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Review Article

A research on mathematical model approaches in biomass supply chain

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ABSTRACT

Nowadays, Energy has become one of the most important issues. Negative environmental effects of fossil fuels lead countries to use renewable and sustainable energy sources day by day. In addition, energy supply and security have been an motivator factor in this field. This study focus on biomass that renewable and sustainable energy source. According to studies in literature, energy production from biomass resource less than other energy sources. The most important reason for this is the logistics costs. Therefore, biomass supply chain optimization is an important issue. In this study, mathematical models of biomass supply chain are reviewed. When the studies are evaluated, there are three approaches in modeling biomass supply chains. These approaches are as follows: 1) Collection and Distirubiton, 2) Selection, 3) Clustering. In additon, researchers generally focus on single-aim mixed integer mathematical models. However, recently, it is seen that there are multi-aim models in the literature for minimizing emissions as well as supply chain costs. In this study, general information about biomass and biomass supply chain, studies of in this area, mathematical models, details of published papers are given. Objective functions, cost/income items, methods of these models are discussed in detail.

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INTRODUCTION

Increasing population, improving living conditions, and developing technology increase energy consumption. Currently, most of the energy needs are provided by fossil resources. However, it is foreseen that this need will not be met in the future. In addition, it is known that these resources have some negative environmental, social and economic effects.

It is known that problems related to energy supply and security are experienced in possible crisis situations between countries. In order to ensure energy supply security, countries turn to their own resources. In this context, renewable and sustainable resources used by countries provide advantages. Renewable energy sources are considered as hydro, geothermal, solar, wind, biomass, tides and waves. Although all resources have advantages, the geographical conditions of the countries also affect the use of these resources. However, biomass energy sources differ from

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other renewable energy sources due to the fact that they are obtained from waste.

In this study, the focus is on biomass energy. Biomass is defined as the total mass of living organisms belonging to a species or a community of various species at a given time [1]. The reasons for the preference of biomass are given in detail below [2].

- It is more environmentally friendly than other energy sources
- It is considered as a domestic and national energy source for countries.
- Generating plants are less costly than many power generation plants.
- It reduces oil imports.
- It supports sustainable energy.
- It contributes to the development of energy agriculture.
- It improves the socio-economic structure of the rural area.
- It creates local job opportunities.
- Since it has a high flash point temperature, it can be stored under the storage conditions of diesel and it burns cleaner than diesel.
- Biomass resources are quite diverse and easy to access. These resources are given Figure 1.

Biomass energy is obtained by using various conversion methods from forest residues, agricultural waste, animal waste, industrial waste, municipal waste. Electricity, fuel and heat are produced from biomass energy.

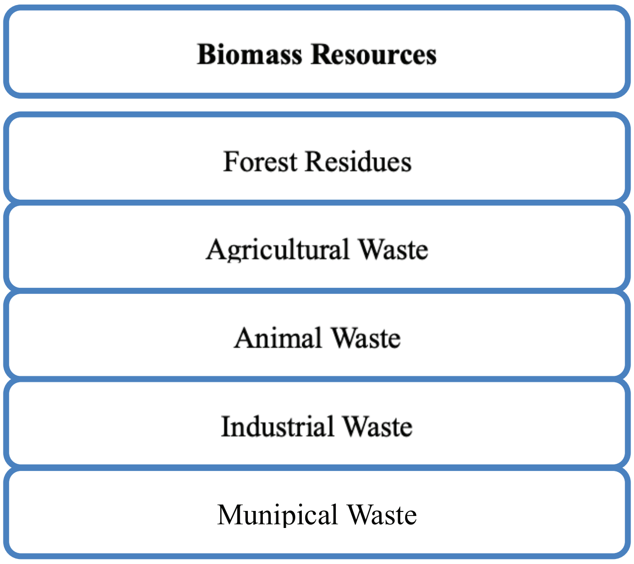

Figure 1. Biomass Resources.

Biomass energy is considered in terms of sustainability with its environmental, social and economic aspects. Considering the environmental aspects of sustainability, reducing climate change is one of the main objectives of bioenergy policies and strategies. In this context, biomass energy; contributes to air quality and greenhouse gas emissions, biodiversity and soil quality, and water quality, water use and productivity.

When the social aspects of sustainability are evaluated, it provides many social benefits such as increasing bioenergy production, creating employment, improving access to energy and rural development. Among the social aspects of sustainability, the following issues are particularly important [2].

- Education, training and capacity
- Development
- Employment
- Food supply and Access
- It provides health and safety.

When the economic aspects of sustainability are evaluated, while the expansion of biomass production provides significant economic effects, the increase in sectors supporting bioenergy can create new income sources.

The supply chain structure is of critical importance to benefit from advantage and impact of biomass. This structure is given Figure 2.

Although the general structure of the supply chain is as Figure 2, the elements in the supply chain may increase depending on the type of biomass source.

This study deals with the mathematical model approaches in this field. The remainder of this study is organized as follows: Section 2 presents literature review, while eveluation of the review is presented in Section 3. Finally, conclusion and future work are presented section 4.

LITERATURE REVIEW

Although the studies related to the biomass supply chain are not old, the number of studies in this field has increased in recent years.

When the studies are examined, it is seen that there is a literature review. For example, [3] gave detailed information about biomass in their study. Sustainable biomass supply chain was divided into 4 categories as lean, agile, flexible and green. Afterwards, mathematical, heuristic and information technology-based studies related to sustainable supply chain are discussed. [4] focused on biomass supply chain

Figure 2. Biomass supply chain.

optimization studies in 1997 and 2016. Studies have been classified in terms of biomass supply chain network design decisions, model approaches, solution methods, model characteristics (period, objective function), uncertainty, sustainability and regions. [1] discussed the biomass energy potential in Turkey. They evaluated the reports and numerical analyzes submitted by international institutions related to biomass. [5] have classified research in the field of biomass supply chain under 8 headings. The classes are decision level, supply chain structure, model approach, numerical performance analysis, shared knowledge, innovation, assumptions, constraints, and future studies. In this context, all of the studies were classified and detailed information about the papers was given. [6] conducted a research on biomass supply chain structures in which forest residues are used as an energy source. Studies dealing with strategic, operational and tactical levels in the biomass supply chain, as well as studies on specific topics that deal with location selection, technology selection, and flow rates between supply chain members are examined. [7] examined mathematical models for the optimization of biomass supply chain costs, case analysis, and studies in which decision support systems.

Some studies are related to the modeling of strategic, tactical, operational level decisions. [8] developed a 2-stage mathematical model involving strategic and operational decisions. At the strategic level, the number, location and capacity of biomass plants are determined in the long term. At the operational level, it is decided how much biomass flow will be on a period basis. At the same time, this model has been tested with the data of the Iowa company. [9] developed an integrated biomass supply chain optimization model to ensure efficient biomass feedstock in large-scale biofuel production and to minimize annual biomass-ethanol production costs. Researchers focused on a mixed integer linear programming model that would simultaneously optimize both strategic and tactical planning decisions.

Some studies in the literature have focused entirely on mathematical approaches. For example, [10] has discussed using a model PSO variant for strategic planning of the biomass supply chain, where the optimal biomass flow from sources to power generation facilities must be properly defined. The decision variables of the model are the continuous decision variable, which indicates the amount of biomass flow, and the binary decision variable, which represents the choice of technology. [11] focused on the multistage biomass supply chain. The supply chain includes biowaste fields, refineries and customers. The model aims to minimize transportation and facility costs. The model includes demand, resource and technology constraints. A dataset of 28 candidate sites, 143 customers and 8 biomass sources was used to validate the model. [12] presented a mixed integer mathematical model approach to the supply chain, which includes the supply, processing, storage and distribution of biomass. [13] focused on the biofuels produced. At the same time, they mentioned that there are uncertain structures in this area and that these uncertainties make it difficult to evaluate investment decisions. For this reason, a model is presented for the optimal design of biomass supply chain networks under uncertainty. [14] considered 1st generation and 2nd generation biomass varieties as hybrids as biomass source. The supply chain network includes collection centers, conversion facilities and customers. The aim is to determine facility locations that minimize costs. [15] proposed a model for biomass supply chain network design. Network includes supply areas, storage areas and conversion facilities. The aim is to decide which of the warehouse and facility areas that maximize the total profit should be opened and to determine the amount of shipments from the supply areas to the warehouses and from the warehouses to the facilities. [16] developed a mathematical model that maximizes total profit. In this model, multiple biomass sources and different technological methods are used. This model has been tested with real test data in Malaysia. [17] have established a general supply chain structure for forest residues. The supply chain consists of the biomass source, bioenergy plants and customers. The aim is to minimize the cost while determining the facility location and capacity to meet customer demands. [18] studied the biogas supply chain network structure. The network is divided into 3 zones. There are 2 different suppliers in the first zone, facilities in the second zone, and the domestic market and gas stations in the third zone with demand for the final product. The aim is to determine profit-maximizing flow quantities under capacity constraints. In this regard, a mixed integer mathematical model is proposed. [19] highlighted the gaps in biomass supply chain studies. For example, it was stated in the studies that only one transport mode was used and there were not many studies on forest residues. For this reason, the researchers designed a multi-stage, multi-modal supply chain. This chain includes collection areas, open storage areas and biorefinery facilities. The aim is to minimize the cost of biofuel production, transportation and facility used. [20] worked on biomass supply chain design. In the network given for the supply chain, firstly, biomass is collected and distributed, followed by hydrogen production from biomass. In the proposed mathematical model, the number of technology usage in the regions, the number of transportation modes used for each biomass resource and the flow amounts are included. The aim is to minimize investment, transportation and inventory costs. [21] pointed out that the most important problem for biomass is high logistics costs. For this reason, they focused on the biomass supply chain design. They proposed a multi-purpose mixed integer mathematical model that maximizes the number of houses using bioenergy while minimizing cost and carbon emissions under flow, balance, capacity, logic constraints. [22] emphasized that the use of biomass in bioenergy and biofuel production is a sustainable solution for the decarbonisation of the energy sector. A biomass supply chain system is proposed using a case study in Malaysia, where the biomass feedstock supply problem is common. In this context, three important terminals have been identified: i) biomass supply point (BSP) where raw biomass materials are located, ii) biomass processing facility

(BPF) as collection center and central conversion center, and iii) biomass demand center (BDC), where processed biomass meets end-use sectors. They designed a mathematical model for the selection of biomass facilities with a new approach. The aim is to minimize the total road travel distance between each terminal. [23] predict that approximately 60 million tons of waste per year can be used sustainably. However, they pointed out that using this waste is logistically difficult due to low density and distributed availability of biomass. For this reason, researchers have created a model to find the locations of mobile and modular production units to convert biomass waste into energy and to determine flows from these places to demand points in order to minimize logistics costs, taking into account the availability of biomass. [24] focused on the production of bioethonal from biomass. The researchers proposed a mixed integer mathematical model, incorporating environmental and social effects. The aim is to ensure cost minimization. The model also determines the number and capacity of bioethanol production facilities. The maximization of the biofuel supply chain was considered in [25]. The supply chain includes biomass sources, facilities, warehouses and demand points. The proposed model is dynamic, multi-product designed and decides plant locations and capacities, as well as material flows between members in the supply chain. Real data were used to test the model from a region in Texas. [26] study focused on bioethanol production. The supply chain includes biomass sources, warehouses, facilities, biorefinery and demand points. The aim is to provide flows between facilities to meet demands at minimum cost. [27] focused on biodiesel production and the supply chain includes biomass sources, refinery and demand centers. The proposed model decides how many refineries should be opened to meet the demand and the amount transported at minimum cost. [28] was emphasized that there are many options to produce bioethanol from agricultural waste. The proposed model evaluates which of these options can be profitable to meet the demand, together with production and technology constraints. The aim is to optimize the route to be used in the processes required for bioethanol production with maximum profit. [29] focuses on supply chain optimization for bioethanol production from biomass sources under uncertainty. Supply chain members are biomass sources, pre-processing plants, refinery, distribution centers, retail and demand centers. The aim is to optimize the routes by determining the location and size of the facilities to meet the demands. The environmental effects of producing bioethanol from biomass are emphasized in [30]. However, it was also mentioned that this situation is costly. For this reason, a bi-objective mathematical model with tradeoffs has been developed to reduce carbon emissions and costs. In [31], a goal programming model is proposed in which the economic, environmental and social effects are weighted in energy production from biomass. Supply chain members are biomass sources, warehouses and demand centers. The aim is to ensure the flow of supply chain members with minimum deviation from the objectives.

In some studies in the literature, different mathematical approaches have been used together. For example, [32] proposed a multi-objective mixed integer linear mathematical model to integrate GIS and AHP techniques for biomass supply chain design. First of all, candidate facilities were determined with GIS. Afterwards, more suitable candidate facilities were determined with 5 criteria determined using the AHP technique. Finally, it was decided which facility locations should be opened with a mathematical model that maximizes profit and minimizes distance. [33] focussed on the facility location selection and routing problem together for the biomass supply chain. In the study, a mixed integer mathematical model is proposed for the routing of biowaste coming from different collection centers to the processing plant and for the selection of candidate collection center areas. Since the location routing problem is NP-Hard, a tabu search algorithm has been developed for large-scale problems. Unlike other studies, [34] presented a new method for demand-driven regional energy targeting and supply chain synthesis. They applied the Regional Energy Clustering approach to evaluate suitable ways to transfer energy from renewable sources to customers in a given region. The investigated region was divided into a series of clusters using the regional energy clustering algorithm developed. The aim is to minimize the system carbon footprint.

[35] investigated the parameters affecting biomass at the supply chain scale. The parameters were determined as biomass demand, crop yield, harvest timing and used technology. A case study was conducted by determining 10 scenarios in a company for the evaluation of the parameters.

Study of [36] is part of the BioREF (Biorefinery for Sustainable Reliable Economic Fuel) project. BioREF aims to dynamically develop a benchmark for future integrated and sustainable bioenergy production systems, which will contribute to strengthening Denmark's position in bioenergy production. The aim of the project is to optimize the harvesting and logistics required for the transportation of oilseed products. It is also important to transport suitable agricultural residues to production facilities and to return process residues for agricultural use as part of the overall biomass feedstock infrastructure. In this context, it was emphasized that the supply chain should consist of optimized steps such as waste areas, waste collection, storage and transportation.

Details of the studies on the biomass supply chain are given Table 2 and 3. Studies generally consist of literature review and mathematical model approaches. The information about the mathematical models is given in the Table 3 and the general situation of the literature is revealed. In Table 1, abbreviations are explained. Table 2 shows the biomass source and usage areas in the studies. In some of these studies, the source of biomass was not specified. For this reason, it is named as a biomass source. The usage area is stated as energy in some studies. This situation can be seen in Table 2.

Table 1. Explanation of Abbreviations (for Table 3)

Objective Function		Method
Maximum	**Minumum**	· MM: Mathematical Model · HM: Heuristic Model · SM: Stochastic Model · FM: Facility Model · CS: Case Study · DM: Decision-making model
· P: Profit · EI: Enviromental Impact	· C: Cost · D: Distance · CF: Carbon Footprint	
Items		
Cost	**Revenue**	
· PU: Purchase · PT: Pretreatment · F: Facility · PR: Production · L/U: Loading Unloading · T: Transportation · I: Inventory · S: Shortage · E: Emission	· PS: Product Sale · CS: Carbondioxide Sale · EA: Enviromental Advantage	

Table 2. Classification of Studies According to Biomass Source and Usage Area

Author	Biomass Resource						Usage Area		
	Agriculture Waste	Animal Waste	Energy Crops	Forest Residues	Industrial Waste	Municipial Waste	Biofuel	Electricity	Heat
[38]				✓			✓		
[37]	✓							**Energy**	
[24]			**Biomass Resource**						
[23]	✓							**Energy**	
[29]	✓						✓		
[33]			**Biomass Resource**				✓		
[30]				✓					✓
[32]		✓						✓	
[22]				✓				✓	
[31]			✓	✓				**Energy**	
[28]	✓						✓		
[39]			**Biomass Resource**					**Energy**	
[20]	✓		✓	✓	✓		✓		
[19]				✓			✓		
[18]				✓			✓		
[27]			✓				✓		
[17]				✓				✓	
[16]	✓						✓		
[26]	✓						✓		
[9]	✓						✓		
[15]	✓	✓					✓	✓	
[8]	✓						✓		
[14]	✓						✓		
[25]			**Biomass Resource**				✓		
[13]				✓			✓		
[12]				✓			✓	✓	✓
[26]			**Biomass Resource**				✓	✓	✓
[11]	✓			✓			✓		
[39]	✓			✓			✓	✓	✓
[10]	✓			✓	✓			**Energy**	

Table 3. Classification of Literature Research

Author(s)	Year	Number of Purpose		Objective Function					Items												Certainty	Dynamic	METHOD					
				MAX		MIN			Cost									Revenue										
		Single	Multi	P	EI	C	D	CF	PU	PT	F	PR	L/U	T	I	S	E	PS	CS	EA			MM	SM	HM	FM	CS	DM
[38]	2022		✓			✓			✓		✓		✓	✓								✓	✓					
[37]	2022	✓				✓			✓	✓			✓	✓	✓						✓		✓					
[24]	2022	✓				✓		✓			✓			✓			✓				✓	✓	✓					
[23]	2021	✓				✓					✓	✓		✓							✓	✓	✓		✓			
[29]	2021		✓			✓		✓	✓		✓			✓			✓					✓	✓					
[33]	2021	✓				✓					✓			✓							✓		✓	✓				
[30]	2020		✓			✓		✓	✓								✓				✓	✓	✓					
[32]	2020		✓	✓			✓		✓		✓	✓		✓				✓			✓	✓	✓					✓
[22]	2019	✓					✓							✓							-	-				✓		
[39]	2018	✓				✓					✓	✓		✓	✓		✓				✓	✓	✓					
[31]	2018		✓			✓		✓	✓		✓	✓		✓	✓		✓				✓	✓	✓					
[28]	2017		✓	✓		✓		✓	✓			✓					✓	✓			✓		✓					
[20]	2016	✓				✓					✓	✓		✓							✓	✓	✓					
[19]	2016	✓				✓			✓		✓	✓		✓	✓						✓	✓	✓					
[18]	2016	✓		✓	✓													✓	✓	✓	✓	✓	✓					
[27]	2015	✓				✓			✓		✓	✓		✓		✓					✓	✓	✓					
[17]	2015	✓				✓			✓		✓	✓		✓							✓	✓	✓					
[16]	2015	✓		✓					✓		✓	✓		✓							✓		✓					
[26]	2014	✓				✓			✓					✓	✓						✓	✓	✓					
[9]	2014	✓				✓			✓	✓		✓		✓	✓						✓	✓	✓					
[15]	2014	✓		✓					✓		✓			✓	✓			✓			✓		✓					
[8]	2013	✓				✓						✓		✓	✓	✓					✓	✓	✓					
[14]	2012	✓				✓			✓		✓	✓		✓							✓		✓					
[25]	2011	✓		✓							✓	✓		✓	✓						✓	✓	✓				✓	
[13]	2011	✓		✓					✓		✓	✓		✓				✓							✓			
[12]	2010	✓				✓						✓		✓	✓		✓				✓	✓	✓					
[26]	2010	✓						✓									✓				✓					✓		
[11]	2010	✓				✓			✓		✓	✓		✓							✓	✓	✓					
[40]	2009	✓				✓					✓		✓	✓	✓						-	-					✓	
[10]	2008	✓				✓			✓		✓	✓		✓				✓			-	-		✓				

EVALUATION

In this study, a detailed research was carried out on the biomass supply chain. The findings obtained as a result of the research are as follows.

- Researchers have generally considered a specific part of the biomass supply chain rather than examining it end-to-end.
- In general, biomass resources are not considered more than once, but only one biomass resource.
- In general, mixed integer mathematical modeling was used in supply chain optimization and case studies were used to validate it.
- Few studies have used legislation constraints in modelling.
- At the same time, no study was found in which all environmental, economic and social factors were evaluated. In particular, it was emphasized that CO_2 emissions are less than fossil fuels. However, this concept was rarely included in the mathematical models studied.
- In some studies, the strategic, operational and tactical decisions of the biomass supply chain are rarely addressed.
- Most of the studies included decisions about facility location selection, but there are very few studies that consider the situation regarding vehicle routing for delivery of the final product to customers.
- Generally, fuzzy logic and heuristic optimization methods are not used in solution approaches.
- At the same time, the disadvantages of biomass in the food industry were mentioned in some articles, and a related contribution was rarely made in the constraints of mathematical models.

The supply chain structures used in the studies are given in the figures below.

Figure 3. Biomass supply chain structure 1.

Figure 4. Biomass supply chain structure 2.

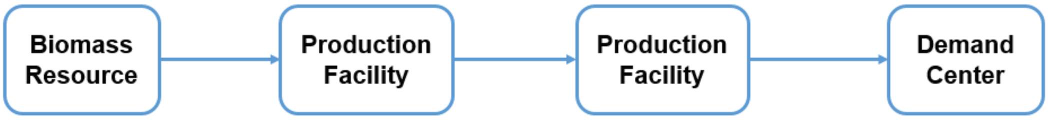

Figure 5. Biomass supply chain structure 3.

Figure 6. Biomass supply chain structure 4.

Figure 7. Biomass supply chain structure 5.

Figure 8. Biomass supply chain structure 6.

Figure 9. Biomass supply chain structure 7.

Figure 10. Biomass supply chain structure 8.

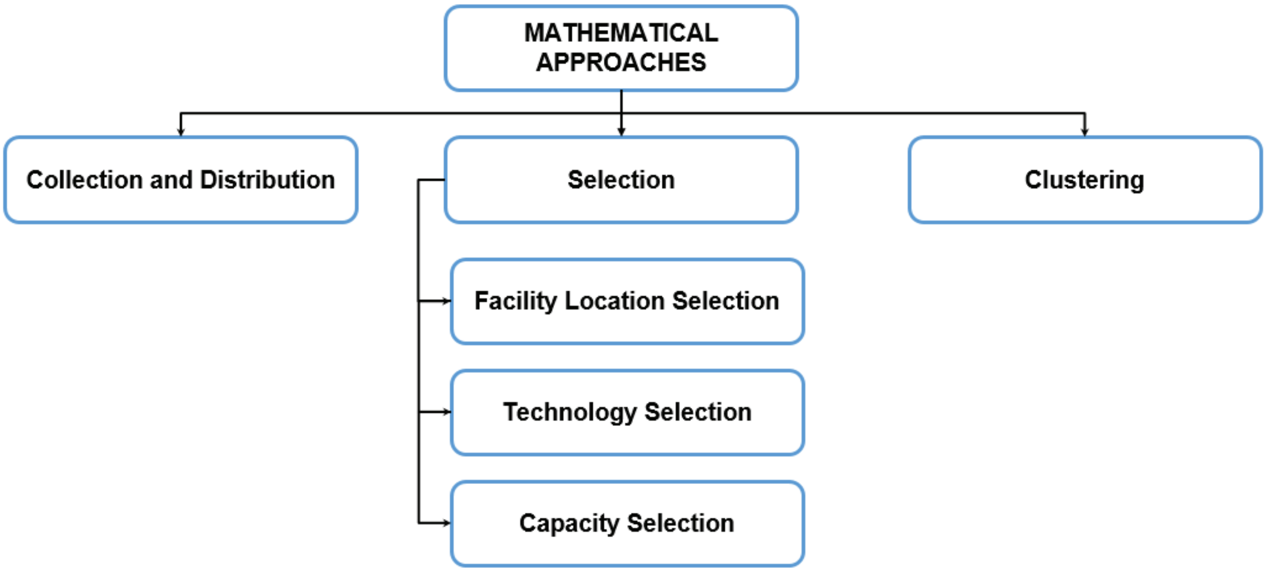

Figure 11. Mathematical approaches of reviewed studies.

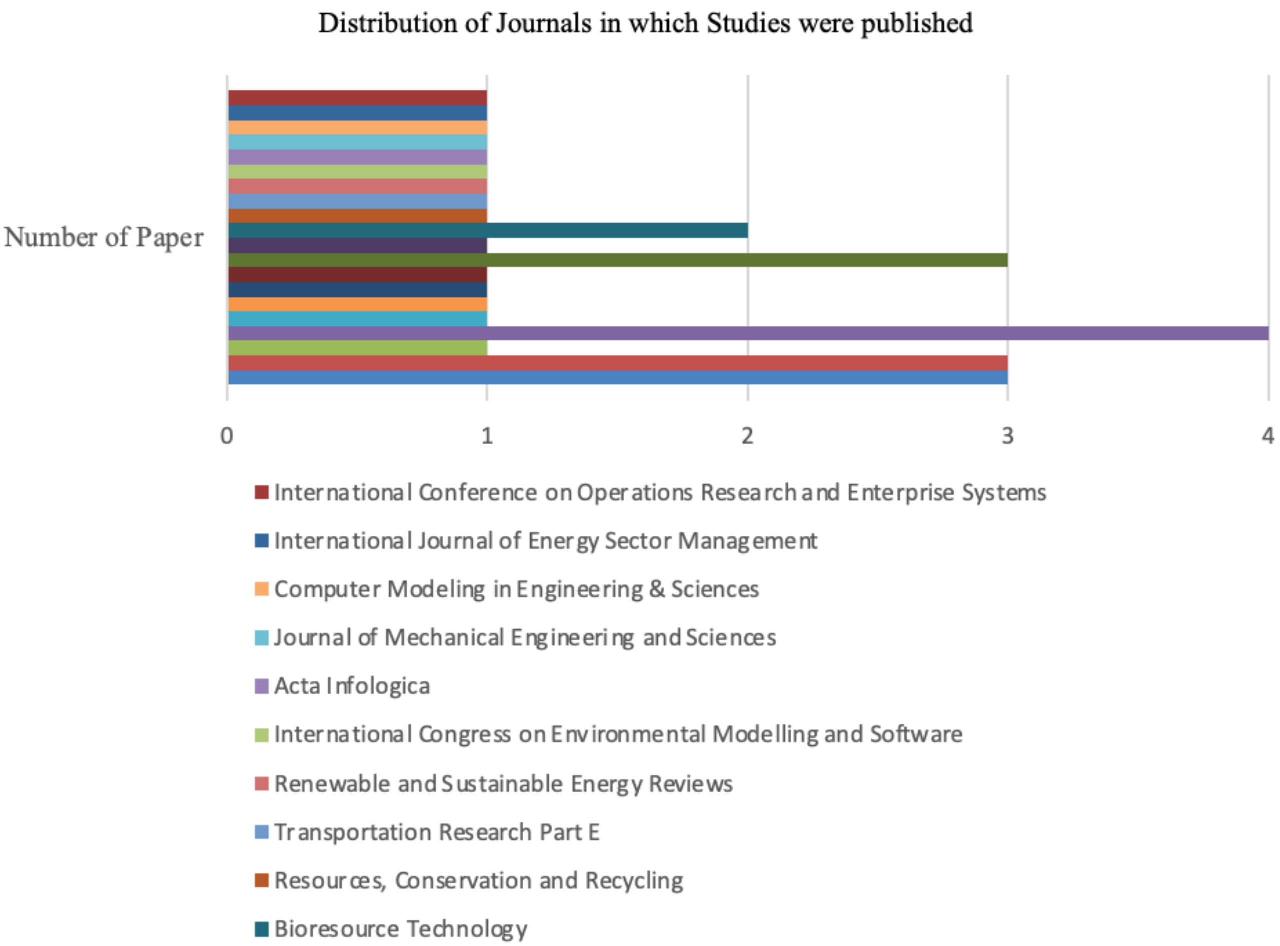

Figure 12. Distribution of Journals in which studies were published.

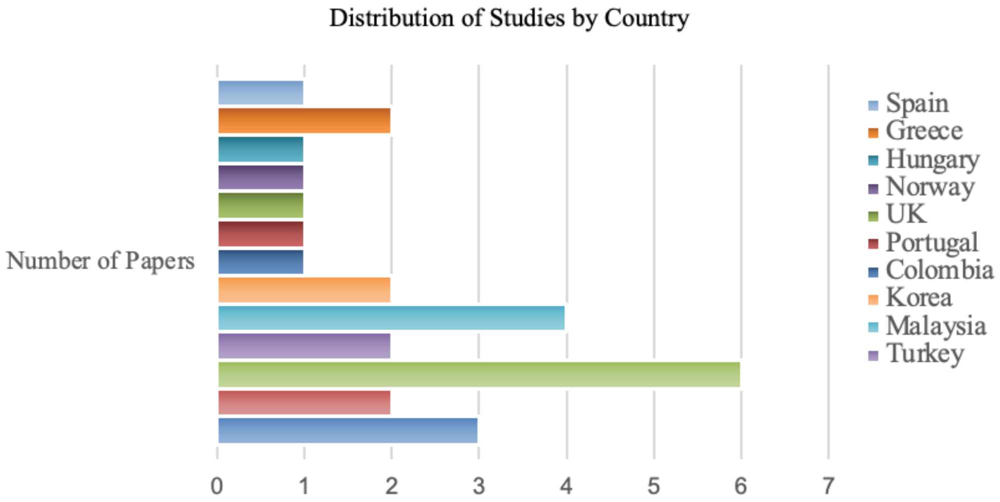

Figure 13. Distribution of Studies by Country.

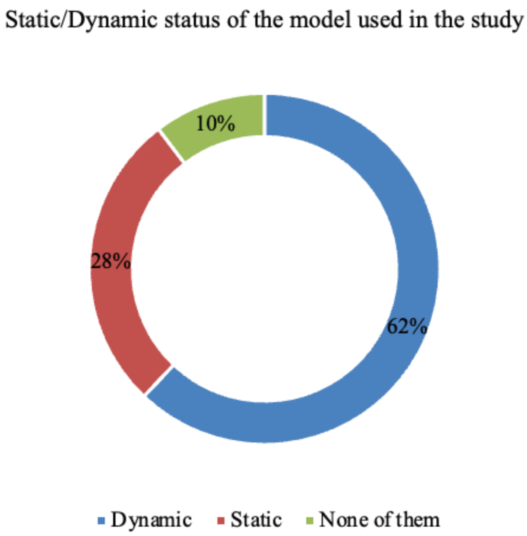

Figure 14. Static/Dynamic status of the model used in the study.

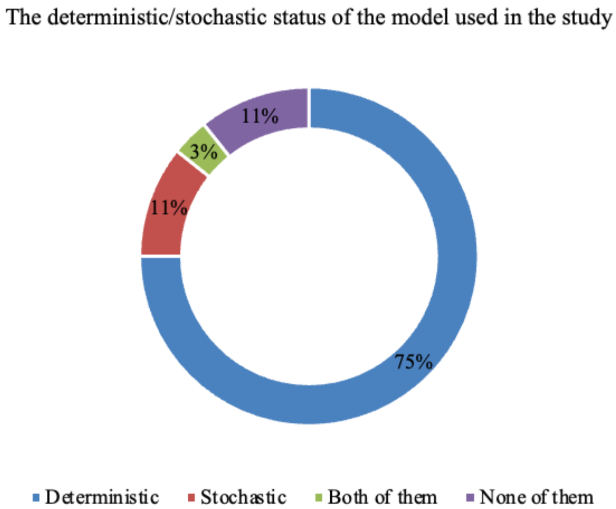

Figure 15. The deterministic/stochastic status of the model used in the study.

The mathematical approaches in the studies can be classified as follows.

The distribution of the journals of the papers is given in figure 12.

The distribution of papers by country is given in figure 13. Studies are generally concentrated in USA, Malaysia and China.

Static/Dynamic status of the model used in the study are given Figure 14. It is seen that the studies mostly use the dynamic structure.

The deterministic/stochastic status of the model used in the study are given Figure 15. It is seen that the studies mostly use the deterministic structure.

CONCLUSION

Energy resources are being depleted day by day in the world. Replacing these depleted resources and their sustainability has become a critical issue. For this reason, countries invest in renewable energy sources. In this way, they not only contribute to energy production, but also benefit the environment. In this context, biomass is one of the important energy sources.

In this study, the concept of biomass was investigated and focused on the biomass supply chain. Because it is important to use this resource efficiently rather than the existence of the resource. When evaluated in terms of countries, companies and individuals, the fact that there is a budget constraint necessitates the work to be done at the lowest cost and to provide the highest benefit. For this reason, mathematical models used in the biomass supply chain have been examined and classified in the literature. While evaluating the models in biomass supply chains, the studies are classified in detail in terms of the supply chain structure, the income and cost items associated with these structures, the biomass sources used and the final product.

The difference between biomass supply chains and traditional supply chains is as follows:

- Biomass resources are small and heterogeneously distributed.
- Different products can be produced from the same biomass source by using different production technologies.
- The same product can be produced from different biomass sources.
- Some biomass sources must be pretreated before entering the main process.

The items listed above complicate the models of the biomass supply chain structure. For this reason, the solution becomes difficult. Since there are many different alternatives, it is important to determine the facility, the technology to be used in the facility, and the capacity of the facility.

Studies have shown that biomass is a type of energy that countries frequently use and will use in the future. Biomass is used as electricity, heat and fuel. In particular, the laws of many countries include fuel usage rates in which biomass is included. This is one of the indicators that sign that the use of biomass will increase further. At the same time, it has been seen in the literature that studies are generally tested with real data. This is very important in terms of closing the energy gap.

In future studies, it is planned to carry out a study in which real data are used in a biomass supply chain structure, where biomass source, biomass plant and demand centers are located in a certain region, and a study is planned to meet some of the energy demands of the region.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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