply chain optimization: Overview, key issues and challenges. Computers & Chemical Engineering, 66, 36-56.

Zarei, M., Niaz, H., Dickson, R., Ryu, J.-H. & Liu, J. J. (2021). Optimal Design of the Biofuel Supply Chain Utilizing Multiple Feedstocks: A Korean Case Study. ACS Sustainable Chemistry & Engineering, 9, 14690-14703.