DOKUZ EYLÜL UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

ANALYSIS OF LOCATION SELECTION CRITERIA FOR SUSTAINABLE DESIGN OF BIOMASS TO ENERGY CONVERSION PLANTS: A FUZZY COGNITIVE MAPPING BASED APPROACH

by

Merve ERSOY

January, 2020

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ANALYSIS OF LOCATION SELECTION CRITERIA FOR SUSTAINABLE DESIGN OF BIOMASS TO ENERGY CONVERSION PLANTS: A FUZZY COGNITIVE MAPPING BASED APPROACH

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We have read the thesis entitled **"ANALYSIS OF LOCATION SELECTION CRITERIA FOR SUSTAINABLE DESIGN OF BIOMASS TO ENERGY CONVERSION PLANTS: A FUZZY COGNITIVE MAPPING BASED APPROACH"** completed by **MERVE ERSOY** under supervision of **ASST. PROF. ŞEBNEM YILMAZ BALAMAN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Asst. Prof. Şebnem YILMAZ BALAMAN

Supervisor

Assoc. Prof. Dr. M. Yavuz Çeliktaş

(Jury Member)

Asst. Prof. Şebnem Demirkol Akyol

(Jury Member)

Prof.Dr. Kadriye ERTEKİN

Director
Graduate School of Natural and Applied Sciences

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ANALYSIS OF LOCATION SELECTION CRITERIA FOR SUSTAINABLE DESIGN OF BIOMASS TO ENERGY CONVERSION PLANTS: A FUZZY COGNITIVE MAPPING BASED APPROACH

ABSTRACT

Biomass is the common name of all non-fossilized biological material procured from living or recently living organisms. The structure of biomass consists mix of carbon, nitrogen, hydrogen, and oxygen. Global warming, pollution and the rapid depletion of non-renewable resources are the issues that need to be solved today. Biomass is a renewable energy source which generates heat, electricity and fuel using different conversion methods therefore biomass is an organic alternative to provide solutions to these problems. Thermochemical conversion technologies such as gasification, pyrolysis and biochemical conversion technologies such as anaerobic digestion, fermentation are used to procure bioproduct from biomass. The thesis focuses on the location selection for a biomass to energy plants to enhance a sustainable biomass supply chain. The type of location selection problem includes economic, environmental, social and technical decision factors. Within the scope of this thesis, a decision support system has been developed by using Fuzzy Cognitive Mapping (FCM) method to establish the relationship between these decision factors. A preliminary thesis was conducted in which biomass supply chain experts are interviewed to reveal the relationship between decision factors. The findings obtained from expert opinions were solved in a MATLAB based FCM decision support algorithm. At the end of the thesis, scenario analysis is conducted in order to better understand the relationship between decision factors.

Keywords: Fuzzy cognitive mapping, location selection problem, biomass, sustainable supply chain

BİYOKÜTLE-ENERJİ DÖNÜŞÜMÜ TESİSLERİNİN SÜRDÜRÜLEBİLİR TASARIMI İÇİN LOKASYON SEÇİMİ KRİTERLERİNİN ANALİZİ: BULANIK BİLİŞSEL HARİTALAMA TABANLI BİR YAKLAŞIM

ÖZ

Biyokütle, yaşayan veya yakın zamanda yaşamış olan organizmalardan elde edilen tüm fosil olmayan biyolojik malzemelerin genel adıdır. Biyokütlenin yapısı karbon, azot, hidrojen ve oksijenin karışımından oluşur. Küresel ısınma, kirlilik ve yenilenemeyen kaynakların hızla tükenmesi günümüzde çözülmesi gereken konulardır. Biyokütle, farklı dönüşüm yöntemleri kullanarak ısı, elektrik ve yakıt üreten yenilenebilir bir enerji kaynağıdır, bu nedenle biyokütle bu sorunlara çözüm üretmek için organik bir alternatiftir. Yanma, gazlaştırma, piroliz gibi termokimyasal dönüşüm teknolojileri ile anaerobik sindirim ve fermantasyon gibi biyokimyasal dönüşüm teknolojileri biyokütleden enerji elde etmek için sıklıkla kullanılan yöntemlerdir. Tez, sürdürülebilir bir biyokütle tedarik zincirini güçlendirmek için biyokütleden enerji elde eden santrallerin konum seçimine odaklanmaktadır. Yer seçimi problemi ekonomik, çevresel, sosyal ve teknik karar faktörlerini içerir. Bu tezde, bu karar faktörleri arasındaki ilişkiyi kurmak için Bulanık Bilişsel Haritalama (BBH) Yöntemi kullanılarak bir karar destek sistemi geliştirilmiştir. Tezin başında karar faktörleri arasındaki ilişkiyi ortaya çıkarmak için biyokütle tedarik zinciri konusu uzmanları ile yüz yüze görüşülerek veri toplandığı bir ön çalışma yürütülmüştür. Uzman görüşlerinden elde edilen bulgular, MATLAB tabanlı bir FCM karar destek algoritmasında çözülmüştür. Tez sonunda, karar faktörleri arasındaki ilişkiyi daha iyi anlamak için senaryo analizi yapılmıştır.

Anahtar kelimeler: Bulanık bilişsel haritalama, yer seçimi problemi, biyokütle, sürdürülebilir tedarik zinciri

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CHAPTER ONE
INTRODUCTION

As a result of globalization and innovations in technology, competition among global companies increased. At the same time, the technological developments have led to the development of many innovative products and process in industry, health and agriculture. Transition of humanity to modern agriculture, innovation in health as a result of the treatment of many diseases and industrialization as a result of the increase in urbanization rate and as a result of all these developments, the prolongation of human life and population increase are the main changes experienced in the century. These developments lead to a significant increase in energy use. In the last century, especially the consumption of fossil fuels has been in the foreground. However, fossil fuel resources have started to decrease or even disappear due to inability to renew itself. On the other hand, today, due to the increasing environmental awareness, the removal of harmful substances releasing from the use of fossil resources is an important problem.

The depletion of fossil resources, environmental problems caused by the use of fossil fuels such as global warming, pollution have led humanity to find alternative energy sources. Obtaining energy from natural resources which is called renewable energy is a useful solution to eliminate these environmental problems. Wind, sola, geothermal, hydraulic, wave, hydrogen and biomass energy are the main renewable energy sources. The greatest benefit of renewable energy sources is their minimal environmental damage and their inexhaustibility. Besides, renewable energy is the other main advantages of preventing erosion, minimizing the greenhouse gas effect and being economical.

Biomass energy is the renewable energy obtained by the conversion of plants, organic wastes to heat energy, electrical energy and fuel by certain conversion methods. The main sources of biomass energy are also the first-generation biomass sources such as corn and maize slabs, which are also used as human and animal nutrition, the second-generation biomass resources that are grown to obtain energy, vegetable, animal and organic municipal wastes.

Like other renewable energy sources, biomass energy is inexhaustible. Contributes to rural development as it uses the products produced as a result of agricultural activities as raw materials. Due to bioenergy obtained from different raw material types, the raw material source does not end and can be grown due to diversity in different climatic conditions. Raw materials and the energy generated after the conversion processes can be stored. It is ensured that the wastes that are released after the conversion process are non-energy organic and that these wastes can be re-used as fertilizer. The process of the raw materials to be used and the processes of energy conversion from biomass are well known. Due to the mentioned properties, biomass energy is one of the renewable energy sources used today.

FCM is a method that results from the inclusion of fuzzy numbers in cognitive maps (CM). FCM, based on the combination of fuzzy logic and neural networks, is a method used in complex decision-making processes. The creation of FCM is awarded to Bart Kosko back in 1986. FCM is a complex decision-making method that enables the use of qualitative and quantitative values together using linguistic variables. FCM is a method used in many social and numerical fields such as psychology, economic, political, energy systems, information systems, health, engineering, robotics, software and etc. The benefits of FCM are as follows:

- Thanks to FCM method, the relationships between the factors can be analyzed dynamically.
- With the scenario analysis, the responses of the system can be easily observed in different situations.
- Data collection is easy because linguistic variables are used in the process of obtaining opinions from decision-makers.
- While other multi-criteria decision-making methods are expected to necessarily have a value between bilateral relations, expert decision-makers at FCM do not have to express opinions for each bilateral relationship.
- Thanks to FCM, complex systems can be easily interpreted using human experience.

The concept of sustainability in a supply chain is a significant element in eliminating the risks in the supply chain, ensuring the continuity of the supply chain without interruption and sustaining the supply chain for many years. For this reason, academic studies have been carried out for many years to ensure a sustainable supply chain. Nowadays, with the increasing use of renewable energy resources, the importance of sustainable supply chains of these resources has increased. On the other hand, the pillar elements for a sustainable supply chain are economic sustainability, technical sustainability, environmental sustainability and social sustainability, respectively.

Energy conversion facilities are essential supply chain element. The main reason for this is that the raw materials used are transformed without degradation due to being organic and that the energy, fuel and heat to be produced after the transformation reach the end consumer uninterrupted and on time are crucial points. For these reasons, it is very important to select the location of the conversion plant at the highest level in order to obtain a sustainable biomass supply chain. In the selection of the location of the energy conversion facility in order to create a sustainable supply chain; economic sustainability factors such as the level of regional economy, biomass price; technical sustainability factors such as traffic situation, IT services; environmental sustainability factors such as pollution and water resources; Social sustainability factors such as social acceptability and job creation are critically effective.

In this thesis, the sustainability factors affecting the selection of the appropriate location for biomass to energy conversion plants are investigated. While determining the sustainability factors, economic, technical, environmental and social sustainability factors, which are frequently encountered in the literature, were taken into consideration. The main goal of this study is to decide the relationship between the decision criteria to be used to determine the correct location. The decision criteria referred to include both verbal and numerical subcriterias. For example, it is difficult to quantify the impact of employee motivation on the supply chain. However, the price of biomass used as raw material is expressed numerically. In this thesis, it is aimed to explain the relationship between qualitative and quantitative factors affecting the location selection problem for energy conversion plants from biomass. FCM method is used in this thesis because it is easy to use qualitative and quantitative factors together, and it provides the opportunity to make deep investigation due to the use of linguistic expressions and fuzzy numbers when taking expert opinions. The reasons for analyzing the system by using static and dynamic analyzes, simulating different situations by using scenario analyzes and allowing them to make the right decision according to their effect on the system are among the reasons for choosing FCM.

When the literature is examined, it is seen that mathematical models, multi-criteria decision making techniques and geographic information systems are generally used to solve the location selection problems in biomass power plants. Besides, in the literature, FCM method used in biomass has been used and generally it is seen that social acceptability factor is examined rather than holistic approach.

In this thesis, it is aimed to examine the sustainability factors that affect the location selection in order to ensure proper location selection for biomass plants. By using FCM, it is aimed to base the system on fuzzy numbers and neural networks and to provide more detailed interpretations. On the other hand, it is aimed to reflect the real conditions of the problem by making use of expert opinions while performing FCM. Through scenario analysis, it is aimed to make it easier for the system to examine the reaction of the system in different situations and thus, the decision-maker to make decisions by considering the scenarios. At the same time, it is aimed to develop a MATLAB based application in order to enable decision makers and investors who have a facility building plan to use the method developed in the thesis easily. On the other hand, since the thesis developed a FCM-based approach to investigate the factors affecting location selection for biomass power plants, it aims to fill the gap in the literature.

This thesis consists of five main chapters. The first chapter is the introduction section of the thesis where the outline of the thesis is mentioned and its purpose is explained. The name of first chapter is “Introduction”. In the second chapter, biomass resources, biomass supply chain elements, transformation methods, biomass decision levels, sustainability, uncertainty are mentioned. On the other hand, this is the chapter called “Fundamentals of Biomass to Energy Conversion Systems and Supply Chains” which contains the literature study about the location selection made on biomass. The third chapter includes the methodology of FCM. In addition, the literature review section which includes the studies using FCM method in energy and supply chain issues is also included. The name of third chapter is “Overview of Fuzzy Cognitive Mapping”. The fourth chapter is the section where the weight matrix is constructed using the FCM method, the fuzzy cognitive mapping is drawn, the static and dynamic analyzes are performed and finally the scenario analyzes are performed. The name of fourth chapter is “Applications of FCM on Prioritization of Sustainability Criteria on Determining the Suitability of Different Regions for Constructing Biomass to Energy Systems”. The last chapter is the “Conclusion” where the thesis is interpreted and given an idea about future studies.

CHAPTER TWO
FUNDAMENTALS OF BIOMASS TO ENERGY CONVERSION SYSTEMS AND SUPPLY CHAINS

2.1 Biomass Resources

Biomass is a term for all organic material that stems from plants (including algae, trees and crops). Biomass is produced by green plants converting sunlight into plant material through photosynthesis and includes all land- and water-based vegetation, as well as all organic wastes. The biomass resource can be considered as organic matter, in which the energy of sunlight is stored in chemical bonds. When the bonds between adjacent carbon, hydrogen and oxygen molecules are broken by digestion, combustion, or decomposition, these substances release their stored, chemical energy. Biomass has always been a major source of energy for mankind and is presently estimated to contribute of the order 10–14% of the world's energy supply (McKendry, 2002a).

Biomass resources are basically divided into three main parts. The resources are energy crops, wastes and residues respectively.

- *Energy crops:*

Energy crops are divided into two parts: herbaceous energy crops and woody energy crops that are lower moisture-content type. Examples of herbaceous energy plants are switchgrass, bamboo, miscanthus, kochia etc. The most preferred herbaceous energy plants are miscanthus and switchgrass because they are suitable for many climates and have a long life. Woody plants are long-lasting and adapt to many climates. It also has important effects on the environment, such as preventing erosion, and being a source of oxygen. Examples of woody energy plants silver maple, willow, green ash, poplar can be given. The most utilised biomass to energy conversion methods for low moisture energy crops are gasification, combustion or pyrolysis.

- *Wastes:*

Nowadays, it is very popular to use wastes for energy conversion since there are important developments in environmental issues. Waste is mainly divided into animal waste, municipal waste and industrial waste. Dairy manure and poultry litter are among the most variety consumed animal wastes in biomass-based production chains around the world. The large scale of manure that a cow process and automated operations that cause continually manure collection make the dairy industry a proper alternative to biomass-based production (Balaman Yılmaz, 2019). The organic wastes of the food, beverage and paper factories, especially the organic waste forming factories, are industrial biomass sources. Fruit pulp from fruit juice factories, fruit and vegetable washing waters in food factories are examples of solid / liquid industrial organic waste. Organic municipal wastes are organic toilet wastes from households, food / beverage wastes from commercial enterprises such as restaurants, cafes, or paper, water, etc. from official institutions. Anaerobic digestion is the most suitable method to convert waste from biomass to energy.

- *Residues*

Residue basically includes agricultural residues and forestry residues. Besides the crops itself, significant amount of residues are produced every year. Rice, wheat, sugar cane, maize (corn), soybeans and groundnuts are just a few examples of crops that generate considerable quantities of agricultural residues. These residues compose a primary part of the total annual production of biomass residues and are an essential resource of energy both for domestic as well as industrial purposes (Koopmans & Koppejan, 1998). Rice straw, maize stalk, maize husk, peelings, and tops/leaves are examples of agricultural residues.

Forest residues comprise of small trees, branches, tops and un-merchantable wood left in the forest after the cleaning, thinning or final felling of forest stands, utilised as fuel without any intermittent applications. Three basic resources of forest residues can be noticeable: slash from final fellings, slash and small trees from thinning and cleanings, and un-merchantable wood (Alakangas, Koponen, & Sokka, 2015).

2.2 Biomass to Energy Conversion Systems

Biomass resources are an efficient renewable energy source that can be transformed into heat, electricity and fuel energy. It is very important to choose the right conversion process to get the most appropriate yield from biomass resources. The type of biomass source, economic, environmental, social and technological must be taken into consideration when making the conversion method selection. Technological methods that convert biomass sources into energy are divided into three main groups. Figure 2.1 shows conversion technologies.

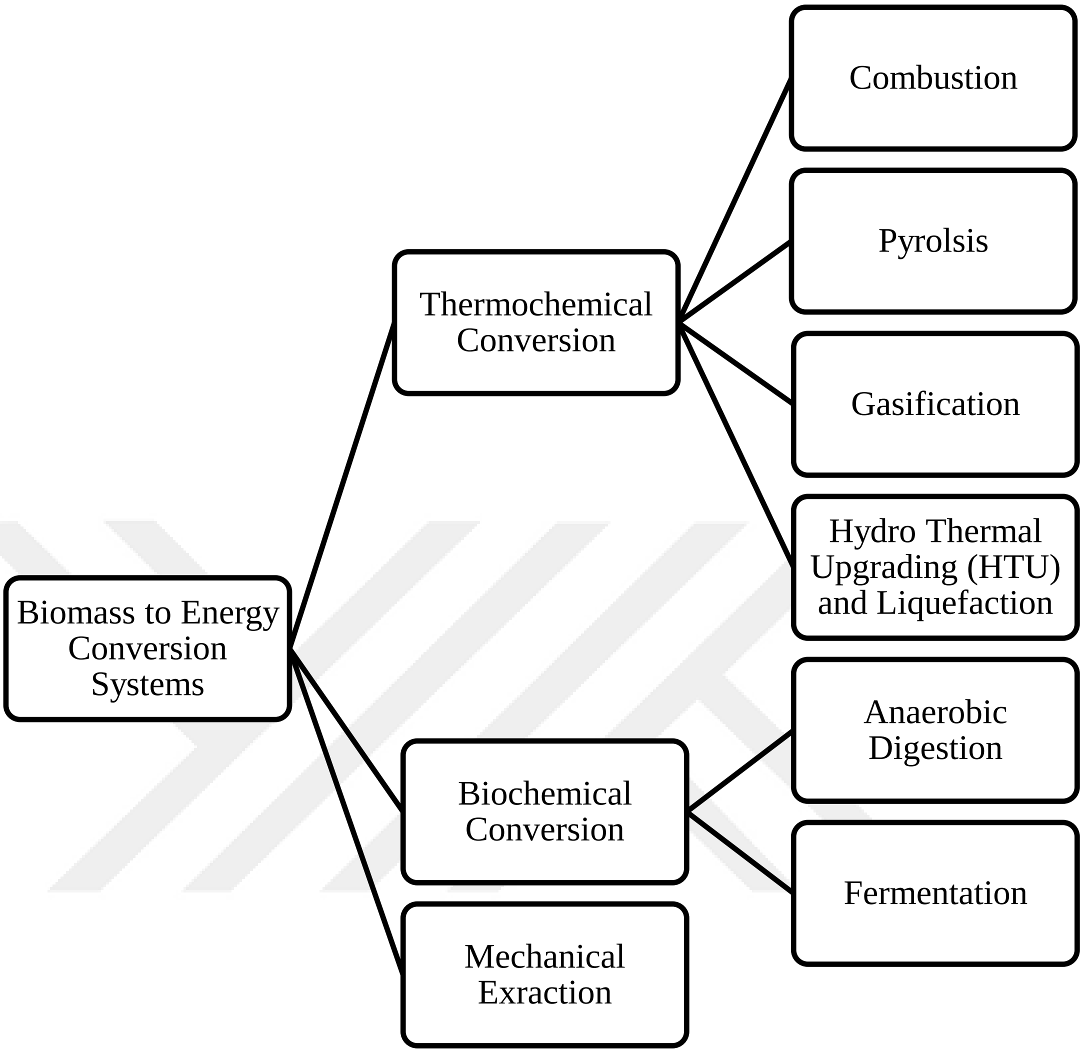

Figure 2.1 The technogies of biomass to energy conversion

Thermo chemical conversion technologies consist of five different main processes, namely combustion, pyrolysis, gasification, hydro thermal upgrading (HTU) and liquefaction.

- *Combustion*

Burning of biomass in air for domestic or industrial purposes called combustion. Various equipments such as stoves, boilers, furnaces, steam turbines, turbo-generators are utilised to transform the chemical energy in biomass into heat or power by combustion. Biomass combustion is one of the basic energy conversion method at the present. (Balaman Yılmaz, 2014)

- *Gasification*

Gasification is the conversion of biomass to a gaseous fuel by heating in a gasification medium such as air, oxygen or steam. Unlike combustion where oxidation is fundamentally complete in one process, gasification converts the internal chemical energy of the carbon in the biomass into a combustible gas in two stages. The gas produced can be standardised in its quality and is easier and more various to utilise than the original biomass e.g. it be used to power gas engines and gas turbines, or used as a chemical feedstock to generate liquid fuels (McKendry, 2002c)

Figure 2.2 contains biomass raw materials commonly used for gasification, various gasification methods and products that result from gasification.

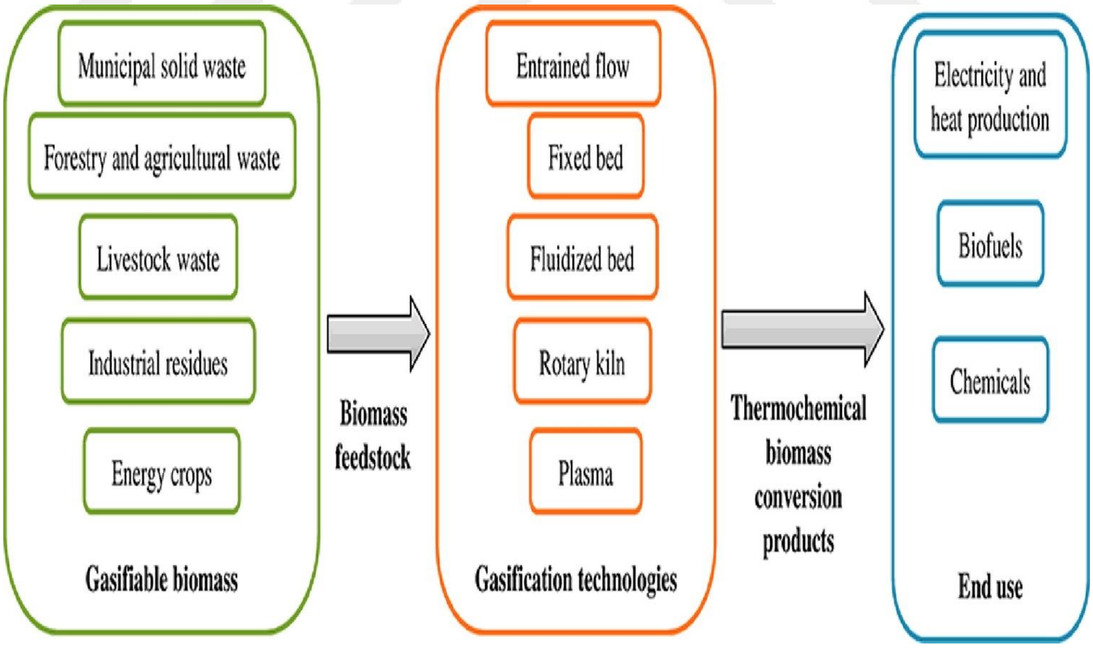

Figure 2.2 Gasification biomass, tehchologies and products (Molinoa & Chianese, 2016)

- *Pyrolysis*

Pyrolysis is a thermal decomposition method that occur in the lack of oxygen to transform biomass into solid charcoal, liquid (bio-oil), and gases at elevated temperatures (Zhang, Xu, & Champagne, 2010)

- *HTU and Liquefaction*

Hydrothermal liquefaction (HTL) contains the reaction of biomass or organic material in the presence of water at hydrothermal conditions, effectualy in the range of temperatures from 250 ^{0}C to 450 ^{0}C, and pressures from nearly 100–350 bars. Under these conditions, water maintains a liquid or relatively dense supercritical state. Due to the necessity of a wet reaction environment, HTL is specially corresponded to wet feedstocks as the requirement for drying is alleviated. Through HTL processing, organic material undergoes several depolymerisation reactions including hydrolysis, dehydration and decarboxylation to form water-soluble intermediates, and repolymerization reactions containtment several condensation mechanisms to form water insoluble products including biocrude and biochar.

Biochemical conversion is divided into anaerobic digestion and fermentation.

- *Anaerobic Digestion*

Anaerobic digestion is a bioconversion method that can be utilised to treat varied organic wastes and recover bioenergy in the form of biogas, which includes basically CH4 and CO2. The biogas can be utilised as a fuel for electricity and heat production. The residual digestate after anaerobic digestion may be used as an organic fertilizer and/or soil amendment. The organic loading rate and hydraulic retention time are two essential parameters used for sizing the digesters and their optimal values are specific to the substrate as well as the operating temperature of digesters (Romano & Zhang, 2008).

Figure 2.3 shows the biomass raw materials involved in the anaerobic digestion process and the outputs of the process.

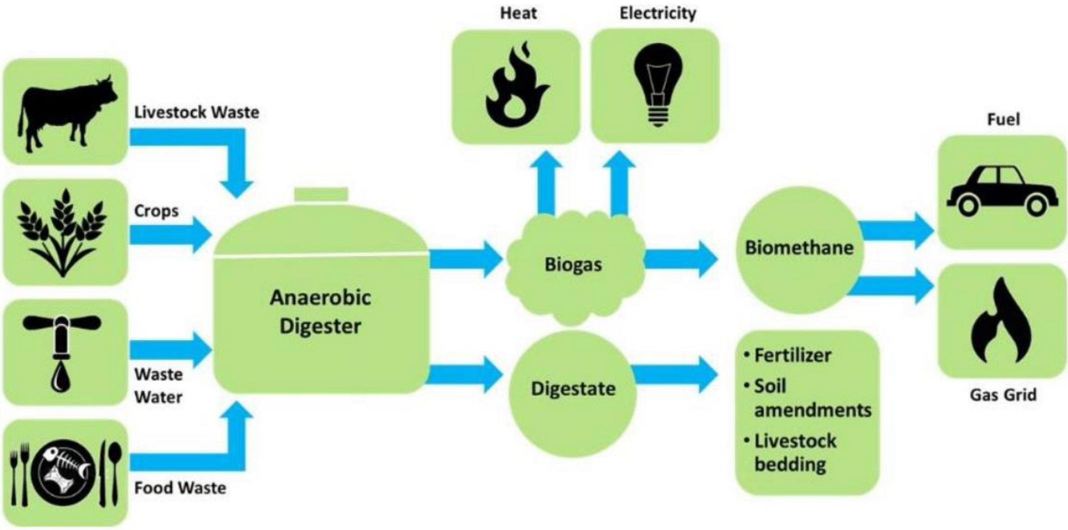

Figure 2.3 Anaerobic digestion process (Tanigawa, 2017)

- *Fermentation*

Fermentation is utilised commercially on an important scale in varied countries to genarate ethanol from sugar and starch crops. The biomass is ground down and the starch transformed by enzymes to sugars, with yeast then transforming the sugars to ethanol (McKendry, 2002b)

- *Mechanical Extraction*

Mechanical extraction is a transformation method used to extract the oil of the seeds of several biomass crops, for example cotton, groundnuts and oilseed rape. The residual solid of mechanical extraction method, in other words “cake” can be utilised for animal fodder. Biodiesel can be obtained from rapeseed oil by reacting it with alcohol. This process is termed “esterification” (Balaman Yılmaz, 2014).

2.3 Fundemental Structures and Main Consistuents of Biomass to Energy Supply Chains

The biomass supply chain is basically classified into five sections. These classes are Biomass harvesting and collection, Biomass storage, Biomass pre-treatment, Biomass transportation and Biomass energy conversion respectively. The following sections contain detailed information about the classification. Figure 2.4 represents the basic concept of supply chain of biomass.

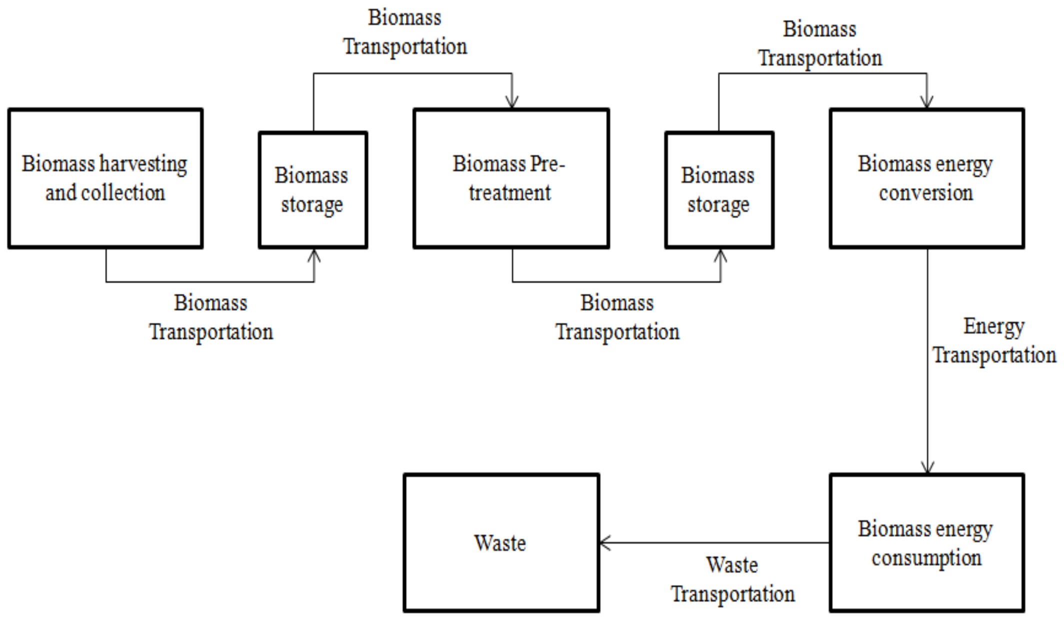

Figure 2.4 The supply chain of biomass

- *Biomass harvesting and collection*

If energy is conversion from biomass using plant resources, it is necessary to collect or harvest these resources.

In this part of biomass supply chains, the key decisions to discuss are allocation of land, harvest scheduling, and biomass collection planning based on the analysis of biomass soil/moisture content, climatic conditions, land availability, and bioenergy request (Mafakheri & Nasiri, 2014).

- *Biomass storage*

Biomass resources vary by season. However, to ensure sustainability in biomass transformation, resources should not be interrupted. It is very important to store the biomass under proper conditions. Because it poses a risk to environmental health as well as degradation of biomass that is not stored in appropriate conditions. Ambient and hypethral storages are the two main types of biomass storage. In addition, warehouse locations and capacities are divided into two as central and decentralized.

Ordinary decisions concern storage element of biomass supply chains are examination of the location of storage facilities and storage capacity planning/scheduling as follows (Mafakheri & Nasiri, 2014).

- *Biomass pre-treatment*

This process is a pretreatment method to facilitate the utilised biomass in energy transformation process and to increase the utilization efficiency. Depending on the sort of biomass, either the pre-treatment process is applied immediately after harvesting or collection. Pretreatment processes vary according to the type of raw material. However, the main pre-treatment types are chopping, drying, ammonia fiber expansion, shredding, grinding, respectively.

- *Biomass transportation*

Transportation is one of the basic actions in supply chain management. In biomass to energy supply chains, transportation planning basically concentrates on how and when to get biomass raw materials and distribute generated biofuel from their respective sources to their destinations and has a substantial affect on the overall costs of the supply chain. The decisions about main problems of biomass and biofuel transportation such as distribution network configuration, distribution amounts and transportation mode selection should be made optimum for cost and time effectual supply chains (Balaman Yılmaz, 2019).

- *Biomass energy conversion*

Biomass resources are an efficient renewable energy source that can be converted into heat, electricity and fuel energy. It is very important to choose the right conversion process to get the most appropriate yield from biomass resources. The type of biomass source, economic, environmental, social and technological must be taken into consideration when making the conversion method selection.

In the conversion step, decision makers require to engage in decisions as varied as location analysis for conversion facilities, conversion technology selection, and capital and operational planning of the conversion facilities (Mafakheri & Nasiri, 2014).

2.4 Decision Levels in Biomass to Energy Supply Chains

Decision making in supply chain management is basically divided into three main levels. The names of levels are strategic decision making, tactical decision making and operational decision making, respectively. In the following sections, details of decision making levels are explained.

- *Strategic decision*

Strategic decision is the level of long-term decisions that have been changed in five years and more. Generally, decisions are determined and followed by an expert management team. The decisions taken are fundamental changes affecting the overall functioning of the system. The uncertainty and risk ratio is high due to long-term and radical changes. These issues are included in the level of strategic decision:

- Establishing an appropriate supply chain network and identifying supply chain stakeholders,
- Selection of biomass to energy plants location, storages (centralized and decentralized) locations,
- Determining the capacity of biomass to energy plant and storages,

– Determination of appropriate biomass resources for the system,
– Determining the appropriate transformation and pre-treatment method required by the system.

- *Tactical decision*

Tactical decision is the level of medium term decision that has been changed in six months or one year. Tactical decisions are used for the planned implementation of strategic decisions. Tactical decisions are crucial for efficient operation of the system. Important tactical decisions within the supply chain:

– Selection of storage methods,
– Inventory management and control,
– Fleet management,
– Aggregate production planning,
– Selection of harvesting, cultivation and collection methods of biomass.

- *Operational decision*

Operational decision is the level of short-term decision making and is generally used in cases requiring weekly, daily and hourly decisions. Operational decisions ensure that strategic and tactical decisions are implemented in the most efficient manner and in accordance with the system. The level of the decision making includes decisions such as daily / weekly fleet management, production planning, scheduling, organizing workers' shifts:

– Vehicle scheduling,
– Daily/weekly fleet management,
– Daily/weekly production planning and storage management,
– Scheduling employees shifts.

Figure 2.5 illustrates the decision levels of supply chains that convert energy from biomass.

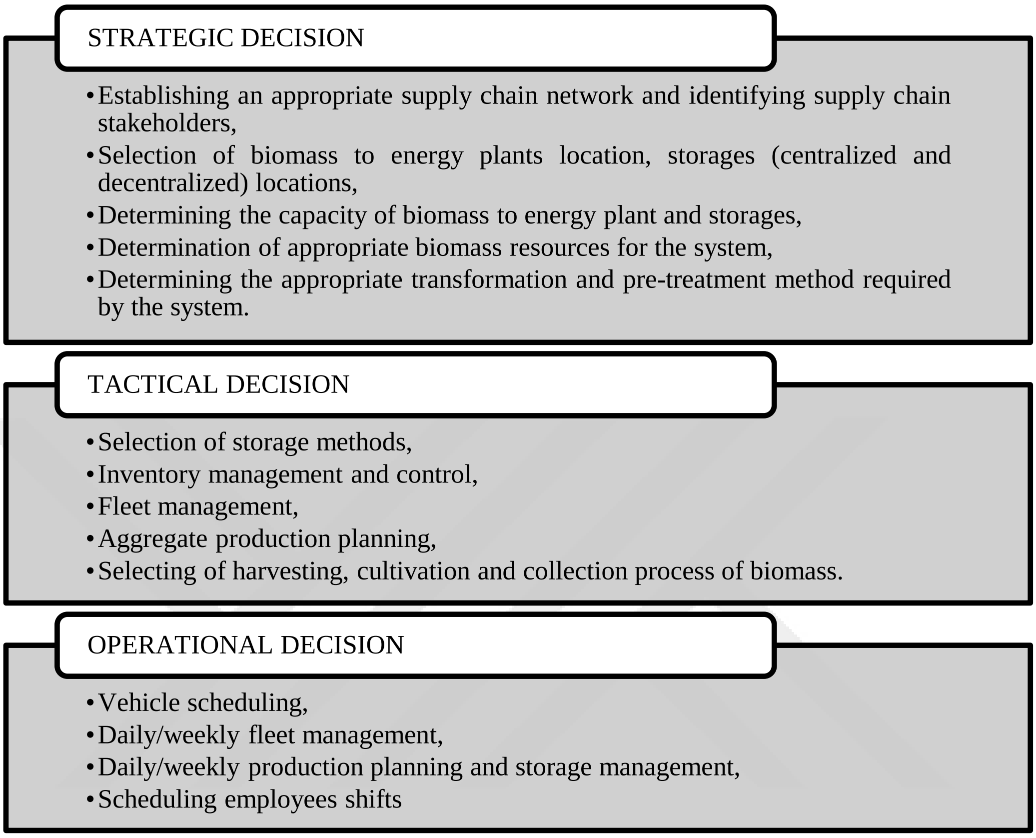

Figure 2.5 The decision levels for biomass to energy supply chain

2.5 Sustainability of Biomass to Energy Systems and Supply Chains

To ensure the continuity of a supply chain, the stakeholders in the chain should work in harmony. In addition, economic, social and technical activities around a supply chain have a positive or negative impact on the supply chain. At the same time, the supply chain affects the environment with its outputs. Supply chain design and management are critically important to ensure the continuity of supply chain activities and to ensure the integrity of stakeholders in the chain. Therefore, sustainable supply chain elements are economic sustainability, technical sustainability, environmental sustainability and social sustainability respectively.

- *Economic Sustainability*

Energy, raw materials, manpower, capital and natural resources that are input in the supply chain are always limited. The most efficient and long-term use of these resources for a sustainable supply chain. Economic sustainability criteria can be classified as system profitability, system flexibility and ability to respond to changes, Efficiency, energy security, resource utilization, competitive structure.

- *Technical Sustainability*

Today, technological innovations are considerably faster. Therefore, in order to ensure the sustainability of the systems, technological and technical developments should be examined and transferred to the system. Technological and technical improvements increase the efficiency and profitability of the system. In addition, as a result of technological and technical improvements, improvements in maintenance activities result in a longer supply chain. At the same time, as a result of technological innovation, the negative outputs of the supply chain have been reduced due to the fact that the plants and structures constructed emit less harmful liquids and gases.

- *Environmental Sustainability*

In today's world, environmental laws are in the foreground especially in developed countries. Water use and pollution of water resources, soil pollution, air pollution due to gas release, and environmentalist approach to using biomass resources are the environmental factors that should be planned in sustainable supply chains. Within this scope, decisions are taken that are beneficial to nature, which ensure recycling and minimize emissions, in the operational, tactical and strategic management of the supply chain.

- *Social Sustainability*

A supply chain interacts with the social environment in which it is located. The supply chain of renewable energy sources is an issue that is particularly debated in today's social acceptability. Since biomass supply chains are of agricultural origin, they create various impacts in the social field such as the development of rural areas and the creation of new business opportunities. In order to achieve a sustainable supply chain, it is vital that social norms accept and support this supply chain.

2.6 Uncertainty in Biomass to Energy Conversion Systems

There are several uncertainties in the process of supplying raw materials in a supply chain and reaching the end product to the customer. There are technical, economic and environmental uncertainties such as seasonal harvesting of biomass supply chain raw materials, stored raw materials or semi-finished products in different forms such as liquid or solid, bioenergy being a new market compared to other markets, environmental impacts in plant location selection from biomass. It is possible to classify the uncertainties in the biomass supply chain as strategic and operational uncertainty.

- *Strategic Uncertainties*

The economic and legal conditions of the region where the system is located, the decisions taken by the state and the uncertainties to be experienced in selecting the location can be given as examples of strategic decisions. Especially in cases where a new supply chain is established, strategic uncertainties should be taken into consideration and solutions to these uncertainties should be produced.

Amendment of the policy rules of the region where the system is located; the tax reduction in the installation of the facility, the taxes collected sanctions of environmental laws, waste regulations, such as causes some rules in the region to change. On the other hand, the import and export potential in the biomass supply chain an uncertain element due to the change in commercial policies constitutes. Economic crises and sanctions in the region are an important strategic uncertainty.

Because economic conditions affect many cost and profit items such as raw material, equipment used, sales price of end product.

Most of the raw material of the supply chains that generate energy from biomass is composed of plant and plant waste. Therefore, the change in natural phenomena is an element of uncertainty in the supply chain. At the same time, the disasters to be experienced are the factors that affect the supply chain fundamentally and that need to be taken beforehand.

Factors that adversely affect the economic conditions of a country such as terrorism and war are also important uncertainty factors in the supply chain. When creating a supply chain, these factors should be the decisive criterion, especially in the location selection.

Today, technology is advancing rapidly. In the supply chains that obtain energy from biomass, there are different transformation technologies that convert biomass into energy, as well as transport methods and different storage systems to transport and store biomass and energy. Innovations in technology are effective in supply chains, transformation technologies, and transport systems, processes of warehouses and facilities that generate energy from biomass. For these reasons, technological innovations are an element of uncertainty for biomass to energy supply chains.

- *Operational Uncertainties*

Operational uncertainties are often uncertainties that affect the weekly and daily functioning of the supply chain. When it compares operational uncertainties to strategic uncertainties, it appears that it is easier to find solutions to operational uncertainties than strategic uncertainties. In addition, operational uncertainties result in lower cost and quality losses than strategic uncertainties.

Some situations in the transportation and logistics system are operational uncertainty. Due to the communication problems in the transport and logistics network, the stakeholders involved in the system cannot communicate and thus a network failure occurs. On the other hand, traffic density and instant weather changes in the region also affect the transportation and logistics system.

The performance, experience and level of knowledge of workers in the supply chain affect the functioning of the supply chain. Therefore, worker performance is an uncertainty for the biomass to energy supply chain.

2.7 A Literature Review on Sustainability of Biomass to Energy Systems and Supply Chains

The literature review on biomass energy includes location selection, location allocation, sustainable biomass supply chain and sustainability consideration. Dates of studies reviewed between 2008 and 2019 Geographical information system and mathematical modeling and programming have been used to reach a solution.

Panichelli & Gnansounou (2008) developed a Geographic Information System combined with location allocation algorithm to select bioenergy locations. The algorithm solves the reasions competition difficulty between energy facilities through a location-allocation model based on least-cost biomass quantities. To use the algorithm, the study includes a case study which is in North Spain. Shi, et al. (2008) focused on transportation productivity and the amount of convenient biomass for planning the biomass plant. On the other hand, the study includes further considerations of other factors, such as land-use type, power transmission cost, environmental impact, economical interest, and political and cultural issues. In order to understand the impact of the issues on a system, a case study is conducted on the Guangdong region of China. In this study, geographic information system method and spatial information technologies is used to determine the appropriate location. Zhang, Johnson, & Sutherland (2011) presented to identify the best location for biofuel production using a two-stage methodology. To identify feasible biofuel facility locations Geographic Information System is used. Besides, to select the best location, the study utilizes a total transportation cost model. The study includes several key variables such as fuel price, transportation distance, and pulpwood availability. Dael, Passel, Pelkmans, Guisson, Swinnen, & Schreurs (2012) focused on select potential locations for biomass valorisation in a specified region. In this study a macro screening approach is used to determine the location of biomass

Project. Yu, et al. (2012) developed a geographic information system model and mathematical model to select the optimal sites for plant and satellite storages. Thanks to geographic information system model is determined the optimal number of storage sites, optimal geographic distribution for the power plant and storage sites, as well as their subcollection network. Bojić, Đatkov, Brcanov, Georgijević, & Martinov (2013) developed a mathematical model to solve a location allocation problem for biomass to energy plants. The study finds determination of capacity, type and location of solid biomass power plants by tending to facilitate minimal electricity generation costs. In addition, the study has a case study on Vojvodina which has high density agricultural biomass and shorter supply distances. Case study shows that investment costs have the greatest impact on power plant capacity determination. Guo, Hodges, & Young (2013) developed a conditional logit model (CLM) to investigate Woody biomass policies in new bioenergy projects. At the end of the study, it was found out that government incentives and new plants had an impact on biomass plant selection. Voets, Neven, Thewys, & Kuppens (2013) proposed a location optimisation for biomass plant sites. In the study, to find the optimum location in the study, the distribution of the contaminated willow supply and parameters of biomass transport costs are considered. In addition, according to the case study included in the study, it is more optimal to install more than one smaller plant when only the transportation cost is considered. Cambero & Sowlati (2014) reviewed studies on the impact of economic, social and environmental factors on a forest biomass supply chain. According to the review study, the majority of studies developed the life cycle assessment, multi-objective optimization models to enhance real benefits to the society and the economy and to minimize the environmental impact of the supply chain. Comber, Dickie, Jarvis, Phillips, & Tansey (2015) focused on the spatial distribution of supply resources and competition for them by potential facility locations. The study includes a case study, which determines ideal locate community scale anaerobic digesters (ADs), in an area in the East Midlands in the UK. In the research, a modified algorithm based on Teitz and Bart search heuristics is used. The most important aim of the study is to propose a change in the classical p-median problem taking spatial distribution into consideration. Natarajan, Leduc, Pelkonen, Tomppo, & Dotzauer (2014) developed a mixed integer programming to find optimal biodiesel production plants locations in Finland. The model minimizes the costs of the entire system by taking into account such issues as supply of raw materials, industrial competition, and energy demand. The result of the study is a decision support system for those who want to produce biodiesel in Finland. Silva, Alçada-Almeida, & Dias (2014) developed a hybrid method which includes Geographic Information System and Multicriteria Decision Aid Method. The study uses ELECTRE as a Multicriteria Decision Aid Method to classify the possible alternatives. The decision making process determines to select sites for biogas plants. Many environmental, economic, safety and social factories are the constraints of the decision making system in the study. Kami Delivand, Cammerino, Garofalo, & Monteleone (2015) developed hybrid solution approach using Geographical Information System and Multi Criteria Analysis (GIS-MCA) to tackle the logistics of biomass-to-electricity system in the area of Apulia, Basilicata, and Campania in Southern Italy. The solution of the study includes different scenarios for finding optimal plant location using minimisation of total distances. Logistic costs and the life cycle of greenhouse gas emission are estimates for each selected locations of plants. Lewandowski (2015) conducted the biggest obstacle to achieving a sustainable biomass supply chain was the reduction of competition in agricultural land for biomass production. In the study, optimization was made in order to ensure a preferable understanding of competition in the supply network and to ensure economic, social and technical sustainability. Mansuy, Thiffault, Lemieux, Manka, Paré, & Lebel (2015) developed different scenarios and optimized by comparing economic and ecological, variables in two different forest units in Canada to compare different pallet plant capacities. Scenarios investigate the potential of biomass removal from salvage logging of fire killed stands. This paper is also suitable for use in other parts of Canada. At the end of the study, it became clear that logistical difficulties are the biggest obstacle in the biomass supply chain. Morales-Rincón, Martínez, Avila-Díaz, Acero, Castillo-Monroy, & Uribe-Rodríguez (2015) presented a GIS-based methodology to describe the idea locations for biomass extraction plants and biomass power plants Agricultural land availability factors and logistic factor to select the most suitable location in the chapter of book. On the other hand, The chapter contains a Generalized Additive Model (GAM) that predicts crop yields using edaphic and climate independent parameters in regions where crops are not currently available, but which are potentially present. By evaluating the information in this chapter, all inputs of the crop-yield estimation statistical model, including system variability and the effect of climate yield on crop yield, are obtained. Wu, Sarker, & Paudel (2015) developed a mixed integer nonlinear programming (MINLP) to decide minimization of the biomethane production supply chain. MINLP is based on to optimise the supply chain by considering building, transportation, and labour costs. The paper proposes an optimization approach to location selection and allocation problems. Cebi, Ilbahar, & Atasoy (2016) proposed the most appropriate location for a biomass power plant which is in Aegean Region of Turkey. The paper consists of eight alternative locations to select the most appropriate site. The quantitative and qualitative data are collected from the candidate location sites in the paper. The paper proposes an integrated model including fuzzy sets, analytic hierarchy process, opinion aggregation method, and information axiom method to find the optimal location from candidate locations. Hong, How, & Lam (2016) reviewed studies on a description of biomass-to-bioproducts supply chain and systematically represent the problems and decisions along the biomass supply chains. Besides, the paper mentions the characteristics of a sustainable integrated biomass supply chain, and finally describes an overview of biomass supply chain synthesis and optimisation process. The paper offers a primal point to understand the concept of sustainable biomass supply chain management and the synthesis and optimisation of sustainable biomass supply chain models for the future researches. Miret, Chazara, Montastruc, Negny, & Domenech (2016) developed a Mixed Integer Linear Programming (MILP) to enhance economic, social and environmental sustainability for the biomass supply chain. The goals of the study are the optimal network design, facilities location, process selection and inventory policy. On the other hand, the study includes a case study, which is in France and about comparison between agricultural and forest residues biomass, to observe the model clearly. Rodríguez, Gauthier-Maradei, & Escalante (2017) developed an integrated GIS-based Fuzzy AHP methodology to eliminate the major bottlenecks success of biomass energy conversion facilities that use crop residues. The study classifies the parameters of the system as spatial and nonspatial factors such as the logistics factor, transport cost indicators, and technical and geographic restrictions. End of the study, to identify 12 ideal places to install a bioenergy plant is determined using the approach of the study. Sanchez-García, Athanassiadis, Martínez-Alonso, Tolosana, Majada, & Canga (2017) developed a Geographic Information System to detect optimal location of a new hypothetical wood-fired power plant in a specific region. Network Analyst tool which name is ArcGIS 10.2.1 is utilized to determine the optimize biomass to energy plant location in the paper. The paper focuses on the minimization of Greenhouse Gas (GHG) emission and distances. The approach of the paper is utilized by policy makers to evaluate possible locations for any future wood-fired power plants using economic inputs and environmental outputs. Silva, Alçada-Almeida, & Dias (2017) developed a Multiobjective Mixed-Integer Linear Programming (MMILP) approach, which considers minimizing initial investment, operation and maintenance costs, minimizing transportation cost, and minimizing social rejection, to select location and to determine capacity of biogas plants. The paper has a case study which is in an area of Portugal. On the other hand, the approach is supported by Geographical Information System. Lin, Liu, & Huang (2018) developed a fuzzy multiple objective linear programming approach to define the location of biomass to biofuel plant. The approach includes two objectives using minimize the total cost and pollution. Kim, Kim, & Kiniry (2018) proposed two simulation approaches to define the ideal locations of biomass storages. First simulation approach focuses on crop yield estimation using a process-based model such as Agricultural Land Management Alternative with Numerical Assessment Criteria. Second simulation approach focuses on biomass transportation cost estimation using agent-based simulation (ABS) such as AnyLogicw, which is utilised Geographical Information System. Thanks to the two simulation approaches, reliable locations of the biomass storages are identified. Kheybari, Kazemi, & Rezaei (2019) proposed the best location of biomass to bioethanol plant. The solution approach utilizes the sustainability criteria classified social, economic and environmental. The paper identifies a decision making process using best-worst method. On the other hand, the paper has a case study in Iran.

Sustainability of biomass in energy systems and supply chains in the literature is given in Table 2.1 in chronological order.

Table 2.1 Studies with sustainability of biomassin energy system and supply chain

Year	Referance	Problem Type	Solution Method
2008	Panichelli, & Gnansounou (2008)	Location Selection	Geographic Information System
2008	Shi et al. (2008)	Location Selection	Geographic Information System
2011	Zhang, Johnson, & Sutherland (2011)	Location Selection	Geographic Information System, Total Transportation Cost Model
2012	Dael et al. (2012)	Location Selection	Macro Screening Approach
2012	Yu et al. (2012)	Location Allocation	Geographic Information System, Mathematical Model
2013	Bojić, Đatkov, Brcanov, Georgijević, & Martinov (2013)	Location Allocation	Mathematical Model
2013	Guo, Hodges, & Young (2013)	Location Selection	Conditional Logit Model
2013	Voets, Neven, Thewys, & Kuppens (2013)	Location Optimisation	Geographic Information System
2014	Cambero, & Sowlati (2014)	Sustainability Considerations	Research Review
2014	Comber, Dickie, Jarvis, Phillips, & Tansey (2014)	Location Allocation	Geographic Information System, Spatial Analysis
2014	Natarajan, Leduc, Pelkonen, Tomppo, & Dotzauer (2014)	Location Selection	Mixed Integer Programming
2014	Silva, Alc¸ada-Almeida, & Dias (2014)	Location Selection	Multiple Criteria Decision Making
2015	Delivand, Cammerino, Garofalo, & Monteleone (2015)	Location Selection	Geographic Information System, Multicriteria Analysis
2015	Lewandowski (2015)	Sustainable Biomass Supply Chain	Research Review
2015	Mansuy et al. (2015)	Sustainable Biomass Supply Chain	Mathematical Model
2015	Morales-Rincón et al. (2015)	Location Selection	Geographic Information System
2015	Wu, Sarker, & Paudel (2015)	Location Selection	Mixed Integer Nonlinear Programming
2016	Cebi, Ilbahar, & Atasoy (2016)	Location Selection	Multiple Criteria Decision Making
2016	Hong, How, & Lam (2016)	Sustainable Biomass Supply Chain	Research Review
2016	Miret et al. (2016)	Sustainability Considerations	Mixed Integer Linear Programming
2017	Rodríguez, Gauthier-Maradei, & Escalante (2017)	Location Allocation	GIS-based Fuzzy AHP
2017	Sanchez-García et al. (2017)	Location Selection	Geographical Information System
2017	Silva, Alc¸ada-Almeida, & Dias (2017)	Location Selection	Geographic Information System, Multiobjective Mixed-Integer Linear Programming
2018	Lin, Liu, & Huang (2018)	Location Selection	Geographic Information System, Fuzzy Multiple Objective Linear Programming
2018	Sojung Kim, Sumin Kim, James R. Kiniry	Location Allocation	Network Partitioning, Integer Linear Programming
2018	Teixeira et al. (2018)	Location Allocation	Geographic Information System
2019	Kheybari, Kazemi, & Rezaei (2019)	Location Selection	Multiple Criteria Decision Making

CHAPTER THREE

OVERVIEW OF FUZZY COGNITIVE MAPPING

3.2 Methodology of FCM

FCM, based on the combination of fuzzy logic and neural networks, is a method used in complex decision-making processes. The creation of FCM is awarded to Bart Kosko back in 1986. FCM basically includes two structures. The first structure is the nodes that represent the concept variables (C_{ij}) such as C1, C2, C3, C4 and C5 in Figure 3.1. These concept variables stand for factors of a system. The second structure is arcs that represent the relationship between the concept variables. Causal variables always picture concept variables at the origin of arcs; effect variables, whereas, stand for concepts-variables at the terminal points of arcs. According to Figure 3.1, at C1 → C2, C1 depicts to impact C2 because C1 is the causal variable, whereas C2 is the effect variable.

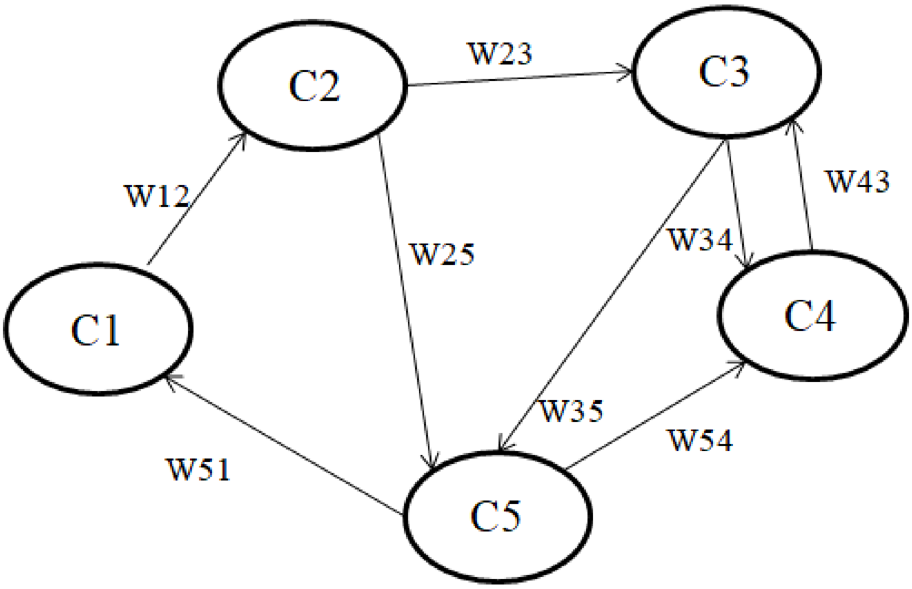

Figure 3.1 Graphical representation of FCM

According to Figure 3.1, W represents the weight of causality (W_{ij}) which is between the concepts. The weight of causality takes values in the range [-1, 1]. The range of numbers refers fuzzy numbers. On the other hand, the weight of causality is expressed by linguistic variables such as "positive very strong", "zero", "negative very strong" etc. Linguistic variables and fuzzy numbers representing linguistic variables are given in Table 3.1. The explanations of the linguistic variables in Table-1 are negatively very strong (nvs), negatively strong (ns), negatively medium (nm), negatively weak (nw), zero (z), positively weak (pw), positively medium (pm), positively strong (ps), positively very strong (pvs), respectively.

Table 3.1 States of set T (Ahmadi, Yeh, Martin, & Papageorgiou, 2015)

Fuzzy membership function (triangular)	**Triangular membership region**
$\boldsymbol{\mu_{nvs}}$ = negatively very strong	(-1, -1, -0.75)
$\boldsymbol{\mu_{ns}}$ = negatively strong	(-1, -0.75, -0.50)
$\boldsymbol{\mu_{nm}}$ = negatively medium	(-0.75, -0.50, -0.25)
$\boldsymbol{\mu_{nw}}$ = negatively weak	(-0.50, -0.25, 0)
$\boldsymbol{\mu_{z}}$ = zero	(-0.25, 0, 0.25)
$\boldsymbol{\mu_{pw}}$ =positively weak	(0, 0.25, 0.50)
$\boldsymbol{\mu_{pm}}$ =positively medium	(0.25, 0.50, 0.75)
$\boldsymbol{\mu_{ps}}$ =positively strong	(0.50, 0.75, 1)
$\boldsymbol{\mu_{pvs}}$ =positively very strong	(0.75, 1, 1)

The $\mu_{i(x)}$ values in Table 3.1 are fuzzy membership functions. In Figure 3.1, there is a graph showing the fuzzy membership functions and the values of the membership function.

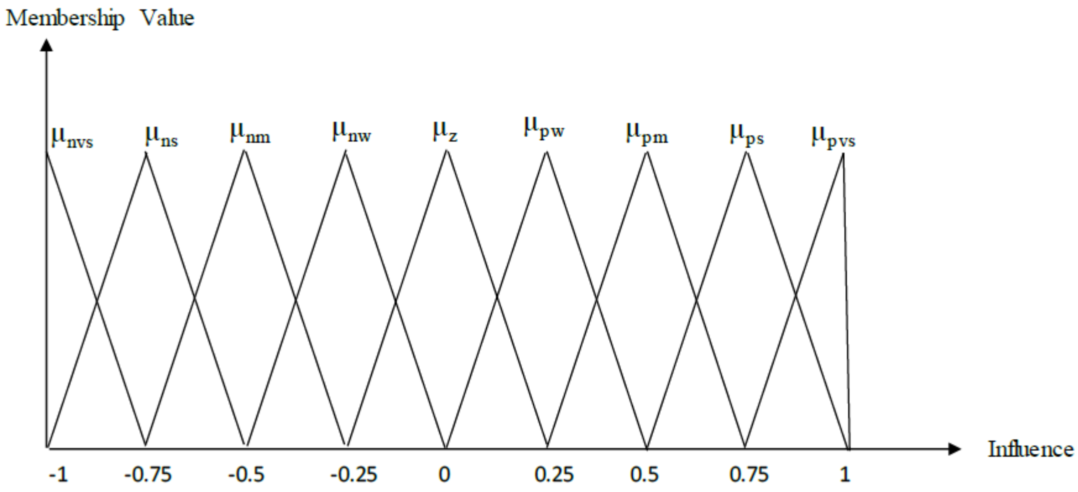

Figure 3.2 The defuzzification numbers in the FCM

Converted to numbers in the range [-1,1] or [0,1] by defuzzification methods. The defuzzification numbers in the FCM are the causal weight shown in Figure 3.2.

The sign of W_{ij} shows different states of the causal relation between two concepts: (Ma, Yu, & Zhang, 2019)

- $W_{ij} > 0$ indicates the influence of C_i on C_j is positive. In other words, an increase or decrease in C_i cause the same result in C_j;
- $W_{ij} < 0$ expresses the negative casual relation between C_i and C_j, which means the change of C_i will cause an opposite effect on C_j;
- $W_{ij} = 0$ suggests that there is no interconnection between C_i and C_j

The value A_i of each concept C_i in a moment k+1 is calculated by the sum of the former value of A_i in a precedent point t with the output of the value A_j of the cause node C_j in precedent moment k, n is the number of concepts and the value of the cause-effect link e_{ji}. The formulation of FCMs has the following form: (Papageorgiou, 2014).

$$Ai(k+1) = f\left(Ai(k) + \sum_{j=1}^{N} Aj(k) * eji\right) \tag{3.1}$$

To make a comparison between nodes The Threshold function f is a threshold (activation) function that converts the output value to a value in the range [0, 1] or [-1.1], and can take a concept to compare between nodes. Descriptions of the threshold function frequently used in the literature are as follows (Kahraman & Onar Çevik, 2015).

- *Sign (bivalent) threshold function* Formulation 3.2 gives either “0” or “1” values for the activation level of each concept which are equivalent “active” or “inactive”, respectively (Kahraman & Onar Çevik, 2015).

$$fsign(x) = \begin{cases} 0, & x \leq 0 \\ 1, & x \geq 0 \end{cases} \tag{3.2}$$

- *Trivalent threshold function* Formulation 3.3 gives more information on the activation levels, as it includes negative activation. Concepts in a trivalent threshold function can have three state values which are equivalent to “positive effect”, “no effect” and “negative effect”, respectively (Kahraman & Onar Çevik, 2015).

$$ftri(x) = \begin{cases} 1, & x > 0 \\ 0, & x = 0 \\ 1, & x < 0 \end{cases} \tag{3.3}$$

- *Sigmoid threshold function* Formulation 3.4 is a continuous activation function, that gives values of concept in the range [0,1] (Kahraman & Onar Çevik, 2015).

$$fsigm(x) = \frac{1}{1 + e^{-\lambda x}} \tag{3.4}$$

- *Hyperbolic tangent threshold function* Formulation 3.5 is also continuous sigmoid-shaped function which gives values of concept in the range [-1, 1] (Kahraman & Onar Çevik, 2015).

$$fhyp(x) = \frac{e^{\lambda x} - e^{-\lambda x}}{e^{\lambda x} + e^{-\lambda x}} \qquad (3.5)$$

New aspect vectors demonstrating the impact of the activated concept are computed using process of successive substitution, i.e., by iteratively multiplying the former aspect vector by the relational matrix using standard matrix multiplication $A^k = A^{k-1} + (A^{k-1} \cdot W)$. The iteration stops when a limit vector is reached, i.e., when $A^k = A^{k-1}$ or when $A^k - A^{k-1} \leq e$; where e is a residua, whose value is subject to the implementation type (and in most implementations are equal to 0.001). Thus, a final vector A f is acquired, where the decision concepts are evaluated to explane the conclusive decision of the particular decision support system (Papageorgiou, 2014).

3.3 A literature review on FCM

When the literature is examined, it is seen that FCM is used in many subjects such as health, social sciences, military, software, and engineering. Since the subject of the thesis is the subject of renewable energy biomass and biomass supply chain, in the literature study, studies using FCM method on energy and supply chain were examined. The content of the literature study for FCM consists of biomass energy, solar energy, wind energy, other energy sources, supply chain and sustainable supply chain, respectively.

In FCM studies used in biomass energy, especially studies on the social acceptability of conversion facilities have been found. Besides one production of bioethanol from biowaste have been found. Lopolito, Prosperi, Maruotti, & Meo (2012) presented the significance of social acceptance of large biomass plants projects. The paper claims social acceptance plays a notable function for investors, which invest their resources to construct a biomass plants, and policy makers. In the study, a semi-quantitative technique based on FCMs method is used to understand the importance of social acceptance in biomass plants of investors and policy makers group experts. Sacchelli (2014) focused on NIMBY effect, which means public opposition, for constructing a biomass plant. The paper developed FCM process and nonlinear modelling figured out by the Social Cognitive Optimisation (SCO) to analyse the NIMBY effect on planning of biomass plants. In order to better interpret the impact, a case study was conducted at a Combined Heat and Power (CHP) facility in Tuscany, in central Italy. Konti & Damigos (2018) developed Fuzzy Cognitive Mapping for analyzing production of bioethanol from biowaste. In this study, the opinions of the stakeholders with different perspectives on social, economic and political factors about bioethanol production biowaste process from are included. Scenario analysis is also included in the study to examine the effects of different situations. Ma, Yu, & Zhang (2019) focused on to promote the development of biomass through enhancing public acceptance. The study includes intuitionistic fuzzy cognitive map (IFCM) to analyse the opinions of active participation of the various stakeholders, such as the government, the industry, and the local residents on different biomass public acceptance factors.

The studies of solar energy, which are include FCM solution method, are about energy convension efficiency, and attractiveness of photovoltaic, capacity, investment and solar energy price. Kottas, Boutalis, & Karli (2006) presented a fuzzy set theory to enhance energy transformation productivity for photovoltaic (PV) generation. On the other hand, the study describes a fuzzy cognitive network, which is in close cooperation with the presented fuzzy controller. Thanks to the presetend methods, maximum power operation of any PV array under different conditions is observed. Karlis, Kottas, & Boutalis (2010) developed Maximum power point trackers (MPPTs) procedure based on fuzzy cognitive networks (FCN) about photovoltaic (PV) power systems. The method evaluates maximum power operation of any PV array under different conditions. The proposed MPPT PV arrays provide a very good maximum power operation under different conditions such as changing sunbathing and temperature. Jetter & Schweinfort (2011) proposed a scenario building method based on Fuzzy Cognitive Maps to identify the attractiveness of photovoltaic (PV) systems. The study includes various photovoltaic systems supply chain stakeholders such as customers which are considered buying PV panels, forecasters which are considered professors of PV panel’s technology as decision maker experts. Besides, the study includes two different scenarios to analyse the model. Çoban, & Çevik Onar (2016) developed Fuzzy Cognitive Map process to model solar generation capacity. The study defines factors of generation solar energy such as global treaties, energy cost and energy supply. Thanks to the scenario analysis, the study investigates eight different scenario about factors of solar generation capacity. Çoban, & Çevik Onar, (2017a) developed Hesitant Fuzzy Cognitive Maps (HFCM) to make decision about solar energy investment. The study includes different scenario analysis and a case study. On the other hand, the study emphasise the advantages of the HFCM. Çoban, Çevik Onar, & Sezi (2018) concentrate on the solar energy prices to analyse the factors of solar energy prices. The paper represents the casual relations factors and the initial state values of the factors which are signed by linguistic variables. The linguistic variables are converted into Trapezoid Fuzzy Membership Functions (TFMFs). The chapter includes various scenarios to analyse the factors of solar energy prices.

In FCM studies used in wind energy are about importance wind energy for developed countries. Amer, Jetter, & Daim, (2011) presented a Fuzzy Cognitive Map (FCM) based scenarios to understand the effect of economic growth and governmental policies towards wind energy on deployment of wind energy. Amer, Jetter, & Daim (2013a) developed FCM based scenarios to investigate the national wind energy sector of a developing country. Thanks to developed scenarios, future sight of the national wind energy sector is established by specialist of wind energy. The scenarios are to examine the impact of economic growth, government policies and greenhouse gas impact on other factors, respectively. These scenarios provide the basis for making long-term plans in the renewable energy sector. Besides, the scenarios represent future perspectives on wind energy. (Amer, Daim, & Jetter (2013b) developed Fuzzy Cognitive Map (FCM) based scenario analysis which includes qualitative and quantitative factors about wind energy in developed countries. On the other hand, the chapter includes a comparison developed FCM-based scenarios with other prominent quantitative scenario development techniques. Amer, Daim, & Jetter (2015) presented an extended technology road mapping (TRM) through FCM-based scenario analysis to understand a national-level wind energy roadmap. TRM includes four levels. The names of the levels are strategic objectives, targets, barriers, and action, respectively. The combination of fuzzy based scenario analysis and TRM are used a case study, which is applied to the wind energy sector of Pakistan.

Other energy-related studies using the FCM method have been found in hybrid energy systems, renewable energy systems and waste energy. Karagiannis, & Groumpos (2013) proposed a model to determine an acceptable combination of energy components for procuring a hybrid energy system. Proposed model contains Fuzzy Cognitive Mapping (FCM) and learning algorithms. On the other hand, the paper includes scenario analysis to obtain verified the effectiveness and reliability of the proposed hybrid energy system. Kyriakarakos, Patlitzianas, Damasiotis, & Papastefanakis (2014) proposed a decision-making model for local planning of renewable energy. The decision-making model includes design and implementation of Fuzzy Cognitive Map (FCM) and decision support toolkits (DST) In the paper, the evaluation of RES investment in a local community are affected parameters such as legal, regulative, administrative, financial, technical, social and environmental etc. On the other hand, the paper includes scenario analysis to procure efficient solution from decision making model. Çoban, & Çevik (2017b) emphasised the importance of the identification of the correct technologies and procedures to make more productive consumption of renewable energy resources, which are solar and wind energy for the paper. The paper developed hesitant linguistic cognitive map method that is an extension of hesitant fuzzy sets and fuzzy cognitive map. The system is analysed by scenario analysis. Therefore, the model helps investors and governments to incisive their solar and wind energy investment determinations. (Kokkinos, Lakioti, Papageorgiou, Moustakas, & Karayannis (2018) focused on social acceptance of Sustainable Waste Biorefinery Facilities (WBFs). In order to the analyze the socio-economic implications and to overcome uncertainties such as environmental, social etc. in Sustainable Waste Biorefinery Facilities, the paper developed Fuzzy Cognitive Map (FCM) model which includes experts opinion and statistical results from surveys distributed to stakeholders participate in the concept circumscription. Besides, the paper includes static and dynamic analyze of the model results.

Supply chain and sustainable supply chain issues including FCM, include supply chain decision steps, risk management, supply chain cooperation, supply chain performance evaluation. Büyüközkan, & Vardaloğlu (2003) development a FCM to analyze the Collaborative planning, forecasting and replenishment (CPFR) coordination on different supply chain management activities. Thanks to the FCM, the relationship between the factors about CPFR in supply chain. Chen, & Wang (2006) presented a FCM simulation model FCM simulation model for the sample performance measurement system of Internet-based supply chain that is developed by Balance Scorecard (BSC). On the other hand, the paper presented promotes group decision-making and forecasting in performance measurement. Feyzioglu, Buyukozkan, & Ersoy (2007) developed a Cognitive Map approach to analyze supply chain risk factors which are about to supply with the customer satisfaction. The approach includes decision variables and uncontrollable variables. Kim M. C., Kim, Hong, & Kwon (2008) developed a Fuzzy Cognitive Map (FCM) model for supply chain management. The model detects static and dynamic states in a supply chain. In the same time, the paper focus on Radio frequency identification (RFID) technology which control the uncontrollable external states with probabilistic behaviours in a supply chain. Ustundag, & Tanyas (2008) developed a FCM approach to measure the impact of Radio frequency identification (RFID) investment in a supply chain process. The factors of the study are tangible and intangible benefits of RFID in supply chain management. Pandari, & Azar (2017) developed a FCM model for service supply chain performance evaluation (SSCPE). The study focuses on strategic, tactical and operational factors for service supply chain. Azhdari (2018) developed a hybrid model which includes fuzzy cognitive mapping (FCM) and causal Bayesian network (CBN) learning. This study focuses on causal links among supply chain opportunities, supply chain management and supply chain productivity. Fuzzy causal knowledge of a committee of decision-makers in SCM is examined using FCM and industry survey data are examined using CBN. Findings of the study are SC opportunities, especially IT technologies that don't have direct impact on SC performance

Irani, Kamal, Sharif, & Love (2017) focused on the impact of Knowledge Management (KM) in Green Supply Chain Collaboration (GrSCC). The paper analysis the relationship between represented GrSCC factors utilising FCM. Thanks to the solution of analysis, a futures-based point of view that improves understanding and refines forward-looking ways for GrSCC is revealed. (Mirghafoori, Sharifabadi, & Takalo (2018a) utilised a FCM process for sustainable supply chain of health services. The study includes a case study which is in Kerman, Iran. On the other hand, the study contents quantitative samples using random sampling method. Finding of the study is service delivery management that the most important impact of sustainable supply chain in hospital. Mirghafoori, Sharifabadi, & Takalo, (2018b) developed Fuzzy Cognitive Map (FCM) to detect the sustainability of a hospital service supply chain. On the other hand, Delphi Method is utilised to identify the initial concepts into 15 concepts of sustainability of a hospital service supply chain which are customer relationship management, supplier relationship management, service management etc. According the study findings, service delivery management is the most important concept for sustainability of a hospital service supply chain.

Shokouhyar, Pahlevani, & Sadeghi (2019) developed scenario analysis based on Fuzzy Cognitive Map (FCM) for smart sustainable supply chains. The study contents seven factors groups such as economic internet of things (IoT), green internet of things, social internet of things etc. This study emphasizes the importance of the Internet of Things in achieving a sustainable supply chain.

The classification and chronological order of the studies about FCM in energy, supply chain and sustainable supply chain in the literature are given in Table 3.2

Table 3.2 Studies with FCM in type of energy and supply chain management

Sort of Study	References	Year
Biomass Energy	Lopolito, Prosperi, Maruotti, & Meo (2012)	2012
	Sacchelli (2014)	2014
	Konti, & Damigos (2018)	2018
	Ma, Yu, & Zang (2019)	2019
Solar Energy	Kottas, Boutalis, & Karlis (2006)	2006
	Karlis, Kottas, & Boutalis (2007)	2007
	Karlis, Kottas, & Boutalis (2010)	2010
	Jetter, & Schweinfort (2011)	2011
	Çoban, & Çevik Onar (2016)	2016
	Çoban, & Çevik Onar (2017a)	2017
	Çoban, & Çevik Onar (2018)	2018
Wind Energy	Amer, Jetter, & Daim (2011)	2011
	Amer, Jetter, & Daim (2013a)	2013
	Amer, Daim, & Jetter (2013b)	2013
	Amer, Daim, & Jetter (2015)	2015
Hybrid Energy	Karagiannis, & Groumpos (2013)	2013
Renewable Energy	Kyriakarakos, Patlitzianas, Damasiotis, & Papastefanakis (2014)	2014
	Çoban, & Çevik Onar (2017b)	2017
Waste	Kokkinos, Lakioti, Papageorgiou, Moustakas, & Karayannis(2018)	2018
Supply Chain	Büyüközkan, & Vardaloğlu (2003)	2003
	Chen, & Wang (2006)	2006
	Feyzioglu, Buyukozkan, & Ersoy (2006)	2006
	M. Kim, C. O. Kim, Hong, & Kwon (2008)	2008
	Ustundag, & Tanyas (2008)	2008
	Pandar, & Azar (2017)	2017
	Azhdari (2018)	2018
Supply Chain Sustainability	Irani, Kamal, Sharif, & Love (2017)	2017
	Mirghafoori, Sharifabadi, & Takalo (2018a)	2018
	Mirghafoori, Sharifabadi, Takalo, & Karimi (2018b)	2018
	Shokouhyar, Pahlevani, & Sadeghi (2019)	2019

CHAPTER FOUR

APPLICATION OF FCM ON PRIORITIZATION OF SUSTAINABILITY CRITERIA ON DETERMINING THE SUITABILITY OF DIFFERRENT REGIONS FOR CONSTRUCTING BIOMASS TO ENERGY SYSTEMS

In this chapter of the thesis, FCM solution method is used to identify the interaction of the criteria affecting the location selection for biomass to energy plants and to analyse the interaction of these criteria with different scenarios. There is a cause-effect relationship between the criteria used to determine the appropriate location for the plants that obtain energy from biomass. The main reason for using fuzzy cognitive mapping in this section is the use of linguistic variables in fuzzy cognitive mapping. By using linguistic variables easily, opinions can be obtained from expert decision makers. On the other hand, fuzzy cognitive mapping analyzes by taking into account the points that experts do not express.

In addition to other classical Multi Criteria Decision Making Methods, Fuzzy Cognitive Mapping provides the ability to convert linguistic variables into fuzzy numbers, to enable decision making using fuzzy numbers, to work in situations where there is no relationship between criteria, and to make detailed decisions with different scenario analyzes.

Firstly, the sustainability factors that influence the location selection of the plants that obtain energy from biomass are determined. These are the concept variables of the FCM. Secondly, the relationship between these concepts and face-to-face interviews with experts in the biomass to energy field is determined using linguistic variables. Third, the linguistic variables identified by the experts are converted to fuzzy numbers. Fourthly, fuzzy number matrices formed as a result of the experts' opinions were aggregated with MATLAB application developed within the scope of the thesis. Fifthly, deffuzification is performed with MATLAB application developed within the goal of the thesis. Sixthly, the weighted matrix is formed with the obtained defuzzifying numbers. Seventhly, FCM map is created. Eighthly, the values of the concepts are obtained and evaluated as a result of FCM. Finally, different scenarios are developed and analyzed.Figure 4.1 provides details of the steps that form the methodology of this thesis.

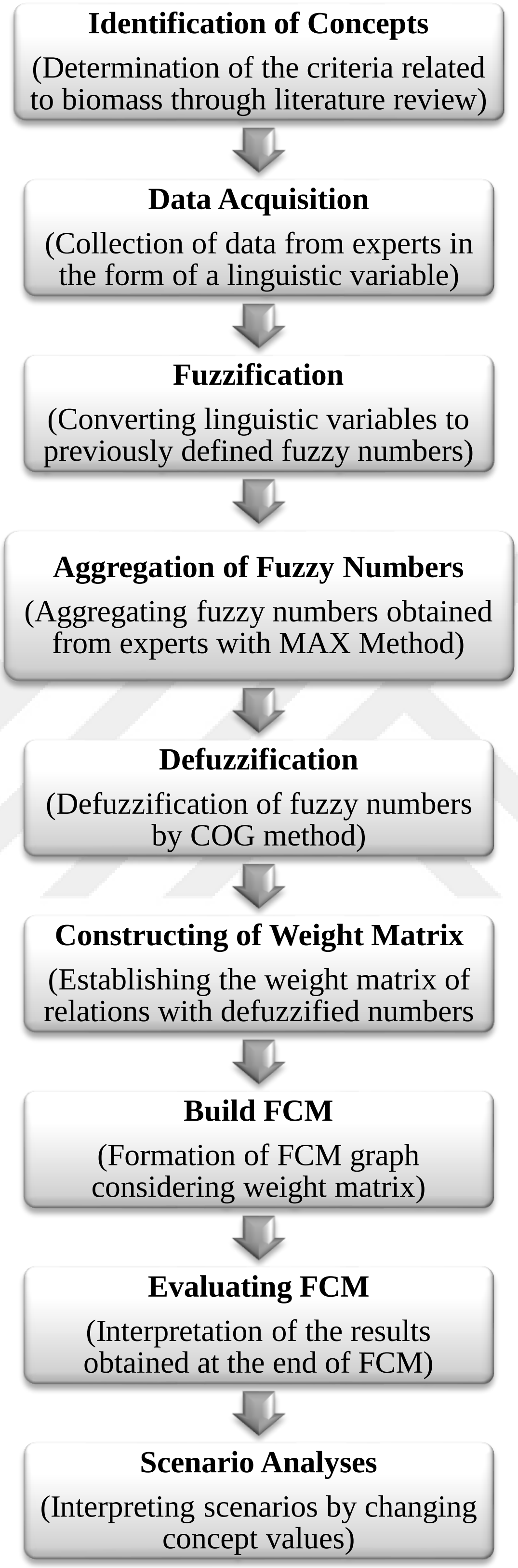

Figure 4.1 FCM steps

4.1 Determination of Sustainability Factors

The concept of sustainability is very important for the supply chain, as resources are limited and risks vary. Time-dependent degradation of resources used to obtain energy from biomass, timely and uninterrupted transmission of the energy released after the conversion to obtain energy from the biomass are the main risks of supply chains created to extract energy from biomass. The selection of the location should be targeted to minimize these risks. Considering the aforementioned risks, sustainability is an issue that needs to be emphasized when selecting the location of the plants that convert energy from biomass.

In this thesis, the factors determined for location selection are divided into four parts. These are economic sustainability factors, technical sustainability factors, environmental sustainability factors and social sustainability factors, respectively. Table 4.1 presents sustainability factors. When Table 4.1 is examined, sustainability factors, factors sub-criteria (factors emerged as a result of the combination of sub-criteria) and references in the literature are seen.

Table 4.1 Sustainability classifications of factors

Sustainability Classifications	Label	Sustainability Factors	Sub-criteria	References
Economic	F1	Biomass Prices	-	(Marvin, Schmidt, Benjaafar, Tiffany, & Daoutidis, 2012)
	F2	Regional Economy	Political Instability Economic Crisis	(Vilko, Ritala, & Hallikas, 2019)
	F3	Regional Financial Facilities	Profit Risk Dept Risk Operational Risk Cash Flow Risk Exchange Rate Risk	(Jiang, Li, & Shen, 2018)
	F4	International Trade Capability	International Trade Risk	(Jiang, Li, & Shen, 2018)
	F5	Regional Competition	Competitor price	(Qazi, Dickson, Quigley, & Gaudenzi, 2018)
	F6	Sufficiency of Plant And Storage Area	-	(Balaman Yılmaz, 2019)
	F7	Energy and Fuel Sale Prices	Fuel Prices	(Vilko, Ritala, & Hallikas, 2019)
	F8	Land Cost and Constraction Cost, Equipment Cost	-	
	F9	Regional First Generation Biofuel Production Potential	-	(Balaman Yılmaz, 2019)
	F10	Agricultural Production Potential for Second Generation Biofuel	-	(Balaman Yılmaz, 2019)
	F11	Total Organic Waste Potential	-	(Balaman Yılmaz, 2019)
Technical	F12	Transportation Network Capacity	Conditions of Transports Equipment Lack of Intermodal Equipment	(Vilko, Ritala, & Hallikas, 2019)
	F13	Transportation Network Expansion Opportunities	The Improvement of The Ship Plan The Improvement of The Handling The Improvement of The Storage The Improvement of The Transfer The Improvement of The Distribution	(Jiang, Li, & Shen, 2018)
	F14	Traffic Congestion	Traffic Accidents Traffic Jams	(Vilko, Ritala, & Hallikas, 2019)
	F15	Communication and IT Capacity	IT Vulnerability Problems in Telephone Connections	(Vilko, Ritala, & Hallikas, 2019)
	F16	Sufficiency of Technological Facilities Companies	-	(Balaman Yılmaz, 2019)
	F17	Constriction Capability	-	(Balaman Yılmaz, 2019)
Environmental	F18	Pollution	-	(Giannakis & Papadopoulos, 2016)
	F19	Emission of Greenhouse Gases, Ozone Depletion (Air Pollution)	-	(Giannakis & Papadopoulos, 2016)
	F20	Density of Underground and Surface Water Resources	-	(Balaman Yılmaz, 2019)
	F21	Density of Forest Areas	-	(Balaman Yılmaz, 2019)
	F22	Density of Protected Wild Areas	-	(Balaman Yılmaz, 2019)
Social	F23	Sufficiency and Competence of Workforce	Workers Poor Motivation Irresponsibility Insufficient Knowledge Not Enough Personnel	(Vilko, Ritala, & Hallikas, 2019)
	F24	Contribution of Rural Development	Development Risk	(Jiang, Li, & Shen, 2018)
	F25	Terrorism and Wars Potential	Terrorism and Wars Risk	(Jiang, Li, & Shen, 2018)
	F26	Energy Security	-	(Balaman Yılmaz, 2019)
	F27	Job Creation	-	(Balaman Yılmaz, 2019)
	F28	Social Acceptability	-	(Balaman Yılmaz, 2019)

4.1.1 Determination of Economic Sustainability Factors

Economic sustainability is important for biomass to energy systems to continue the system existence in the market of energy, to utilize all types of limited resources, to compete with a competitor in the market. Therefore, the economic conditions have to be taken into account when selecting the most proper location for the construction of the biomass to energy systems. The explanation of the economic sustainability criteria in Table 4.1 is as follows:

- *Biomass prices*

It refers to cost of biomass which are used to obtain energy in the system. The first-generation biomass and the second generation of biomass have prices. However, animals and plants wastes have not prices.

- *Regional economy*

It represents economic conditions of the regions, main economic activities, economic and political stability of the region.

- *Regional financial facilities*

It denotes to the capacity and the number of lending banks in the region in order to supply financial credits for investors who intent to construct a biomass to energy plant and to support operation financial risks.

- International Trade Capability

It refers to the region's trade capacity export and import rates and its export and import products. It also represents trade risks and how to deal with them.

- *Regional competition*

It signifies the level of competitiveness of the region in energy sales with other regions.

- *Sufficiency of plant and storage area*

It refers to empty areas in the region for constructing plants that convert electrical energy or heat energy from biomass and for constructing warehouses which are system needs.

- *Energy and fuel sale prices*

It represents sales prices of energy and fuel in the region, which is the output of the system.

- *Land and construction cost, equipment cost*

It denotes the price of the areas suitable for constructing of the system and the cost of the construction required for constructing of the system. In addition, the cost of the equipment to be used in the constructing of the system.

- *Regional first generation biofuel production potential*

The raw materials of the first generation biofuels are obtained from food crops. Examples are corn, sugar beets, sugarcane, and any sugar or starch. The technological process utilised to produce first generation biofuel is named enzymation, or enzyme digestion that releases sugars from starchy materials in the feedstock. Awudu & Zhang (2012) represents the resources of the first generation biofuels are used in energy generation as well as food consumption.

Regional first generation biofuel production potential refers to the amount of growth of the first generation biomass in the region.

- *Agricultural production potential for second generation biofuel*

The resources for the second generation involve cellulosic materials, switchgrass, waste biomass, wheat stalks, corn stalks, wood, and special energy or biomass crops, e.g. Miscanthus. Second generation biofuels use liquid technology to transform solid biomass to biofuel (Inderwildi & King, 2009).

Agricultural production potential for second generation biofuel refers arable land in the region to produce second generation biofuel raw material.

- *Total organic waste potential*

It signifies to proportion of animal or plant organic waste generated in the period to be determined in the region.

4.1.2Determination of Technical Sustainability Factors

Technical sustainability is essential for the uninterrupted operation of a supply chain system that generates energy from a biomass. Technical sustainability includes the status of vehicles and roads in the supply chain, the communication capacity of the system and the technical infrastructure. At the same time, due to the rapid technological innovations today, sustainability is affected by the innovation.

- *Transportation network capacity*

It denotes capabilities of the railroad transportation, road transport, maritime transport for shipping inputs and outputs of the biomass to energy plants. On the other hand, this criterion refers to the conditions of transport equipment and vehicles.

- *Transportation network expansion opportunities*

It signifies the capabilities of the improvement of the shipping plan, transfer capacity, distribution network, and number of vehicles.

- *Traffic congestion*

It refers to the traffic density of the region and the technologies developed to solve the traffic density

- *Communication and IT capacity*

It signifies the capacity of the region to have strong and wide communication networks and the level of software technical and technology required to ensure the management of the system to be developed

- *Sufficiency of technological facilities companies*

It denotes the condition of the technology developing companies in the region in order to determine the technical and technological infrastructure of the environment where the plant is located.

- *Construction capability*

It represents the construction companies in the region have the techniques and technologies to build the biomass to energy plants.

4.1.3 Determination of Environmental Sustainability Factors

Recently, with the increase of environmental awareness and the importance of environmental laws worldwide, it is expected that plants that convert energy from biomass will adapt to environmental conditions and have a positive influence on the environment.

- *Pollution*

It refers the solid liquid wastes of the region and the ratio of these wastes to soil, water.

- *Emission of greenhouse gases, ozone depletion (Air pollution)*

It denotes greenhouse gas emissions and air pollution values of the region.

- *Density of underground and surface water resources*

It signifies underground and surface waters, rivers and lakes in the region.

- *Density of forest areas*

It represents the density of forested areas in the region.

- *Density of protected wild areas*

It refers the density of national parks and protected areas in the region.

4.1.4 Determination of Social Sustainability Factors

Social sustainability refers the positive or negative impacts on issues such as justice, business ethics, ethics, community welfare, social equality, human rights, health and cultural impact in the region where the biomass to energy plant be construct. On the other hand, it indicates whether the facility to be constructed can survive under social influences.

- *Sufficiency and competence of workforce*

It denotes qualities the employee that are planned to work in the system such as work motivation, irresponsibility, knowledge, etc.

- *Contribution of rural development*

It represents the potential of the system to be established, especially in rural areas, economic and social development of the region.

- *Terrorism and wars potential*

It signifies possibility of terrorist acts resulting from the political situation in the region where the system is planned to be constructed or the possibility of the region entering a war.

- *Energy security*

It refers to the transportation of energy resources to the end customer without any problems. In addition, reducing energy dependency and providing energy at an affordable price to meet energy needs in the long term are under the heading of energy security.

- *Job creation*

It denotes possibility of job opportunities in the region where the plant that convert energy from the biomass to be installed will be established.

- *Social Acceptability*

It refers to the tendency of the social environment to accept the effects of the system to be established on the social environment.

4.2 Data Acquisition

In this part of the thesis, data were collected through face-to-face interviews from 3 experts who are experts in biomass, biomass power plants and biomass sustainable supply chain. Experts considered the following steps when evaluating relationships between concepts.

If concept C_i is increasing / decreasing, and concept C_j is increasing / decreasing, the linguistic variables found in the positively part are used according to the degree of change.

- If concept C_i is increasing / decreasing, and concept C_j is decreasing/ increasing, the linguistic variables found in the negatively part are used according to the degree of change.
- If there is no relationship between the two concepts, zero is used.
- If experts do not provide an opinion, that relationship is left blank.

The linguistic variables in Table 3.1 were used for data collection. Table 4.2, Table 4.3 and Table 4.4 contain data from experts.

Table 4.2 Linguistic variables from expert-1

Ex.-1	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22	F23	F24	F25	F26	F27	F28
F1	z	ps	pw	ns	ns	pw	ps	pm																				
F2	ps	z	pvs	pvs	pvs		ps	ps				pm	pm	pm	pm	ps	ps	pm	pm	ps	ps	ps	ps	ps			pvs	
F3	pw	ps	z	pvs	pvs		ps	ps							pm	ps							pw				ps	
F4	ns	pvs	pvs	z	pvs	pvs	ps	pm						pvs	ps	ps	ps										pvs	
F5	ns	pvs	pvs	pvs	z	ps	pm	ps						pvs	ps	pm		ps	pvs								pvs	
F6	pw			pvs	ps	z		nvs									ps							ps			pm	
F7	ps	ps	ps	ps	pm		z							nvs				nvs	nvs							ns		
F8	pm	ps	ps	ps	pm	pn	nvs	z	nvs	nvs							ns							nm			nm	
F9								nvs	z	nw				pw				nm	nm								pm	
F10								nvs	nw	z				pw				nm	nm								pm	
F11											z							nm	nm									
F12		pm										z	nm	ns				ps	ps					ps			pm	
F13		pm										nm	z															
F14		pm		pvs	pvs		nvs		pw	pw		ns		z				pvs	pvs									
F15		pm	pm	ps	ps										z	pvs								ps			ps	
F16		ps	ps	ps	pm											z								ps			ps	
F17		ps		ps		ps		ns									z	ps	ps					ps			ps	
F18		pm			ps		nvs		nm	nm	nm	ps		pvs			ps	z	pvs									
F19		pm		pvs		nvs		nm	nm	nm	ps		pvs			ps	pvs		z									
F20		ps																		z								
F21		ps																			z							
F22		ps																				z						
F23		ps	pw																				z				pvs	
F24		ps				ps		nm				ps			ps	ps	ps							z			pvs	
F25																									z			
F26							ns																			z		
F27		pvs	ps	pvs	pvs	pm		nm	pm	pm		pm			ps	ps	ps						pvs	pvs			z	
F28																												z

Table 4.3 Linguistic variabes from expert-2

Ex.-2	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22	F23	F24	F25	F26	F27	F28
F1	z				nw		pm		nw	nw		z	z	z	z	z	z	ns	ns		nw		nw	nw		nm	nw	
F2	pw	z	pvs	pvs	pvs		pw	pm	pm	pm	pm	pm	pm	pm	pw	pw	pm	pm	pm	pm	nw	nw	pm	pm		pm	pm	pw
F3	pw	pvs	z	ps	ps		pw	pm	pm	pm	pw	pm	pm	pm	pw	pw	pw	pm	pm	pm	nw	nw	pm	pm		pm	pm	pm
F4	pw	pvs	pvs	z	pm		pm	pm	pm	pm	pw	pm	pm	pm	pw	pm	ps	ps	pm	ps	nw	nw	ps	pm		pw	pm	pw
F5	nw	pw	pw	pw	z		nw	nw	nw	nw	nw	nw	nw	nw	nw	nw	nw	nm	nm	nm	nw	nw	nm	nm		nw	nm	nm
F6						z																						
F7	pm				nw		z		nw	nw		z	z	z	z	z	z	ns	ns		nw		nw	nw		nm	nw	
F8	pvs	nm	nm	nm	nm		nw	z	nm	ns	nm	ns	nw	nw	nw	nw	nw	nw	nw	nw	pw	pw	nw	nw		nw	nm	nm
F9	ns	pm	pm	pm	pm		nw		z	ps	pvs	pw	pw	pw	pw	pw	pw	nw	nw	nw	nw	ns	ps	ps		pm	pm	pm
F10	ns	pm	pm	pm	pm		nw		ps	z	pvs	pw	pw	pw	pw	pw	pw	nw	nw	nw	nw	ns	ps	ps		pm	pm	pm
F11	nw	pw	pw	pw	pw		nw	z	z	z	z	pw	pw	pw	pw	pw	pw	pm	pm	pw	z	z	pw	pw		pw	pw	pw
F12	nw	pvs	pvs	pvs	ps		nw	pw	pw	pw	pw	z	pvs	pvs	pm	pm	pm	pw	pw	pw	nw	nw	pm	pm		pm	pm	pm
F13	nw	pvs	pvs	pvs	ps		nw	pw	pw	pw	pw	pvs	z	nvs	pm	pm	pm	pw	pw	pw	nw	nw	pm	pm		pm	pm	pm
F14	nw	pvs	pvs	pvs	ps		nw	pw	pw	pw	pw			z	pm	pm	pm	pw	pw	pw	nw	nw	pm	pm		pm	pm	pm
F15		pw	pm	pm	pm		z	z	z	z	z	nw	nw	nw	z	ps	pw	z	z	z	z	z	pm	pm		z	pm	pm
F16		pw	pm	pm	pm		z	z	z	z	z	nw	nw	nw	pvs	z	pw	z	z	z	z	z	pm	pm		z	pm	pm
F17		pm	pm	pm	pw		z	nw	z	z	z				pw	pw	z	pw	pw	pw	nm	nm	pm	pm		nw	pm	pm
F18		nw	nw	nw	nw		z	ns	ns	ns	ns	nw	nw	nw	z	z	z	z	pvs	z	z	z	z	nw		nw	nw	nvs
F19		nw	nw	nw	nw		z	ns	ns	ns	ns	nw	nw	nw	z	z	z	pvs	z	z	z	z	z	nw		nw	nw	nvs
F20	nw	pw	pw	pw	pw		nw	nw	pw	pw	pw	pw	pw	pw				nm	nm	z	pvs	z	pw	pw		z	z	pvs
F21	nw	pw	pw	pw	pw		nw	nw	pw	pw	pw	pw	pw	pw				nm	nm	z	z	z	pw	pw		z	z	pvs
F22	nw	pw	pw	pw	pw		nw	nw	pw	pw	pw	pw	pw	pw				nm	nm	z	z	z	pw	pw		z	z	pvs
F23	nw	pvs	pvs	pvs	pvs		nw	nw	pw	pw	pw	pm	pm	pm	pw	pw	pw	nm	nm	z	z	z	z	pvs		nm	pm	pm
F24	nw	pvs	pvs	pvs	pvs		nw	nw	pw	pw	pw	pm	pm	pm	pw	pw	pw	nm	nm	z	z	z	pvs	z		nm	pm	pm
F25	pm	nvs	nvs	nvs	nvs		pm	ns	ns	ns	ns	nvs	nvs	nvs	nvs	nvs	nvs	nvs	nvs	z	z	z	nvs	nvs	z	nvs	nvs	nvs
F26	nw	pm	pm	pm	pm		nw	z	pw	pw	pw	pw	pw	pw	pw	pw	pw	nm	nm	nw	z	z	pm	pm		z	pm	pm
F27	nw	pvs	pvs	pvs	pvs		nw	nw	pw	pw	pw	pm	pm	pm	pw	pw	pw	nm	nm	z	z	z	pvs	pvs		nm	z	pm
F28	nw	pw	pw	pw	pw		nw	nw	pw	pw	pw							pw	pw					pw		pw	pw	z

Table 4.4 Linguistic variables from expert-3

Ex.-3	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22	F23	F24	F25	F26	F27	F28
F1	z	pm	pm	z	pw	pvs	nw	pw	pvs	pvs	pvs	pm	ps				ps	z	z	z	nw	pm	pm	pvs		pvs	pvs	pvs
F2	nvs	z	z	pm	pw	z	pw	pm	pw	nm	pvs	pw	pvs	nm	pvs	pvs	pvs	nvs	nvs	nvs	nvs	nvs	pvs	pw		z	pvs	ps
F3	z	pvs	z	pvs	pw	z	z	nw	z	z	z	pvs	pvs	nw	pvs	pvs	pvs	nvs	nvs	nvs	nvs	nvs	pvs	z		pw	ps	ps
F4	pw	pvs	pvs	z	pvs	z	z	pm	z	z	z	ps	ps	nm	pm	pvs	nm	nm	nm	nm	nm	nm	pvs	pm		pvs	ps	ps
F5	z	pvs	z	pvs	z	z	z	nvs	z	z	pm	pvs	pvs	nvs	pvs	pvs	pvs	nm	nm	nm	nm	nm	pvs	nvs		pm	pvs	pvs
F6	nvs	z	z	z	z	z	nvs	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z		z	z	z
F7	pvs	nm	z	z	pvs	z	z	z	pm	pm	z	pw	ps	nvs	nvs	nvs	z	pvs	pvs	z	z	z	pvs	pm		pvs	ps	pm
F8	pm	pvs	z	z	pm	pvs	z	z	pw	pw	z	z	z	z	z	z	pvs											
F9	nvs	pm	z	z	ps	pm	pvs	pm	z	nvs	pvs	pm	pm	nvs	z	z	z	pvs	pvs	z	z	z	ps	pvs		pvs	pvs	pvs
F10	nvs	pm	z	z	ps	pm	pvs	pm	nvs	z	nvs	pm	pm	nvs	z	z	z	pvs	pvs	z	z	z	ps	pvs		pvs	pvs	pvs
F11	z	pm	z	z	z	z	pw	z	pvs	nm	z	z	z	z	z	z	z	ps	ps	z	z	pw	pvs	pw		pm	pm	pm
F12	pw	pvs	pw	pvs	pvs	z	z	z	z	z	z	z	nvs	nw	z	z	pw	pvs	pvs	z	nw	nvs	pvs	pvs		z	pm	pw
F13	pw	pvs	pw	pvs	pvs	z	z	z	z	z	z	nvs	z	nw	z	z	pw	pvs	pvs	z	nw	nvs	pvs	pvs		z	pm	pw
F14	pw	pvs	pw	pvs	pvs	z	z	z	z	z	z	nvs	nw	z	z	z	pw	pvs	pvs	z	nw	nvs	pvs	pvs		z	pm	pw
F15	pvs	pvs	pvs	pvs	ps	z	z	z	z	z	z	z	z	z	z	pvs	z	nvs	nvs	pm	pm	z	nvs	nvs		pm	pvs	pw
F16	pm	pvs	pvs	ps	ps	z	z	nw	z	z	z	nw	nvs	nvs	pvs	z	nvs	nvs	nvs	z	pw	z	nvs	pm		pm	nvs	nvs
F17	z	pw	pvs	z	pm	z	z	pvs	z	z	z	z	pvs	nvs	z	z	z	nw	nw	z	nvs	nw	ps	nvs		z	pvs	pvs
F18	nm	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	pvs	nvs	nvs	z	z	z		z	z	nw
F19	nm	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	pvs	z	nvs	nvs	z	z	z		z	z	nw
F20	pm	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z
F21	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	nvs	nvs	z	z	z	z	z	z	z	z	z
F22	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z
F23	z	pvs	z	pvs	pvs	z	z	z	z	z	z	pw	pm	ns	pvs	pvs	nw	z	z	z	z	z	z	pw		z	pvs	pvs
F24	pvs	ps	z	z	pw	z	pm	z	pvs	pvs	pvs	pm	nvs	nvs	z	z	ns	ps	ps	z	pw	z	nw	z		z	pvs	pvs
F25	z	nvs	nvs	nvs	nvs	z	nvs	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	nw	z	nvs	z	nvs
F26	z	pm	z	pm	pvs	z	pvs	z	pw	pw	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	pvs
F27	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z
F28	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z	z

4.1 Fuzzification

At this step, linguistic variables from three experts are converted to fuzzy numbers. The fuzzy numbers in Table 3.1 are used in this process. The explanations of the linguistic variables are negatively very strong (nvs), negatively strong (ns), negatively medium (nm), negatively weak (nw), zero (z), positively weak (pw), positively medium (pm), positively strong (ps), positively very strong (pvs).

Table-8 refers linguistic variables and triangular fuzzy numbers corresponding to linguistic variables.

Table 4.5 Linguistic variables and triangular fuzzy numbers

Linguistic Variables	**Triangular fuzzy numbers**
nvs = negatively very strong	(-1, -1, -0.75)
ns = negatively strong	(-1, -0.75, -0.50)
nm = negatively medium	(-0.75, -0.50, -0.25)
nw = negatively weak	(-0.50, -0.25, 0)
z = zero	(-0.25, 0, 0.25)
pw =positively weak	(0, 0.25, 0.50)
pm =positively medium	(0.25, 0.50, 0.75)
ps =positively strong	(0.50, 0.75, 1)
pvs =positively very strong	(0.75, 1, 1)

In Table 4.6, Table 4.7 and Table 4.8, the translation of the linguistic variables specified by the experts into fuzzy numbers is given for the first ten concepts.

Table 4.6 The matrix of fuzzy numbers according to the expert-1 (first ten concepts)

Ex.-1	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	(-0.25,0,0.25)	(0.50,0.75,1)	(0,0.25,0.50)	(-1,-0.75,-0.50)	(-1,-0.75,-0.50)	(0,0.25,0.50)	(0.50,0.75,1)	(0.25,0.50,0.75)		
F2	(0.50,0.75,1)	(-0.25,0,0.25)	(0.75,1,1)	(0.75,1,1)	(0.75,1,1)		(0.50,0.75,1)	(0.50,0.75,1)		
F3	(0,0.25,0.50)	(0.50,0.75,1)	(-0.25,0,0.25)	(0.75,1,1)	(0.75,1,1)		(0.50,0.75,1)	(0.50,0.75,1)		
F4	(-1,-0.75,-0.50)	(0.75,1,1)	(0.75,1,1)	(-0.25,0,0.25)	(0.75,1,1)	(0.75,1,1)	(0.50,0.75,1)	(0.25,0.50,0.75)		
F5	(-1,-0.75,-0.50)	(0.75,1,1)	(0.75,1,1)	(0.75,1,1)	(-0.25,0,0.25)	(0.50,0.75,1)	(0.25,0.50,0.75)	(0.50,0.75,1)		
F6	(0,0.25,0.50)			(0.75,1,1)	(0.50,0.75,1)	(-0.25,0,0.25)		(-1,-1,-0.75)		
F7	(0.50,0.75,1)	(0.50,0.75,1)	(0.50,0.75,1)	(0.50,0.75,1)	(0.25,0.50,0.75)		(-0.25,0,0.25)			
F8	(0.25,0.50,0.75)	(0.50,0.75,1)	(0.50,0.75,1)	(0.50,0.75,1)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(-1,-1,-0.75)	(-0.25,0,0.25)	(-1,-1,-0.75)	(-1,-1,-0.75)
F9								(-1,-1,-0.75)	(-0.25,0,0.25)	(-0.50,-0.25,0)
F10								(-1,-1,-0.75)	(-0.50,-0.25,0)	(-0.25,0,0.25)

Table 4.7 The matrix of fuzzy numbers according to the expert-2 (first ten concepts)

Ex.-2	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	(-0.25,0,0.25)				(-0.50,-0.25,0)		(0.25,0.50,0.75)		(-0.50,-0.25,0)	(-0.50,-0.25,0)
F2	(0,0.25,0.50)	(-0.25,0,0.25)	(0.75,1,1)	(0.75,1,1)	(0.75,1,1)		(0,0.25,0.50)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.25,0.50,0.75)
F3	(0,0.25,0.50)	(0.75,1,1)	(-0.25,0,0.25)	(0.50,0.75,1)	(0.50,0.75,1)		(0,0.25,0.50)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.25,0.50,0.75)
F4	(0,0.25,0.50)	(0.75,1,1)	(0.75,1,1)	(-0.25,0,0.25)	(0.25,0.50,0.75)		(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.25,0.50,0.75)
F5	(-0.50,-0.25,0)	(0,0.25,0.50)	(0,0.25,0.50)	(0,0.25,0.50)	(-0.25,0,0.25)		(-0.50,-0.25,0)	(-0.50,-0.25,0)	(-0.50,-0.25,0)	(-0.50,-0.25,0)
F6						(-0.25,0,0.25)				
F7	(0.25,0.50,0.75)				(-0.50,-0.25,0)		(-0.25,0,0.25)		(-0.50,-0.25,0)	(-0.50,-0.25,0)
F8	(0.75,1,1)	(-0.75,-0.50,-0.25)	(-0.75,-0.50,-0.25)	(-0.75,-0.50,-0.25)	(-0.75,-0.50,-0.25)		(-0.50,-0.25,0)	(-0.25,0,0.25)	(-0.75,-0.50,-0.25)	(-1,-0.75,-0.50)
F9	(-1,-0.75,-0.50)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.25,0.50,0.75)		(-0.50,-0.25,0)		(-0.25,0,0.25)	(0.50,0.75,1)
F10	(-1,-0.75,-0.50)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(0.25,0.50,0.75)		(-0.50,-0.25,0)		(0.50,0.75,1)	(-0.25,0,0.25)

Table 4.8 The matrix of fuzzy numbers according to the expert-3 (first ten concepts)

Ex.-3	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	(-0.25,0,0.25)	(0.25,0.50,0.75)	(0.25,0.50,0.75)	(-0.25,0,0.25)	(0,0.25,0.50)	(0.75,1,1)	(-0.50,-0.25,0)	(0,0.25,0.50)	(0.75,1,1)	(0.75,1,1)
F2	(-1,-1,-0.75)	(-0.25,0,0.25)	(-0.25,0,0.25)	(0.25,0.50,0.75)	(0,0.25,0.50)	(-0.25,0,0.25)	(0,0.25,0.50)	(0.25,0.50,0.75)	(0,0.25,0.50)	(-0.75,-0.50,-0.25)
F3	(-0.25,0,0.25)	(0.75,1,1)	(-0.25,0,0.25)	(0.75,1,1)	(0,0.25,0.50)	(-0.25,0,0.25)	(-0.25,0,0.25)	(-0.50,-0.25,0)	(-0.25,0,0.25)	(-0.25,0,0.25)
F4	(0,0.25,0.50)	(0.75,1,1)	(0.75,1,1)	(-0.25,0,0.25)	(0.75,1,1)	(-0.25,0,0.25)	(-0.25,0,0.25)	(0.25,0.50,0.75)	(-0.25,0,0.25)	(-0.25,0,0.25)
F5	(-0.25,0,0.25)	(0.75,1,1)	(-0.25,0,0.25)	(0.75,1,1)	(-0.25,0,0.25)	(-0.25,0,0.25)	(-0.25,0,0.25)	(-1,-1,-0.75)	(-0.25,0,0.25)	(-0.25,0,0.25)
F6	(-1,-1,-0.75)	(-0.25,0,0.25)	(-0.25,0,0.25)	(-0.25,0,0.25)	(-0.25,0,0.25)	(-0.25,0,0.25)	(-1,-1,-0.75)	(-0.25,0,0.25)	(-0.25,0,0.25)	(-0.25,0,0.25)
F7	(0.75,1,1)	(-0.75,-0.50,-0.25)	(-0.25,0,0.25)	(-0.25,0,0.25)	(0.75,1,1)	(-0.25,0,0.25)	(-0.25,0,0.25)	(-0.25,0,0.25)	(0.25,0.50,0.75)	(0.25,0.50,0.75)
F8	(0.25,0.50,0.75)	(0.75,1,1)	(-0.25,0,0.25)	(-0.25,0,0.25)	(0.25,0.50,0.75)	(0.75,1,1)	(-0.25,0,0.25)	(-0.25,0,0.25)	(0,0.25,0.50)	(0,0.25,0.50)
F9	(-1,-1,-0.75)	(0.25,0.50,0.75)	(-0.25,0,0.25)	(-0.25,0,0.25)	(0.50,0.75,1)	(0.25,0.50,0.75)	(0.75,1,1)	(0.25,0.50,0.75)	(-0.25,0,0.25)	(-1,-1,-0.75)
F10	(-1,-1,-0.75)	(0.25,0.50,0.75)	(-0.25,0,0.25)	(-0.25,0,0.25)	(0.50,0.75,1)	(0.25,0.50,0.75)	(0.75,1,1)	(0.25,0.50,0.75)	(-1,-1,-0.75)	(-0.25,0,0.25)

4.2 Aggregation of Fuzzy Numbers

This step is intended to obtain a single matrix using fuzzy number matrices obtained for each expert in the fuzzification step. For this purpose, MATLAB application developed within the scope of the thesis is utilized. In addition, the MAX method was used for aggregation, which was coded on MATLAB in the aforementioned application.

4.3 Defuzzification

In this step, the matrix obtained by the aggregation is defuzzified to form the weight matrix. In this thesis, the Center of Gravity (COG) method which is one of the defuzzification methods is used. This process is performed in the MATLAB-based application, as in the fuzzification step. As a result of the aggregation, the weight matrix takes values in the range [-1, 1] Formulation 4.1 contains the formulation of the COG method used in the thesis.

$$Wij = \frac{\int \mu i(x) x dx}{\int \mu i(x) dx} \tag{4.1}$$

In Formulation 4.1, W_{ij} represents the value between [-1, 1], which is defuzzified and will be used in the weight matrix. $\mu_i(x)$ represents the aggregation fuzzy membership function.

The expert opinions with fuzzy numbers, aggregation and defuzzification of the opinions of three experts are explained with an example. The example is as follows.

- According to Expert-1, regional economy impacts land cost and construction cost and equipment cost with a *positively strong* linguistic variable.
- According to Expert-2, regional economy impacts land cost and construction cost and equipment cost with a *positively medium* linguistic variable.
- According to Expert-3, regional economy impacts land cost and construction cost and equipment cost with a *positively medium* linguistic variable.

Figure 4.1 and Figure 4.2 show graphs of fuzzy membership functions of linguistic variables obtained from Expert-1, Expert-2 and Expert-3 respectively. FX Draw program was used to draw these graphs.

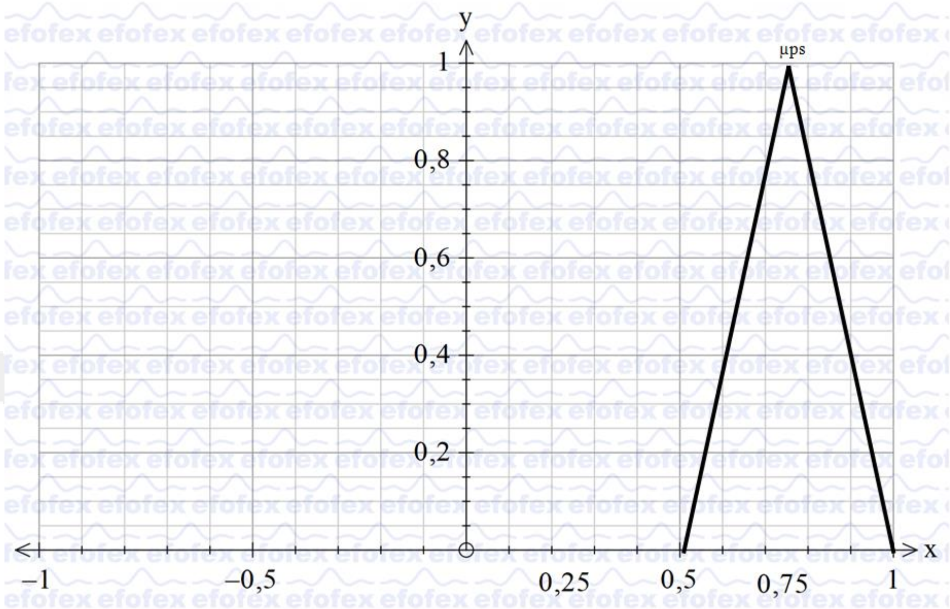

Figure 4.2 Fuzyy membership function for expert-1

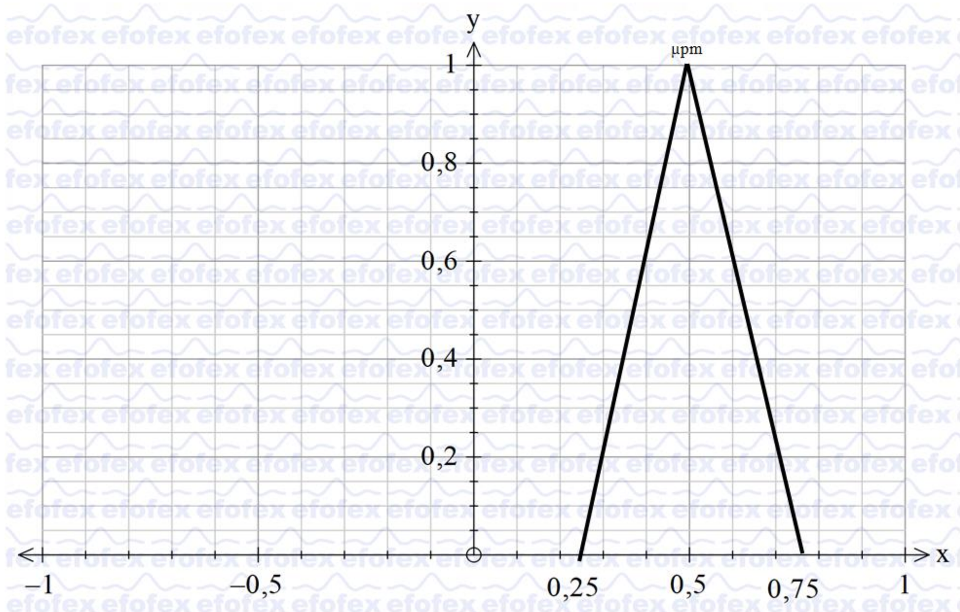

Figure 4.3 Fuzzy membership function for expert-2 and expert-3

Figure 4.3 shows the aggregation graph of the fuzzy membership function values of three experts using the MAX method.

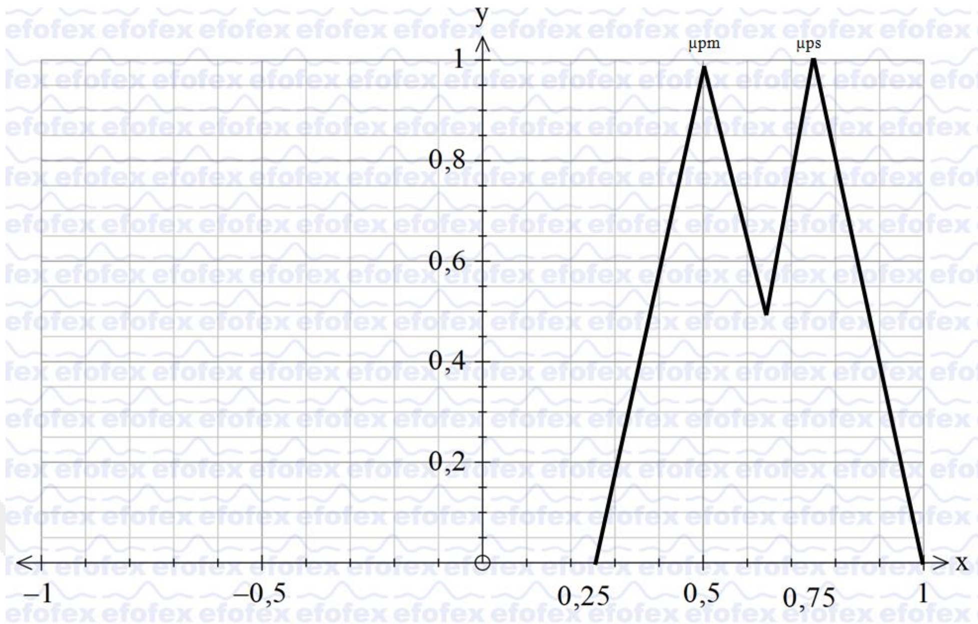

Figure 4.4 Aggregation graphic

The steps of defuzzyification using Formulation 4.2 are as follows.

$$\frac{\int_{0.25}^{0.50}\frac{x-0.25}{0.25}x\,dx+\int_{0.50}^{0.625}\frac{x-0.50}{0.25}x\,dx+\int_{0.625}^{0.75}\frac{x-0.625}{0.25}x\,dx+\int_{0.75}^{1}\frac{1-x}{0.25}x\,dx}{\int_{0.25}^{0.50}\frac{x-0.25}{0.25}dx+\int_{0.50}^{0.625}\frac{x-0.50}{0.25}dx+\int_{0.625}^{0.75}\frac{x-0.625}{0.25}dx+\int_{0.75}^{1}\frac{1-x}{0.25}dx}=0.75 \qquad (4.2)$$

4.4 Constructing of Weight Matrix

For the analysis of the factors that are effective in the selection of the location for the plants that conversion energy from biomass, the matrix formed by aggregation and defuzzification is the weight matrix. In the weight matrix, 729 relationships were determined between the twenty-eight predetermined factors. The weight matrix is analyzed in subsequent steps utilized the FCM Mapper toolbox. Figure 4.3 shows the FCM drawing. On the other hand, Table 4.9 shows the weight matrix. The FCM map is plotted according to the weight matrix in Table 4.9.

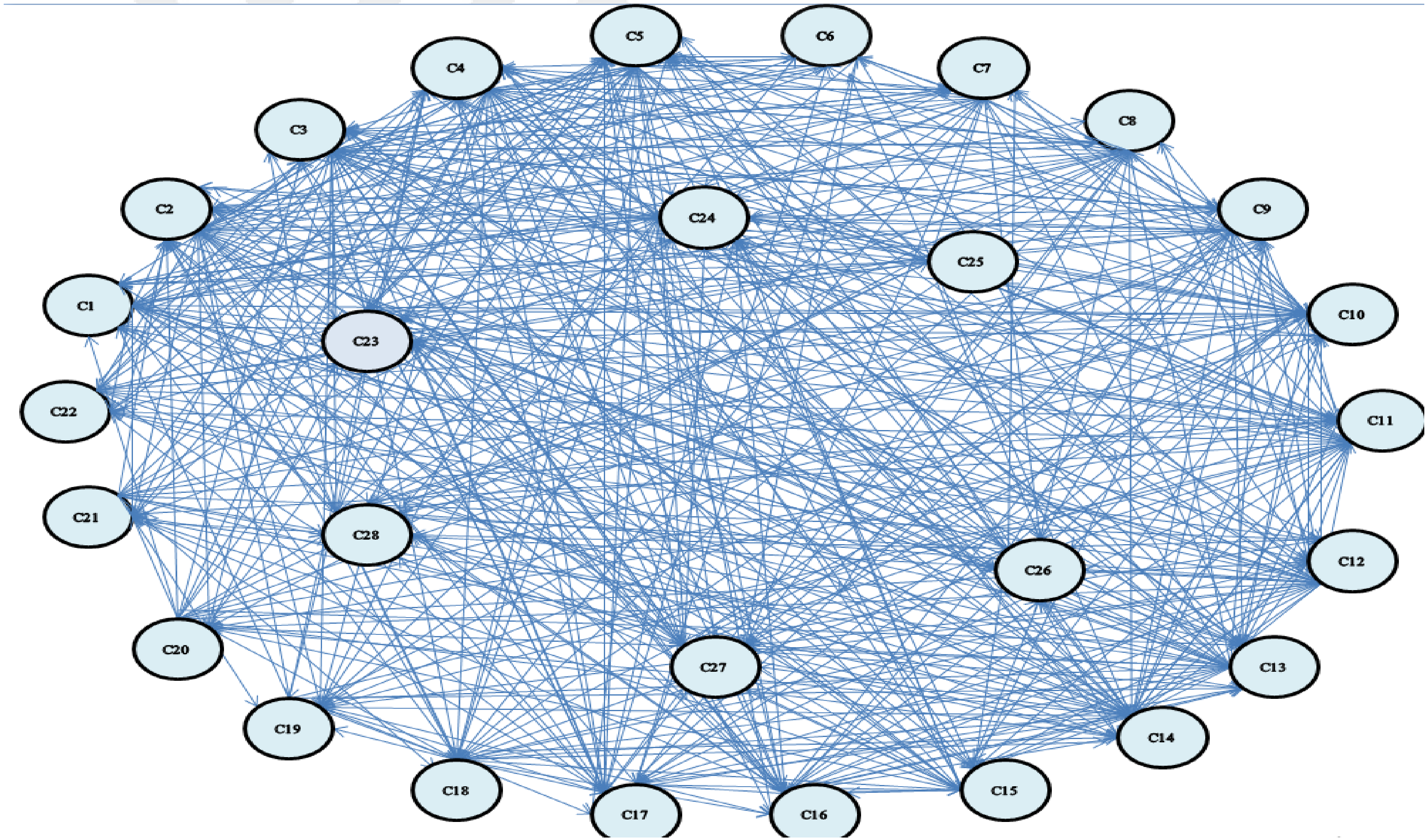

Figure 4.5 Fuzzy cognitive map of the problem

Table 4.9 The weight matrix of FCM

Weight M.	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22	F23	F24	F25	F26	F27	F28
F1	0.00	0.75	0.50	0.00	0.25	0.94	0.75	0.50	0.94	0.94	0.94	0.50	0.75	0.00	0.00	0.00	0.75	0.00	0.00	0.00	-0.25	0.50	0.50	0.94	0.00	0.94	0.94	0.94
F2	0.75	0.00	0.94	0.94	0.94	0.00	0.75	0.75	0.50	0.50	0.94	0.50	0.94	0.50	0.94	0.94	0.94	0.50	0.50	0.75	0.75	0.75	0.94	0.75	0.00	0.50	0.94	0.75
F3	0.25	0.94	0.00	0.94	0.94	0.00	0.75	0.75	0.50	0.50	0.25	0.94	0.94	0.50	0.94	0.94	0.94	0.50	0.50	0.50	-0.25	-0.25	0.94	0.50	0.00	0.50	0.75	0.75
F4	0.25	0.94	0.94	0.00	0.94	0.94	0.75	0.50	0.50	0.50	0.25	0.75	0.75	0.94	0.75	0.94	0.75	0.75	0.50	0.75	-0.25	-0.25	0.94	0.50	0.00	0.94	0.94	0.75
F5	0.00	0.94	0.94	0.94	0.00	0.75	0.50	0.75	0.00	0.00	0.50	0.94	0.94	0.94	0.94	0.94	0.94	0.75	0.94	-0.50	-0.25	-0.25	0.94	-0.50	0.00	0.50	0.94	0.94
F6	0.25	0.00	0.94	0.94	0.75	0.00	-0.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.50	0.00
F7	0.94	0.75	0.75	0.75	0.94	0.00	0.00	0.00	0.50	0.50	0.00	0.25	0.75	0.00	0.00	0.00	0.00	0.94	0.94	0.00	0.00	0.00	0.94	0.50	0.00	0.94	0.75	0.50
F8	0.94	0.94	0.75	0.75	0.50	0.94	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.94	-0.25	-0.25	-0.25	0.25	0.25	-0.25	-0.25	0.00	-0.25	-0.50	-0.50
F9	-0.75	0.50	0.50	0.50	0.75	0.50	0.94	0.50	0.00	0.75	0.94	0.50	0.50	0.25	0.25	0.25	0.25	0.94	0.94	0.00	0.00	0.00	0.75	0.94	0.00	0.94	0.94	0.94
F10	-0.75	0.50	0.50	0.50	0.75	0.50	0.94	0.50	0.75	0.00	0.94	0.50	0.50	0.25	0.25	0.25	0.25	0.94	0.94	0.00	0.00	0.00	0.75	0.94	0.00	0.94	0.94	0.94
F11	0.00	0.50	0.25	0.25	0.25	0.00	0.25	0.00	0.94	0.00	0.00	0.25	0.25	0.25	0.25	0.25	0.25	0.75	0.75	0.25	0.00	0.25	0.94	0.25	0.00	0.50	0.50	0.50
F12	0.25	0.94	0.94	0.94	0.94	0.00	0.00	0.25	0.25	0.25	0.25	0.00	0.94	0.94	0.50	0.50	0.50	0.94	0.94	0.25	-0.25	-0.25	0.94	0.94	0.00	0.50	0.50	0.50
F13	0.25	0.94	0.94	0.94	0.94	0.00	0.00	0.25	0.25	0.25	0.25	0.94	0.00	-0.25	0.50	0.50	0.50	0.94	0.94	0.25	-0.25	-0.25	0.94	0.94	0.00	0.50	0.50	0.50
F14	0.25	0.94	0.94	0.94	0.94	0.00	0.00	0.25	0.25	0.25	0.25	-0.75	-0.25	0.00	0.50	0.50	0.50	0.94	0.94	0.25	-0.25	-0.25	0.94	0.94	0.00	0.50	0.50	0.50

Table 4.9 continues

F15	0.94	0.94	0.94	0.94	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.25	0.00	0.00	0.50	0.50	0.00	0.50	0.75	0.00	0.50	0.94	0.50
F16	0.50	0.94	0.94	0.75	0.75	0.00	0.00	0.00	0.00	0.00	0.00	-0.25	-0.25	-0.25	0.94	0.00	0.25	0.00	0.00	0.00	0.25	0.00	0.50	0.75	0.00	0.50	0.75	0.50
F17	0.00	0.75	0.94	0.75	0.50	0.75	0.00	0.94	0.00	0.00	0.00	0.00	0.94	-0.94	0.25	0.25	0.00	0.75	0.75	0.25	-0.50	-0.25	0.75	0.75	0.00	0.00	0.94	0.94
F18	-0.50	0.50	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.94	0.00	0.00	0.75	0.00	0.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F19	-0.50	0.50	0.00	0.94	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.94	0.00	0.00	0.75	0.94	0.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F20	0.50	0.75	0.25	0.25	0.25	0.00	0.00	0.00	0.25	0.25	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.00	0.25	0.25	0.00	0.00	0.00	0.94
F21	0.00	0.75	0.25	0.25	0.25	0.00	0.00	0.00	0.25	0.25	0.25	0.25	0.25	0.25	0.00	0.00	0.00	-0.50	-0.50	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.94
F22	0.00	0.75	0.25	0.25	0.25	0.00	0.00	0.00	0.25	0.25	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.94
F23	0.00	0.94	0.94	0.94	0.94	0.00	0.00	0.00	0.25	0.25	0.25	0.50	0.50	0.50	0.94	0.94	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.00	0.00	0.94	0.94
F24	0.94	0.94	0.94	0.94	0.94	0.75	0.50	0.00	0.94	0.94	0.94	0.75	0.50	0.50	0.75	0.75	0.75	0.75	0.75	0.00	0.25	0.00	0.94	0.00	0.00	0.00	0.94	0.94
F25	0.50	-0.94	-0.94	-0.94	-0.94	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.25	0.00	-0.94	0.00	-0.94
F26	0.00	0.50	0.50	0.50	0.94	0.00	0.94	0.00	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.50	0.94
F27	0.00	0.94	0.94	0.94	0.94	0.50	0.00	0.00	0.50	0.50	0.25	0.50	0.50	0.50	0.75	0.75	0.75	0.00	0.00	0.00	0.00	0.00	0.94	0.94	0.00	0.00	0.00	0.50
F28	0.00	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.25	0.00	0.25	0.25	0.00

4.5 Evaluating FCM

This step includes static and dynamic analysis of the Fuzzy Cognitive Map. Static analysis is the instant analysis of the map and dynamic analysis is the time-dependent analysis of the map.

With the dynamic analysis performed in FCM, the underlying aspects of the system that cannot be obtained in the static analysis are examined which are more effective for understanding the system. Dynamic analysis simulates the entire system and its sub-components. Dependence between the concepts and the existence of the concepts are examined in depth thanks to the iterations of the simulations. This scenario analysis gives the concepts different initial conditions and allows them to examine "what-if" scenarios. Dynamic analysis allows the decision maker to interpret the system more easily and make detailed decision making (Stach, Kurgan, & Pedrycz, 2008).

4.5.1 Static Analysis of FCM

In the static analysis, the indices of each concept are examined. The Table 4.10 shows the outdegree, indegree and centrality indices of each concept.

Table 4.10 Indices of concepts

Concepts	Outdegree	Indegree	Centrality
F1	13.56	10.03	23.58
F2	18.94	20.03	38.97
F3	16.50	17.97	34.47
F4	18.00	18.03	36.03
F5	17.53	18.33	35.86
F6	5.83	6.58	12.42
F7	11.67	8.53	20.19
F8	9.28	5.94	15.22
F9	15.06	8.58	23.64
F10	15.06	7.64	22.69
F11	8.64	8.97	17.61
F12	14.44	10.58	25.03
F13	13.75	12.17	25.92
F14	13.56	9.47	23.03
F15	9.92	9.72	19.64
F16	9.08	10.67	19.75
F17	12.92	12.47	25.39
F18	5.14	12.36	17.50
F19	6.28	12.31	18.58
F20	5.89	4.50	10.39
F21	5.44	5.19	10.64
F22	4.44	3.50	7.94
F23	11.00	15.64	26.64
F24	17.39	15.56	32.94
F25	6.92	0.00	6.92
F26	8.08	10.67	18.75
F27	11.67	15.44	27.11
F28	3.00	18.08	21.08

Outdegree is the sum of the absolute values of each row in the weight matrix. This value indicates how much the concepts affect other concepts. Indegree is the sum of the absolute values of each column in the weight matrix. This value indicates how much the concepts are affected by other concepts. Centrality is the sum of outdegree and indegree. For example, the outdegree calculation for the F_1 concept is the absolute sum of the values in the first line in the weight matrix. For example, the indegree calculation for the F_1 concept is the absolute sum of the values in the first column of the weight matrix. The centrality calculation for F_1 is the sum of the outdegree and indegree values of F_1.

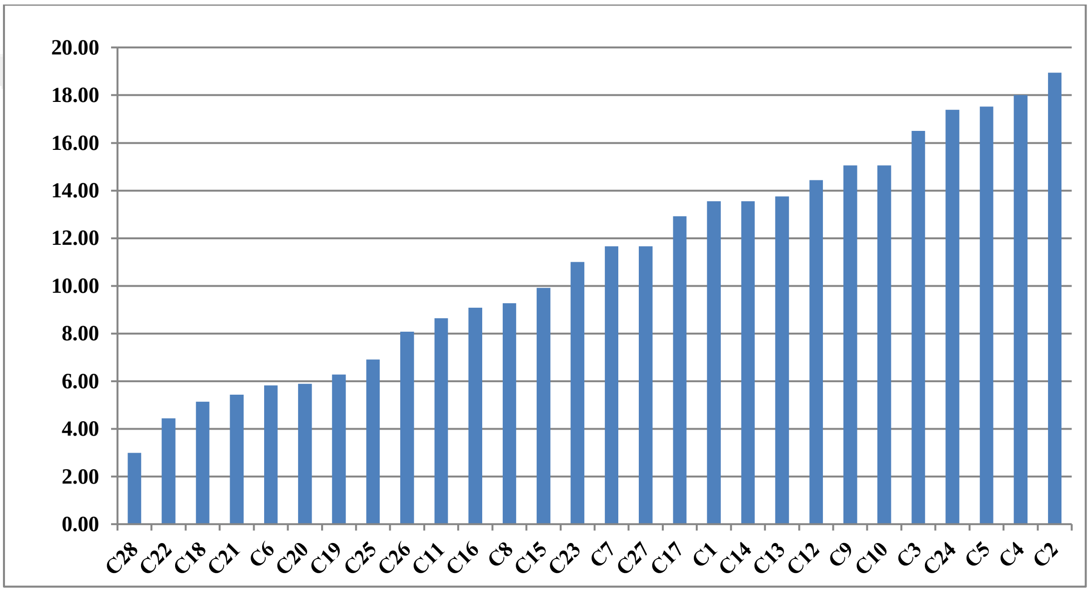

Figure 4.6 Outdegrees of factors

When the graph in Figure 4.4 is examined. It is seen that the highest outdegree is in the F2 (Regional Economy) concept, F2 is followed by F4 (International Trade Capacity), F5 (Regional Competition), F24 (Contribution of Rural Development), F3 (Regional Financial Facilities) and F10 (Agricultural Production Potential for Second Generation Biofuel), respectively.

The main economic livelihood of the region and the development of economic activities of the region contribute positively to the decision maker's preference for the region to establish a facility. Because it is easier to find raw materials for biomass energy especially in the regions where the regional economic livelihood is agriculture. At the same time, as the economic development level of the region increases, so does the awareness of using renewable energy. For this reason, biomass is a preferred renewable energy source. Because it also contributes to the recycling of waste.

When the trade capacity of the region is analyzed, it is seen that countries that export technological products are more prone to use renewable energy. In addition to the national perspective, it is seen that regions with a high trade value are more likely to use renewable energy among the regions that are nominated to establish a country.

Some regions are areas that sell energy due to their location. For example, oil, which is one of the fossil sources, is the main export source for some regions. The region's tendency to generate revenue from energy sales is an important criterion when choosing location for the facility.

Supply chains that generate energy from biomass are important because they generate new business occasions in the region where they are constituted and contribute to the recycling of wastes in the district where they are established. At the same time, since the raw material resources are located in the densely populated area, it is preferable to establish the plant locations in rural areas. This situation leads to rural development as it increases job opportunities in the countryside and starts to increase its investments thanks to the installed facility. For this reason, rural development is taken into consideration when choosing the facility location.

The regions where the regional financial resources are intense are an important resource for the investor aiming to open a facility. Because the investor is in favor of meeting the credit needs effortlessly in the first opening of the facility and ensuring the continuity of production.

It is critical to have vacant land for second generation biomass resources that are used directly to generate energy. Because biomass is seasonal. The investor wants to use own plant when he needs it in order to prevent the disruptions caused by the seasonality in the supply chain.

When all explanations are taken into consideration, it is logical that the factors that affect the system in static analysis are the most mentioned factors.

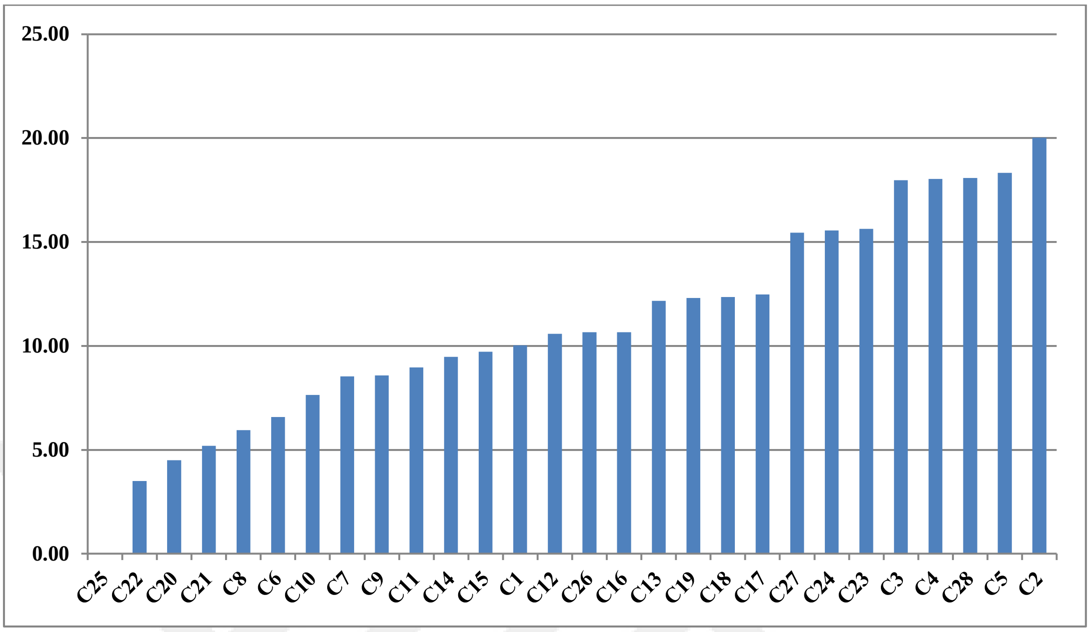

Figure 4.7 Indegrees of factors

When the graph in Figure 4.5 is examined it is seen that the highest outdegree is in the F2 (Regional Economy) concept. F2 is followed by F5 (Regional Competition), F28 (Social Acceptability), F4 (International Trade Capability), F3 (Regional Financial Facilities) and F28 (Sufficiency and Competence of Workforce), respectively. When the six most affected concepts are analyzed. It is seen that economic and social sustainability factors are affected more than other factors.

Plants that conversion energy from biomass contribute to the revitalization of the agricultural economy in the region where they are established because they use organic resources as raw materials. Plants that conversion energy from biomass contribute to the revitalization of the agricultural economy in the region where they are established because they use organic resources as raw materials.

It is possible that in regions where biomass power plants are established, the region where the facility is in the forefront due to the sale of energy will come to the forefront. Therefore, it makes sense that this factor is the affected factor.

The social acceptability of the establishment of energy facilities has been the subject of many studies today. Because the establishment and operation of these facilities is quite new today. Therefore, it causes discussion issues in the society. For this reason, other factors in the thesis are effective on social acceptability.

Since the establishment of biomass energy plants will affect the development level of the region, it can contribute to the creation of new products or business lines that will increase trade capacity as it will trigger different sectors such as agriculture.

The opening of the biomass energy plant leads to the development of the region and promotes regional development as it creates different business lines and therefore contributes to the increase in the number and qualifications of financial institutions in the region.

Since the facility opened can create a new business in the region, the tendency of the people living in the region increases and they are experienced in this field.

When the explanations made in parallel with the indegree graph are considered, the order in which the factors are influenced by other factors makes sense.

4.5.2 Dynamic Analysis

In dynamic analysis, the values of the concepts change with time. In this thesis, Formulation 3.1 in Methodology of FCM was used to see the time-dependent change of concepts. The vector A= [1,1….,1] was used to activate the activation of Formulation 3.1. Since Ai values may be negative and the range to which these values belong is [-1, 1]. F (x) = tanh (x) is the appropriate threshold function. Thus, the values of this vector were terminated using Formulation 3.5 and a threshold function. The new vector that is procured by proceeding the iterative formulation with this threshold function is considered as the initial vector for the next iteration. These vectors are updated by using Formulation 3.1 until positive as well as negative correlations between the concepts have obtaind equation (Göker, 2016). Table 4.11 presents the concept values of the factors that influence the location selection for the plants that conversation energy from biomass.

Table 2.11 Concept values of factors inclucencing location selection

Label of Concepts	Name of Concepts	Values of Concepts
F1	Biomass Prices	1.00
F2	Regional Economy	1.00
F3	Regional Financial Facilities	1.00
F4	International Trade Capability	1.00
F5	Regional Competition	1.00
F6	Sufficiency of Plant And Storage Area	0.999489202
F7	Energy and Fuel Sale Prices	0.999428001
F8	Land Cost and Constriction Cost, Equipment Cost	0.999034
F9	Agricultural Production Potential for Second Generation Biofuel	0.999921
F10	Regional First Generation Biofuel Production Potential	0.999796
F11	Total Organic Waste Potential	0.999946
F12	Transportation Network Capacity	0.999921
F13	Transportation Network Expansion Opportunities	0.999994
F14	Traffic Congestion	0.999417
F15	Communication and IT Capacity	0.999978
F16	Sufficiency of Technological Facilities Companies	0.999991
F17	Constriction Capability	0.999999
F18	Pollution	0.999994
F19	Emission of Greenhouse Gases, Ozone Depletion (Air Pollution)	0.999993
F20	Density of Underground and Surface Water Resources	0.981688
F21	Density of Forest Areas	0.816759
F22	Density of Protected Wild Areas	0.658602
F23	Sufficiency and Competence of Workforce	1.00
F24	Contribution of Rural Development	0.999999
F25	Terrorism and Wars Potential	0.659046
F26	Energy Security	0.999932
F27	Job Creation	1.00
F28	Social Acceptability	1.00

When Table 4.11 is examined, it is seen that the values of the factors are very close. The main reason for this is that all the factors mentioned in the thesis are selected from other studies in the literature. At the same time, the most important factors were taken into consideration in this selection. On the other hand, the values of the factors are close to one, even some factor values are directly one. This is because decision-makers establish similar relationships between variables. When the factors that take a value are examined, “Biomass Prices”, “Regional Economy”, “Regional Financial Facilities”, “International Trade Capability”, “Regional Competition”, “Sufficiency and Competence of Workforce”, “Job Creation” and “Social Acceptability”, respectively. As a result of the dynamic analysis, when the most influential factors were examined, it was found that economic sustainability factors were more effective on other factors. Because most of the factors whose value is equal to one are economic sustainability factors. The causes of the most influential factors are as follows.

The price of raw materials to be used when choosing a biomass conversion plant location is one of the most effective factors. Because it is important to obtain the raw materials that are inputs to the plant at an affordable price in order to be economical. Therefore, biomass price is a bit more important than other factors.

The economic development level of a region supports the use of biomass, which is one of the renewable energy sources. At the same time, the issue of which product or service the economy of a region is based on is directly related to the establishment of a facility in that region. For example, in areas where agriculture is dense, energy can be obtained from agricultural wastes or plants. Therefore, it is reasonable that the economic conditions of the region are more effective than other factors in the location selection.

If financial resources are sufficient for the construction and operation of a new facility, the existence of financial institutions to be supported is important for the sustainability of the supply chain. Therefore, it is conceivable that the presence, number and quality of the financial enterprises in the region affect the other factors that determine the location choice.

Trade trends, products and processes of a region give an idea about the development level and economic adequacy of a region. As the level of development increases, the idea of building a new facility becomes more confident. Therefore, the trade potential of the region is highly influential among other sustainability factors.

The fact that energy sales are the subject of regional competitiveness has an important place among other sustainability factors as the plants that conversion energy from biomass have become prominent in the competition.

The adaptation of employees working in biomass energy plants is important to ensure the sustainability of the human population and work motivation in the region to be established. Therefore, it is inevitable that this factor overcomes other factors.

Increasing the potential of job creation in a region increases the acceptability of a facility for the people of that region. For this reason, it is logical that the factor of job creation capacity should come to the forefront when selecting the location of the energy conversion facilities from biomass.

The construction of renewable energy sources greatly affects social acceptability. Because, the use of renewable energy sources and their effects on the environment are being discussed. In fact, there are many studies in the literature on this subject. For this reason, it is a logical conclusion that social acceptability is a more prominent factor than other factors.

As Table 4.11 shows," Density of Forest Areas", " Density of Protected Wild Areas", and "Terrorism and Wars Potential" factors have little impact on others among economic, technical, environmental and social sustainability factors that affect location selection for plants that convert energy from biomass.

The density of forested areas and the density of protected wild areas are very important factors for environmental protection and sustainability. However, for plants converting from biomass to energy, it is not a very significant factor when compared with other factors at the first stage.

Given the terror events and the potential for war, it is quite natural that it is one of the least influential factors in sustainability, since it is difficult to think of a new facility in such areas.

When the results of static analysis are examined, it is reasonable that one of these factors is taken into account. In the static analysis, these factors were found to be both the most affected and the most effective factors.

4.6 Scenario Analysis

In this thesis, the effect of the factors on each other is examined in order to better understand the relationship between the factors. For this study, when the weight of the factors in the system is at the highest level, namely when the factor value is one, the status of the other factors in the system and if the factors are not present in the system as well as zero, the behavior of the system is evaluated. Scenario-1 examines how the system reacts in the absence of the most influential factors. In Scenario-2, the lack of the least influencing factors in the system is examined. In Scenario-3 and Scenario-4, the effect of economic sustainability factors on other factors is examined. For this reason, Economic sustainability factors are given as one in Scenario-3 and zero value in Scenario-4. In Scenario-5, the effect of technical sustainability on other factors is examined. In Scenario-6, the situation of other factors in the system in the absence of technical sustainability factors is examined. In Scenario-7 and Scenario-8, the effects of environmental sustainability factors on other factors were examined. In Scenario-9 and Scenario-10, the effects of social sustainability factors on other factors were examined. Finally, Scenario-9 and Scenario-10 examined the effect of social sustainability factors on other factors.

- Scenario-1

In Scenario-1, the effects of “Biomass Price”, “Regional Economy”, “Regional Financial Facilities”, “International Trade Capability”, “Regional Competition”, “Sufficiency and Competence of Workforce”, “Job Creation” and “Social Acceptability” concepts on other concepts were examined. To examine the effect of these concepts on other concepts, the value of these concepts is equal to zero. The lack of these concepts has led to a strong positively change in the strength of the Density of Forest Areas concept. It has caused a strong negative change on the concepts of “Sufficiency of Plant and Storage Area”, “Energy and Fuel Sale Prices”, “Land Cost and Constriction Cost, Equipment Cost”, “Traffic Congestion”, “Density of Underground and Surface Water Resources” and “Density of Protected Wild Areas”

- Scenario-2

In Scenario-2 the effects of,” Density of Forest Areas”, “Density of Protected Wild Areas”, and “Terrorism and Wars Potential” factors concepts on other concepts were examined. To examine the effect of these factors on other factors, the value of these concepts is equal to zero. In the absence of these factors, it has been found that it does not have a strong effect on other factors. Therefore, when selecting locations for plants that conversation energy from biomass, there is no error if these criteria are not included in the problem.

Table 4.12 shows the results of Scenario-1 and Scenario-2.

- Scenario-3

In this scenario, the values of economic sustainability factors 1 are given to see the effect of economic sustainability factors on other factors. This has made very weak negative changes on the "Density of Underground and Surface Water Resources" and "Density of Forest Areas" factors. This scenario made a very weak positive change on all other factors. The main reason for this is that the value of the majority of economic sustainability factors is equal to one another.

- Scenario-4

In this scenario, when the factors of economic sustainability are excluded from the system, the response of the other factors in the system is examined. In this case " “Terrorism and Wars Potential " factor weak positive change occurred, while all other factors "strong negative change occurred. With this scenario, it is clear that economic sustainability factors are very critical for the location selection problems of biomass eenergy plants.

Table 4.13 shows the results of Scenario-3 and Scenario-4.

- Scenario-5

In this scenario, a value is assigned to the technical sustainability factors on the purpose of research the effect of technical sustainability factors on other factors. The effect of "Density of Forest Areas" and "Density of Protected Wild Areas" is weak negative change. The effect on all other factors is weak positive change. As can be seen here, technical sustainability factors have less impact on other factors.

- Scenario-6

In this scenario, in the absence of technical sustainability factors, 0 is given to the technical sustainability factor values to examine the state of the system. This strongly influenced the "Density of Forest Areas" and "Density of Protected Wild Areas" factors. "Biomass Price" and "Density of Underwater and Surface Water Resources" were strongly negatively affected by the absence of technical sustainability factors, while all other factors were weakly negatively affected.

Table 4.14 includes Scenario-5 and Scenario-6.

Table 4.12 Result of scenario-1 and scenario-2

Name of Concepts	No Change	Scenario-1	Scenario-2
Biomass Prices	1	0	0.995981567862539
Regional Economy	1	0	0.999999991000000
Regional Financial Facilities	1	0	0.999999975000000
International Trade Capability	1	0	0.999999977000000
Regional Competition	1	0	0.999999983000000
Sufficiency of Plant and Storage Area	0.999489201799586	0.987913335279818	0.999488624278946
Energy and Fuel Sale Prices	0.999428001018156	0.981086523225507	0.99920399776838
Land Cost and Constraction Cost, Equipment Cost	0.999034327542422	0.974769824274016	0.999033649260137
Agricultural Production Potential for Second Generation Biofuel	0.999920831940433	0.997319589600117	0.999885365432718
Regional First Generation Biofuel Production Potential	0.999796458691394	0.993143463997991	0.999705293201744
Total Organic Waste Potential	0.999946363260851	0.997823631634018	0.999922341160219
Transportation Network Capacity	0.999921014861169	0.991537570053762	0.999885727273126
Transportation Network Expansion Opportinuties	0.999994026629083	0.998679010951707	0.999991353158805
Traffic Cognestion	0.99941704765148	0.969829775917386	0.999156966887273
Communication and IT capacity	0.999977940248159	0.995567445427508	0.999977936300325
Sufficiency of Technological Facilities Companies	0.999991420869089	0.997901401970293	0.999991419348445
Constraction Capability	0.999998584861205	0.999690501848244	0.999998583413200
Pollution	0.999993550163965	0.999891311440231	0.999995709926820
Emission of Greenhouse Gases, Ozone Depletion (Air Pollution)	0.999993181671469	0.999891311440231	0.999995464825519
Density of Underground and Surface Water Resources	0.981688378192216	0.917674012804968	0.981686907385668
Density of Forest Areas	0.816758710490935	0.847521636311444	0
Density of Protected Wild Areas	0.658601762260204	0.501071380908693	0
Sufficiency and Competence of Workforce	1	0	1
Contribution of Rural Development	0.999999496103126	0.999957159540929	0.999999381052620
Terrorism and Wars Potential	0.659046068407364	0.659046068407415	0
Energy Security	0.999932006560469	0.997304041329650	0.999963455169185
Job Creation	1	0	1
Social Acceptability	1	0	1

Table 4.13 Results of scenario-3 and scenario-4

Name of Concepts	No Change	Scenario-3	Scenario-4
Biomass Prices	1	1	0
Regional Economy	1	1	0
Regional Financial Facilities	1	1	0
International Trade Capability	1	1	0
Regional Competition	1	1	0
Sufficiency of Plant and Storage Aarea	0.999489201799586	1	0
Energy and Fuel Sale Prices	0.999428001018156	1	0
Land Cost and Constraction Cost, Equipment Cost	0.999034327542422	1	0
Agricultural Production Potential for Second Generation Biofuel	0.999920831940433	1	0
Regional First Generation Biofuel Production Potential	0.999796458691394	1	0
Total Organic Waste Potential	0.999946363260851	1	0
Transportation Network Capacity	0.999921014861169	0.999921000000000	0.985211000000000
Transportation Network Expansion Opportinuties	0.999994026629083	0.999994000000000	0.996220000000000
Traffic Cognestion	0.99941704765148	0.999417000000000	0.974944000000000
Communication and IT Capacity	0.999977940248159	0.999978000000000	0.998260000000000
Sufficiency of Technological Facilities Companies	0.999991420869089	0.999991000000000	0.999176000000000
Constraction Capability	0.999998584861205	0.999999000000000	0.998714000000000
Pollution	0.999993550163965	0.999994000000000	0.997711000000000
Emission of Greenhouse Gases, Ozone Depletion (Air Pollution)	0.999993181671469	0.999993000000000	0.997711000000000
Density of Underground and Surface Water Resources	0.981688378192216	0.981684000000000	0.917217000000000
Density of Forest Areas	0.816758710490935	0.816673000000000	0.807565000000000
Density of Protected Wild Areas	0.658601762260204	0.659095000000000	0.344218000000000
Sufficiency and Competence of workforce	1	1	0.999780000000000
Contribution of Rural Development	0.999999496103126	0.999999000000000	0.999878000000000
Terrorism and Wars Potential	0.659046068407364	0.659046000000000	0.659046000000000
Energy Security	0.999932006560469	0.999932000000000	0.955197000000000
Job Creation	1	1	0.999560000000000
Social Acceptability	1	1	0.999882000000000

Table 4.14 Results of scenario-5 and scenario-6

Name of Concepts	No Change	Scenario-5	Scenario-6
Biomass Prices	1	1	0.973140000000000
Regional Economy	1	1	0.999999000000000
Regional Financial Facilities	1	1	0.999991000000000
International Trade Capability	1	1	0.999994000000000
Regional Competition	1	1	0.999997000000000
Sufficiency of Plant and Storage Area	0.999489201799586	0.999489000000000	0.998889000000000
Energy and Fuel Sale Prices	0.999428001018156	0.999428000000000	0.999417000000000
Land Cost and Constraction Cost, Equipment Cost	0.999034327542422	0.999034000000000	0.99468000000000
Agricultural Production Potential for Second Generation Biofuel	0.999920831940433	0.999921000000000	0.999837000000000
Regional First Generation Biofuel Production Potential	0.999796458691394	0.999796000000000	0.999581000000000
Total Organic Waste Potential	0.999946363260851	0.999946000000000	0.999890000000000
Transportation Network Capacity	0.999921014861169	1	0
Transportation Network Expansion Opportinuties	0.999994026629083	1	0
Traffic Cognestion	0.99941704765148	1	0
Communication and IT capacity	0.999977940248159	1	0
Sufficiency of Technological Facilities Companies	0.999991420869089	1	0
Constraction Capability	0.999998584861205	1	0
Pollution	0.999993550163965	0.999994000000000	0.999761000000000
Emission of Greenhouse Gases, Ozone Depletion (Air pollution)	0.999993181671469	0.999993000000000	0.999747000000000
Density of Underground and Surface Water Resources	0.981688378192216	0.981692000000000	0.918310000000000
Density of Forest Areas	0.816758710490935	0.816732000000000	0.881202000000000
Density of Protected Wild Areas	0.658601762260204	0.658553000000000	0.864040000000000
Sufficiency and Competence of Workforce	1	1	0.999989000000000
Contribution of Rural Development	0.999999496103126	0.999999000000000	0.999921000000000
Terrorism and Wars Potential	0.659046068407364	0.659046000000000	0.659046000000000
Energy Security	0.999932006560469	0.999932000000000	0.999154000000000
Job Creation	1	1	0.999987000000000
Social Acceptability	1	1	0.999997000000000

- Scenario-7

In this scenario, the effects of environmental impacts on other scenarios are examined by giving one degree. As a result, the "Terrorism and Wars Potential" function experienced a weak negative change while all other functions experienced a weak positive change. When other factor effects are examined, it is seen that environmental factors have the least effect.

- Scenario-8

In this scenario, the reaction of the system is examined in the absence of environmental factors. Therefore, the value of the environmental sustainability factors is zero. In this case the "Biomass price" function has changed moderately positive. The factors "Sufficiency of Plant and Storage Area", "Energy and Fuel Sales Prices" and” Terrorism and Wars Potential” have experienced a weak positive change or other factors have changed poorly negative.

Table 4.15 shows the results of Scenario-7 and Scenario-8

Table 4.15 Results of scenario-7 and scenario-8

Name of Concepts	No Change	Scenario-7	Scenario-8
Biomass Prices	1	1	0.998262000000000
Regional Economy	1	1	1
Regional Financial Facilities	1	1	1
International Trade Capability	1	1	1
Regional Competition	1	1	1
Sufficiency of Plant and Storage Area	0.999489201799586	0.999489000000000	0.999490000000000
Energy and Fuel Sale Prices	0.999428001018156	0.999428000000000	0.999428000000000
Land Cost and Constraction Cost, Equipment Cost	0.999034327542422	0.999034000000000	0.999034000000000
Agricultural Production Potantial for Second Generation Biofuel	0.999920831940433	0.999931000000000	0.999854000000000
Regional First Generation Biofuel Production Potential	0.9997964586 91394	0.999822000000000	0.999624000000000
Total Organic Waste Potential	0.999946363260851	0.999953000000000	0.999790000000000
Transportation Network Capacity	0.999921014861169	0.999931000000000	0.999692000000000
Transportation Network Expansion Opportinuties	0.999994026629083	0.999995000000000	0.999972000000000
Traffic Cognestion	0.99941704765148	0.999491000000000	0.997229000000000
Communication and IT capacity	0.999977940248159	0.999978000000000	0.999978000000000
Sufficiency of Technological Facilities Companies	0.999991420869089	0.999991000000000	0.999982000000000
Constraction Capability	0.999998584861205	0.999999000000000	0.999992000000000
Pollution	0.999993550163965	1	0
Emission of Greenhouse Gases, Ozone Depletion (Air pollution)	0.999993181671469	1	0
Density of Underground and Surface Water Resources	0.981688378192216	1	0
Density of Forest Areas	0.816758710490935	1	0
Density of Protected Wild Areas	0.658601762260204	1	0
Sufficiency and Competence of Workforce	1	1	1
Contribution of Rural Development	0.999999496103126	1	0.999999000000000
Terrorism and Wars Potential	0.659046068407364	0.659046000000000	0.659046000000000
Energy Security	0.999932006560469	0.999932000000000	0.999932000000000
Job Creation	1	1	1
Social Acceptability	1	1	0.999999000000000

- Scenario-9

In this scenario, the effects of social sustainability factors impacts on other scenarios are examined by giving one degree.When social sustainability is examined, it is seen that it is not as important as other factors.

- Scenario-10

In this scenario, the reaction of the system is examined in the absence of social sustainability factors. Therefore, the value of the social sustainability factors is zero. As a result of this analysis, "Density of Forest Areas" factor experiences a strong negative change while all remaining factors experience a weak negative change. Table 4.16 shows the results of Scenario-9 and Scenario-10.

Table 4.16 Result of scenario-9 and scenario-10

Name of Concepts	No Change	Scenario-9	Scenario-10
Biomass Prices	1	1	0.989644322000000
Regional Economy	1	0.999999993000000	0.999999892000000
Regional Financial Facilities	1	0.999999956000000	0.999999372000000
International Trade Capability	1	0.999999959000000	0.999999409000000
Regional Competition	1	0.999999970000000	0.999999319000000
Sufficiency of Plant and Storage Area	0.999489201799586	0.999489421000000	0.998202427000000
Energy and Fuel Sale Prices	0.999428001018156	0.999517850000000	0.996606281000000
Land Cost and Constraction Cost, Equipment Cost	0.999034327542422	0.999035000000000	0.999028770000000
Agricultural Production Potantial for Second Generation Biofuel	0.999920831940433	0.999921000000000	0.999272800000000
Regional First Generation Biofuel Production Potential	0.999796458691394	0.999797000000000	0.998132375000000
Total Organic Waste Potential	0.999946363260851	0.999946000000000	0.999617000000000
Transportation Network Capacity	0.999921014861169	0.999921000000000	0.999407000000000
Transportation Network Expansion Opportinuties	0.999994026629083	0.999994000000000	0.999965000000000
Traffic Cognestion	0.99941704765148	0.999417000000000	0.996600000000000
Communication and IT capacity	0.999977940248159	0.999978000000000	0.999673000000000
Sufficiency of Technological Facilities Companies	0.999991420869089	0.999991000000000	0.999873000000000
Constraction Capability	0.999998584861205	0.999999000000000	0.999989000000000
Pollution	0.999993550163965	0.999994000000000	0.999983000000000
Emission of Greenhouse Gases, Ozone Depletion (Air pollution)	0.999993181671469	0.999993000000000	0.999982000000000
Density of Underground and Surface Water Resources	0.981688378192216	0.981688000000000	0.981669000000000
Density of Forest Areas	0.816758710490935	0.816739000000000	0.768268000000000
Density of Protected Wild Areas	0.658601762260204	0.658667000000000	0.657738000000000
Sufficiency and Competence of Workforce	1	1	0
Contribution of Rural Development	0.999999496103126	1	0
Terrorism and Wars Potential	0.659046068407364	1	0
Energy Security	0.999932006560469	1	0
Job Creation	1	1	0
Social Acceptability	1	1	0

CHAPTER FIVE
CONCLUSION

Nowadays, the population is increasing. Finding alternative ways to supply the energy requirement of the growing population is an issue that scientists are working on. On the other hand, awareness of environmental protection has increased today. Fossil resources used to obtain energy are disappearing from day to day. At the same time, environmentally harmful substances emerge in the production of energy from fossil resources. Global warming and many other environmental problems are the main cause of these harmful substances. For all these reasons, the utilize of energy from renewable energy resources has become very important, today. Biomass is a renewable energy source. In the process of conversion energy from biomass, living organisms and recently living organisms are used as raw materials. It is popular today to conversion energy from biomass because it is organic in its by-products released from biomass. At the same time, the process of conversation energy from biomass contributes to recycling as it is used to generate energy in organic animal, human and municipal waste.

Deterioration due to the organic content of the products entering the plants from biomass energy; the final product obtained after the conversion process is energy and the uninterrupted transmission of this energy at the right time are important factors for the biomass supply chain. Therefore, it is necessary to create a sustainable supply chain and to manage it correctly. In this thesis, the selection of the location of the plants that conversion energy from biomass is taken into consideration in order to develop a sustainable biomass supply chain.

In the thesis, FCM method was used to examine the sustainability criteria affecting the location selection. The main reason for using fuzzy cognitive mapping in this section is the use of linguistic variables in fuzzy cognitive mapping. By using linguistic variables easily, opinions can be obtained from expert decision makers. On the other hand, fuzzy cognitive mapping analyzes by taking into account the points that experts do not express. Another reason for using fuzzy cognitive mapping in the thesis is that FCM is a method based on fuzzy logic and neural networks and also dynamic and static analysis can be performed while analyzing FCM.

In this thesis, determining the criterias of location selection, data collection, fuzzification, aggregation of matrix, defuzzification, weight matrix formation, drawing of FCM map, evaluation of FCM and scenario analysis are given respectively.

Literature was researched for the thesis and sustainable criteria were collected under four headings. These are economic sustainability, technical sustainability, environmental sustainability and social sustainability respectively. All of the sub-criteria of sustainability concepts have been determined with reference to the literature.

Data were collected through face-to-face interviews from 3 experts who are experts in biomass, biomass power plants and biomass sustainable supply chain. Experts considered the following steps when evaluating relationships between concepts. While collecting the data, it was ensured that the experts used linguistic variables for binary comparison. In this way, experts have easily expressed the relationship between qualitative and quantitative sustainability concepts.

The literature was used to linguistic collected data and fuzzy numbers suggested by Ahmadi, Yeh, Martin, & Papageorgiou (2015) were used in response to appropriate linguistic variables.

A MATLAB-based application developed within the scope of the thesis was used to aggregate the fuzzy number matrices obtained as a result of the experts' opinions into a single matrix, and defuzzification and form the weight matrix. MAX formulation is used for aggregation and COG formulation is used for defuzzification.

In the weight matrix, 729 relationships were determined between the twenty-eight predetermined factors. The weight matrix is analyzed in subsequent steps utilized the FCM Mapper toolbox.

In this thesis, static and dynamic analyzes of FCM are used together. When the rankings obtained as a result of static analysis are examined, the importance of economic sustainability factors is understood especially for the plants converting energy from biomass. However, these factors are both the most influential factors and the most influenced by other factors. On the other hand, social factors are the most affected by other factors. Because the establishment of a new renewable energy facility is a subject of social debate. Since the social acceptability of biomass has been examined in the studies conducted in the literature and the effect of other factors on social acceptability is considered, it is logical that the social acceptability factor is among the most affected factors.

On the other hand, the results of FCM dynamic analyses are examined, ”Density of Forest Areas”, Density Density of Protected Wild Areas ”, and“ Terrorism and Wars Potential ”factors have little impact on others energy from biomass. Moreover, the relationships between the remaining 25 factors were very close. The main reasons for this are choosing from the literature and choosing the most influential ones when choosing sustainability factors.

In this thesis, ten different scenarios have been developed and analyzed by using the values obtained from the dynamic analysis. When the first two scenarios were examined, it was observed that the removal of the most influential factors had a significant effect on the system, but no significant changes were observed when the factors with low impact on the system were removed. In other eight scenarios, the effects of economic, technical, environmental and social sustainability factors on the system are examined. As a result of dynamic analysis, it is understood that economic sustainability factors constitute the majority of the factors affecting the system the most. In scenario-4, which analyzes the absence of economic sustainability factors, a significant change in the system has been observed. In the scenarios where other factors were examined, there were no significant changes in the system in the absence of factors.

When static analysis, dynamic analysis and scenario analysis are examined together, it was found that economic sustainability factors were slightly more important than other factors. The main reason why economic factors are the most important factor affecting other factors is that economic values are at the forefront when a system is established.

As a result of the thesis, it was understood that economic sustainability factors are the most important selection criteria when choosing sustainable biomass location. At the same time, it was understood that the importance of technical, environmental and social sustainability criteria and which criteria affected more and which criteria were affected more. The MATLAB application developed in the thesis is a flexible application suitable for use in many different subjects, not only in determining the criteria affecting location selection.This thesis will contribute to the literature as the first study that develops an FCM-based approach when examining location selection factors for plants that generate energy from biomass.

Based on this thesis, the following suggestions are made for future studies.

- The MATLAB application developed within the scope of the thesis converts the answers of more than one decision maker to a single matrix by aggregation and then defuzzification to obtain the weight matrix. This application can be used in all studies aimed at using FCM.

- Multi-Criteria Decision-Making Methods or mathematical model can be used to make location selection in future studies by using factor weights obtained from the thesis and these weights can be used as criterion weight in these studies.
- The solution of thesis support investors in decision-making processes who want to build plants that convert biomass into energy.
- Policy makers can create new policies about the biomass supply chain by considering the factors evaluated and interpreted within the scope of the thesis.

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