

DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**BIOMASS SUPPLY CHAIN NETWORK DESIGN
OPTIMIZATION**



by
Yeşim GİTAL

December, 2018

İZMİR

BIOMASS SUPPLY CHAIN NETWORK DESIGN OPTIMIZATION

**A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
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in Industrial Engineering, Industrial Engineering Program**

**by
Yeşim GİTAL**

December, 2018

İZMİR

M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled “**BIOMASS SUPPLY CHAIN NETWORK DESING OPTIMIZATION**” completed by **YEŞİM GİTAL** under supervision of **PROF. DR. BİLGE BİLGEN** 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.


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Yeşim GİTAL

BIOMASS SUPPLY CHAIN NETWORK DESIGN OPTIMIZATION

ABSTRACT

This thesis, firstly, aims to present a comprehensive literature review on sustainability of biomass supply chain. Within the scope of the literature research, previous literature reviews on sustainable biomass supply chain are analyzed to present more detailed information about the scope, scheme, and gaps on the field. The differences and the shortcomings of the existed literature are revealed and important aspects are displayed. A classification scheme is proposed by investigating the previous literature reviews and the previous quantitative papers are examined according to this classification scheme. According to this classification scheme, sustainability dimensions in the previous papers are analyzed in detailed in terms of economic, environmental and social aspects. Then, solution methodologies employed in these papers are analyzed. Bioenergy generations and sustainability evaluations captured in previous papers are also investigated.

A novel multi-stage solution methodology and multi-objective mixed integer linear programming model is developed to solve sustainable biomass supply chain network design problem with a real case study. The real case study is about electrical energy generation by using poultry farm wastes in İzmir region. In the first stage, geographic information system is used to determine suitable locations to establish biogas facilities under environmental constraints. In the second stage, environmentally suitable locations, obtained by geographic information systems, is improved and reduced by using analytical hierarchy process method. Then, multi-objective mixed integer linear programming model is developed with the aim of maximizing total profit and minimizing total distance of entire supply chain.

Keywords: Biomass supply chain, sustainability, supply chain network design, geographical information systems, analytical hierarchy process, multi-objective mixed integer linear programming

BİYOKÜTLE TEDARİK ZİNCİRİ AĞ TASARIMI OPTİMİZASYONU

ÖZ

Bu tez, öncelikle, sürdürülebilir biyokütle tedarik zinciri hakkında kapsamlı bir literatür taraması sunmayı amaçlamaktadır. Bu literatür araştırmasının kapsamında, sürdürülebilir biyokütle tedarik zinciri kavramını ve literatürdeki boşluklarını daha iyi anlamak amacıyla, önceki literatür çalışmaları incelenmiştir. Literatür araştırmasında, var olan literatürün farklılıkları ve eksiklikleri ortaya çıkarılmakta ve önemli yönleri ortaya konmaktadır. Önceki literatür çalışmalarını inceleyerek, bir sınıflandırma şeması önerilmiştir ve sürdürülebilir biyokütle tedarik zinciri konusunda yapılmış sayısal çalışmalar bu sınıflandırma şemasına göre incelenmiştir. Bu sınıflandırma şemasına göre, önceki makalelerin çözüm yöntemleri ve sürdürülebilirlik boyutları, ekonomik, çevresel ve sosyal açıdan ayrıntılı olarak analiz edilmektedir. Ayrıca, bu çalışmaların biyoenerji nesilleri ve sürdürülebilirlik değerlendirmeleri de araştırılmaktadır.

Gerçek bir vaka problemi ile sürdürülebilir biyokütle tedarik zinciri ağ tasarımını çözmek için yeni birçok aşamalı çözüm yöntemi ve çok amaçlı karışık tamsayı doğrusal programlama modeli geliştirilmiştir. Gerçek vaka çalışması İzmir bölgesindeki tavuk çiftliği atıklarını kullanarak elektrik enerjisi üretimini konu almaktadır. İlk aşamada, coğrafi bilgi sistemleri çevresel kısıtlar altında biyogaz tesislerini kurmak için uygun yerleri belirlemek için kullanılır. İkinci aşamada, coğrafi bilgi sistemleri kullanılarak elde edilen çevresel olarak uygun yerler, analitik hiyerarşi süreci yöntemi kullanılarak geliştirilmekte ve azaltılmaktadır. Son aşamada, toplam karı maksimize ederek ve tüm tedarik zincirinin toplam mesafesini en aza indirerek çok amaçlı karışık tamsayılı doğrusal programlama modeli uygulanır.

Anahtar kelimeler: Biyokütle tedarik zinciri, sürdürülebilirlik, tedarik zinciri ağ tasarımı, coğrafi bilgi sistemleri, analitik hiyerarşi süreci, çok amaçlı karışık tamsayılı doğrusal programlama

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CHAPTER ONE

INTRODUCTION

1.1 Motivation

Since the last century, technological developments are experienced consecutively and rapidly. Especially with industrialization, production and consumption have increased every year. The number and variety of technological products working with energy has increased continuously. With the increase in production and industrialization, developments in economy and transportation sector have been experienced. Transportation has improved between cities, countries and continents, thus fuel consumption and demand have increased.

Additionally, more widespread use of technology in daily life and increased world population have resulted in increased energy consumption. The dependence on energy use is ever increasing. Nowadays, almost all of our daily needs are met with electrical energy. People use continuously electricity in heating, enlightenment, communication and kitchen. In other words, daily electricity consumption is constantly increasing with the increase of world population.

Over the worldwide, the main part of energy need currently is met from fossil fuels. However, it is expected that these mainly used resources will be depleted within the next 50-100 years. And, by reason of the burning of fossil fuels, the level of CO₂ have increased in the atmosphere which is directly associated with global warming. The researchers emphasize its negative environmental impacts and limited resources and, fossil source is accepted not to be sustainable for energy generation (Meyer et al. 2014; Naik et al. 2010; Sharma et al. 2013). Therefore, recent studies on energy supply focus on sustainable energy source in many aspects.

By The Brundtland Commission in 1987, sustainability was accepted as “meeting the present needs without compromising the ability of future generations to meet their own needs” This concept has gained importance in the energy supply and is

considered in economic, environmental and social fields. The potential of alternative and renewable energy sources is increasingly investigated to reduce society's dependency on fossil fuel and to mitigate climate change.

In this way, bioenergy from biomass is among the most important issues in energy generation, because of especially its renewable and environmental friendly features, and also is a potential substitution of fossil fuels (Akgul, Shah, & Papageorgiou, 2012; Čuček, Drobež, Pahor, & Kravanja, 2012; Hong, How, & Lam, 2016; Mafakheri & Nasiri, 2014). Greenhouse gas emission, pollution and resource depletion caused by fossil fuels are strongly reduced or absent with bio transportation fuels. Bioenergy is generated from biomass feedstock that includes organic contents (Voivontas et al. 2001). Biomass is thought to become one of the major global primary energy sources during the next century, and it is expected that the modernized bioenergy systems will contribute to future sustainable energy systems in industrialized countries as well as in developing countries (Azadeh et al. 2014).

In this thesis we consider a real biomass supply chain network design problem in İzmir area. In the network, there are laying poultry farms and potential locations for biogas facilities. In biogas facilities, electricity will be generated using poultry farm waste. For this purpose, suitable locations will be determined to be established biogas facility.

We propose a three-stage solution methodology. In the first stage, we determine candidate facility locations by using geographical information systems (GIS) under ecological constraints. Then, in the second stage, the results of GIS are improved and reduced with analytical hierarchy process (AHP). In the third stage, a multi-objective mixed integer linear programming (MOMILP) model is developed to solve sustainable biomass supply chain (BSC) problem.

The main objective of this MSc thesis is to develop a real-world representing mathematical model, and to establish solution frameworks and tools that can effectively solve the biomass supply chain network design problem.

1.2 Contributions

The original contributions of this thesis to sustainable BSC network design are listed below.

1. An extensive literature review on sustainable BSC is presented. A classification scheme is proposed for an advanced analysis. Economic, environmental and social sustainability dimensions, and also sustainability drivers of previous papers are analyzed in detail. In addition to that, literature on solution methodologies, decision levels and bioenergy generations are investigated.
2. Sustainable BSC network design problem is performed on a real case problem. Locations and waste capacities of laying poultry farms in İzmir region are considered as real data.
3. A multi-stage solution methodology is proposed by combining GIS, AHP and mixed integer mathematical programming (MILP) model.
4. A novel MOMILP model is developed to solve sustainable BSC. Besides the classical constraints such as single sourcing, capacity requirements, conservation of biomass flows, we take into account covering constraints, and define maximum distance and maximum waste amount parameters. By using these parameters, we have written constraints: one guarantees that each farm must supply waste to a facility if only located in *maximum distance* of this facility, and the other one ensures that the sufficient amount of poultry farm waste should be available in the locations that a biogas facility is opened.

1.3 Organization of Thesis

This thesis is constituted of 5 chapters. The first chapter consists of the introduction. The remainders of the thesis are organized as follows:

Chapter two gives basic information about related concepts and definitions. Biomass, bioenergy and sustainability definitions are mentioned in this chapter. The advantages of biomass and bioenergy usage field are also presented. In addition, biogas conversion processes and biogas feedstock are briefly explained.

Chapter three is devoted to present a comprehensive literature review on sustainable BSC network design. The aim of the classification scheme is to better analyze previous studies on BSC. The previous studies are classified in terms of objective functions, solution methodologies, decision levels in detail. In addition, bioenergy generations and types of feedstock used in studies are analyzed.

Chapter four presents a real case BSC network design problem at İzmir region. A multi-stage solution methodology is developed to design sustainable BSC network under economic and environmental conditions. Firstly, the structure and characteristics of the problem are explained to design sustainable BSC, and a multi-stage solution methodology is presented. In first stage, GIS is used to provide environmental conditions. In the second stage, the results of GIS are improved and evaluated in terms of multi criteria by using AHP. In the third stage, a novel multi-objective mixed integer linear programming model is developed and performed on real case problem. Then, the computational results are presented.

Finally, chapter five is devoted to summarize and to conclude the thesis. This chapter covers a summary of all chapters and includes future research directions.

CHAPTER TWO

BIOMASS AND BIOENERGY

This section gives basic information about biomass and bioenergy, and some definitions of basic concepts are given below. Section 2.1 presents information about biomass such as benefits of using biomass, and sustainability concepts in bioenergy generation, and Section 2.2 mentions about biogas conversion processes.

Terms used in the study;

- **Biomass:** Biomass is feedstock that includes organic contents, which used for bioenergy production. It can be wood residues generated from industries, agricultural residues, agroindustries and animal farms, and municipal solid waste (Voivontas et al., 2001).
- **Bioenergy:** Bioenergy is obtained from biomass feedstock and it is the renewable and the environmental-friendly energy (Kwant, 2003).
- **Renewable Energy Source:** Renewable energy sources are biomass, hydropower, geothermal, solar, wind and marine energy such as solar energy, wind energy, biomass energy, and geothermal energy. it is defined as resource that can be used again and again for energy production (Panwar, Kaushik, & Kothari, 2011).
- **Sustainability:** sustainability is an acceptability criterion that is used to asses impacts of an issue on different aspect. In general, sustainability assessment is made on economic, environmental and social aspects (Pope, Annandale, & Morrison-Saunders, 2004).
- **Biofuels:** Biofuels are derived from biomass and have high energy density, also are sustainable and the alternative of fossil fuels. Biodiesel and bioethanol are the widely used biofuels. Biofuels can be liquid, solid and gas (Correa, Beyer, Possingham, Thomas-Hall, & Schenk, 2017).

- **Biogas:** Biogas is a biofuel and derived from anaerobic degradation of organic material. It can be used for heat or electricity production (Rasi, Veijanen, & Rintala, 2007).
- **Bioethanol:** Bioethanol can be used as fuel in motor vehicles and a versatile feedstock in the chemical industry. It is obtained from fermentation of biomass (Rass-Hansen, Falsig, Jørgensen, & Christensen, 2007).
- **Biodiesel:** Biodiesel is a renewable fuel, produced from biomass (Sheehan, Camobreco, Duffield, Graboski, & Shapouri, 1998).
- **Cellulosic Biomass:** Cellulosic biomass can be referred to as lignocellulosic biomass and is the plant-derived biomass. Cellulose is the main structural component of plant cell walls (Rubin, 2008).
- **Organic Waste:** Organic waste is an organic matter which has soil microbial metabolism and soil enzymes and contains a great quantity of nitrogen. It has high agricultural value and can be sewage sludge, animal manures, agroindustrial wastes, city refuse, and plant residues (Paredes, Roig, Bernal, & Sa, 1998).

2.1 Biomass and Bioenergy

Biomass, which entails any organic matter derived from living organisms, is one of the most utilized sources of renewable energy. In other words, biomass can be defined as organic matter produced by photosynthesis. The term includes all forest residues, crops, seaweed, agricultural residues, as well as, animal wastes and municipal solid waste can be used as biomass (Mafakheri & Nasiri, 2014; Saidur, Abdelaziz, Demirbas, Hossain, & Mekhilef, 2011). Biomass is one of the most important renewable resources, approved as sustainable and environmental friendly, for meeting energy needs of the increasing population and industrialized world. In addition, as long as the sun exists, biomass is an inexhaustible source of energy.

By The Brundtland Commission in 1987, sustainability was accepted as “meeting the present needs without compromising the ability of future generations to meet their own needs”. This concept has gained importance in the energy supply and is considered in economic, environmental and social fields. Biomass is thought to become one of the major global primary energy sources during the next century, and it is expected that the modernized bioenergy systems will contribute to future sustainable energy systems in industrialized countries as well as in developing countries (Azadeh et al., 2014). The developments on economics, environmental and social aspects are composed the three pillars of sustainability: The Triple Bottom Line (TBL). Especially in the energy sector, sustainability becomes a well-known concept, with concerns about limited fossil resources and adverse environmental impacts (Hong et al., 2016).

Biomass is seen as a suitable and important source of energy. The advantages of biomass usage are as follows;

- Biomass can be grown anywhere and is easy to reach,
- It is suitable for energy efficiency at any scale,
- It can be stored,
- It provides socio-economic developments especially in rural areas,
- Biomass usage does not create environmental pollution, greenhouse effect,
- It does not cause acid rain.

In addition, the use of biomass in the energy sector has economic advantages;

- Biomass has positive impact on employment and Gross Domestic Product,
- Biomass usage supports energy generation to basically waste management system,
- Biomass can be regained to the ecosystem with secondary byproducts such as fertilizer,
- It reduces the cost of municipal waste disposal,
- It supports use of domestic resources,
- It reduces energy import.

The biomasses are considered as three generations depending on feedstock. The common biomasses in first generation are agricultural crops, animal wastes, oil plants and plant silage as feedstock; sugars and vegetable oils are the most widely used ones. The second generation bioenergy is obtained from nonfood feedstock; agricultural residues, woody crops, lignocellulose biomass with an advanced technology. The third generation bio-fuel, recently joined the main classification, is the one produced from algae (Akgul et al., 2012; Ghaderi, Pishvaei, & Moini, 2016).

Bioenergy has quite wide usage field. Electricity and heat generation is the most common usage field of bioenergy. Heat and electricity can be produced by using less energy with combined heat-power (CHP) technology. With anaerobic fermentation of organic based wastes in an anaerobic environment, biogas, which is a colorless - odorless and a lighter gas mixture, emerges. Biogas composition contains approximately 40-70% methane, 30-60% carbon dioxide, 0-3% hydrogen sulfide and very little nitrogen and hydrogen.

1 m³ of biogas provides 4700-5700 kcal / m³ of heat and 4.70 kWh of electrical energy.

1 m³ of biogas is equivalent to;

- 0.62 liters of gasoil,
- 1.46 kg of charcoal,
- 3.47 kg of wood,
- 0.43 kg of butane gas,
- 12.3 kg of dried dung,

and also,

- 0.666 liters of diesel fuel,
- 0.75 liters of gasoline,
- 0.25 m³ of propane.

Biodiesel is used as fuel in pure form or by mixing with oil based diesel. Biodiesel is released as a result of the reaction of vegetable oils (such as canola, sunflower, soybean, and safflower) with methanol or ethanol in the presence of a catalyst. Bioethanol is an alternative fuel that is blended with petrol in certain proportions. It is obtained by fermentation of starch or cellulose cored agricultural products (Ministry of Energy and Natural Resources, 2018).

2.2 Biogas Conversion Processes

Biogas is obtained from decomposition of organic matter by anaerobic microorganisms. Anaerobic digestion is decomposition of complex organic substances to the simplest components, with different types of bacteria. This process results in the production of methane (CH_4) and carbon dioxide (CO_2) by decomposing organic matter as a result of metabolic activities of acid and methane producing bacteria in oxygen-free environments. The composition of biogas is shown in Table 2.1. In Figure 2.1, Anaerobic digestion consists of four processes; hydrolysis, acidogenesis, acetogenesis and methanogenesis.

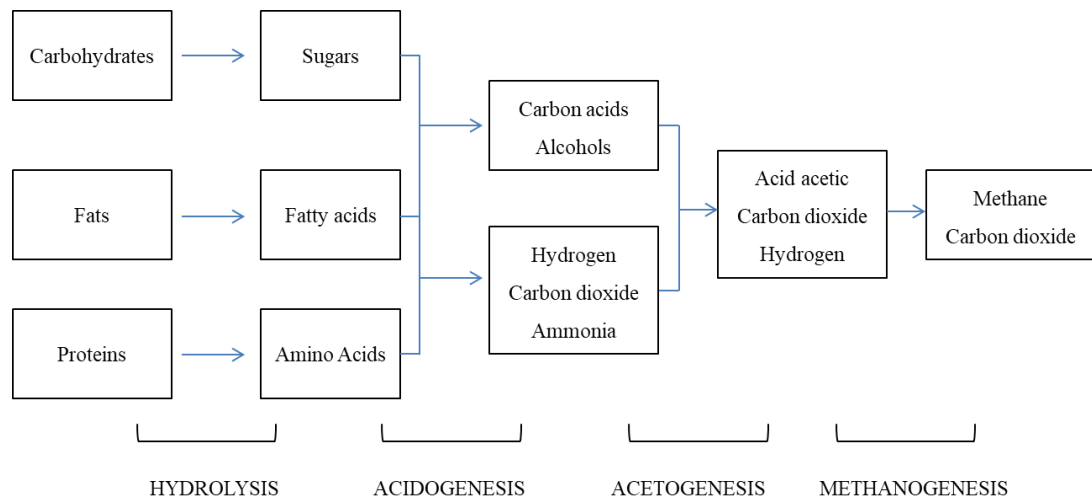


Figure 2.1 Processes of anaerobic digestion (Al Seadi, 2008)

At hydrolysis stage, complex molecules are broken down into simple building blocks by hydrolytic bacteria, shown in Figure 2.2. Oligomers and monomers are formed by the breakdown of complex compounds in the polymer structure through

enzymes during the hydrolysis process. At the end of these metabolic activities, most of the complex molecules found in the lignin environment are fragmented.

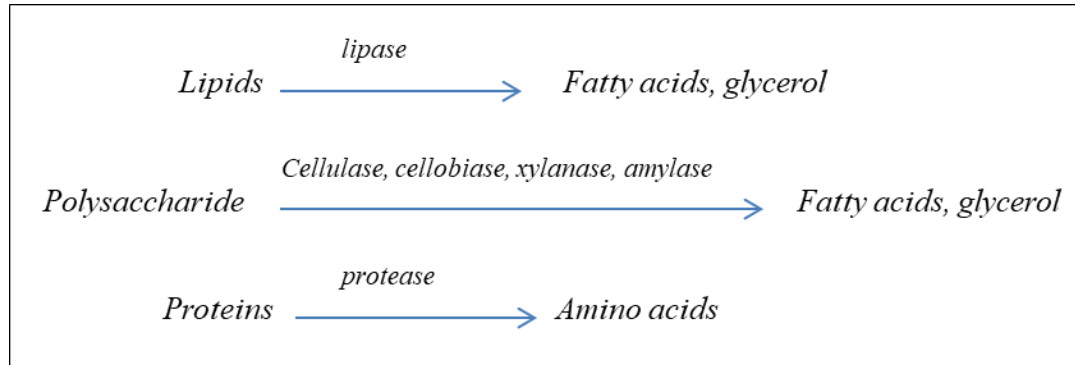


Figure 2.2 Decomposing polymers into smaller units (Al Seadi, 2008)

In acidogenesis process, the products of hydrolysis are converted to hydrogen, alcohol and volatile fatty acids by acidogenic bacteria and methanogenic substrates are obtained.

In the acetogenesis process, the molecules are converted into hydrogen, carbon dioxide and acetic acid by secondary fermentation bacteria.

In the methanogenesis process, methane and carbon dioxide are produced from acetate, hydrogen (H), and carbon dioxide (CO₂) with methanogenic bacteria, in Figure 2.3.

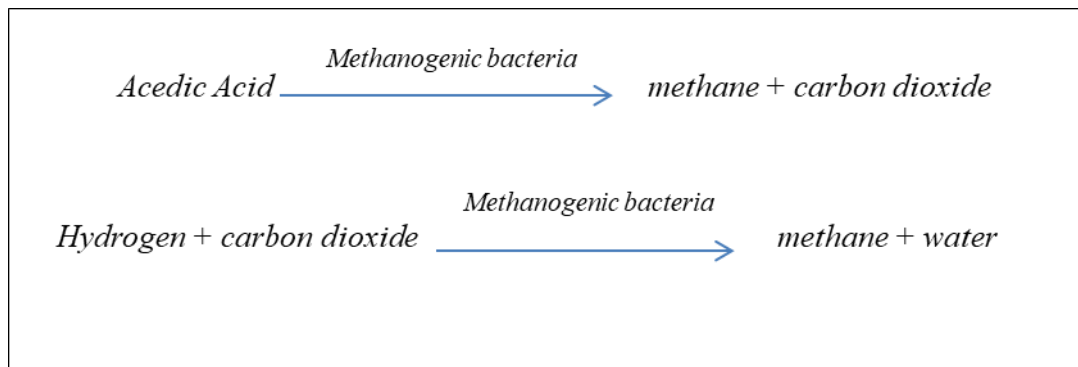


Figure 2.3 Methanogenesis process equation (Al Seadi, 2008)

Table 2.1 Composition of biogas (Al Seadi, 2008)

Compound	Chemical Symbol	Content (%)
Methane	CH_4	50-75
Carbon dioxide	CO_2	25-45
Water Vapour	H_2O	2 (20°C) – 7(40 °C)
Oxygen	O_2	< 2
Nitrogen	N_2	< 2
Ammonia	NH_3	< 1
Hydrogen	H_2	< 1
Hydrogen sulphide	H_2S	< 1

2.3 Biogas Feedstock

2.3.1 Animal Waste

Especially animal wastes are feedstock of great importance for biogas production. It is necessary to prevent uncontrolled release of solid and liquid wastes that occur in animal farms. The use of solid or liquid animal waste in energy production contributes to waste management. Thus, positive environmental impact is ensured by preventing the release of farm waste to the environment. In addition, as a result of the biogas production, animal wastes are brought to agricultural areas as organic fertilizers. Animal wastes, depending on the type of animal farms, animal wastes can be evaluated in two groups as poultry and cattle. Table 2.2 shows biogas yields and methane content of cattle and poultry manure. The amount and nature of animal waste may vary depending on the weight, age, health and nutrition of the animals. Poultry farms are classified as broiler and laying. There are differences in the waste contents of these plants due to production differences. According to Food and Agriculture Organization of the United Nations (2016), daily average of 120 kg of laying chicken manure and 80 kg of broiler chicken manure arise per 1000 chickens.

Considering the animal weight, annual amount of manure that can be obtained is stated below (Ministry of Energy and Natural Resources, 2018).

- 3.6 tons of manure is obtained from 1 cattle per year.
- 0,022 tons of manure per year is obtained from 1 poultry animal.

With these values,

- 33 m^3 of biogas is obtained per year from 1 ton of cattle manure.
- 78 m^3 of biogas is obtained per year from 1 ton of poultry animal manure.

Table 2.2 Biogas yield and methane content of animal manure (FNR, 2010)

Feedstock	Biogas production (Nm^3)	Methane Content (Nm^3)
Wet cattle manure	20-30	11-19
Average value	25	14
Dry cattle manure	60-120	33-56
Average value	80	44
Poultry manure	130-270	70-140
Average value	140	90

2.3.2 Industrial Waste

Remains of grains, beets, potatoes and fruit used in food and agro facilities emerge as waste. These residues are digestible organic waste and, biogas is obtained from the fermentations of these wastes. Biogas obtained from these food and agro facilities can be used as electricity and heat. Thus, energy is produced for the plant from renewable raw materials. Main industrial waste and their biogas yields is shown in Table 2.3.

Table 2.3 Biogas yield and methane content of main industrial wastes (FNR, 2010)

Feedstock	Biogas production (Nm ³)	Methane Content (Nm ³)
Beer pulp	105-130	62-112
Average value	118	70
Grainy pulp	30-50	18-35
Average value	39	22
Potato pulp	70-90	44-50
Average value	80	47
Crude glycerin	240-260	140-155
Average value	250	147
Grape	250-270	169-182
Average value	260	176
Sugar beet	60-75	44-54
Average value	68	49
Apple pulp	145-150	98-101
Average value	148	100

2.4 Main Components of Biogas Facility

The biogas plant is a large structure and consists of many parts. The structure, layout and technology of a biogas plant may vary depending on the type and quantity of the biomass used in the production. Main components and general flow of a biogas facility are shown in Figure 2.5. A biogas plant mainly consists of storage, mixing tank, anaerobic digester and cogeneration. Figure 2.4 presents the processes of an agricultural biogas facility.

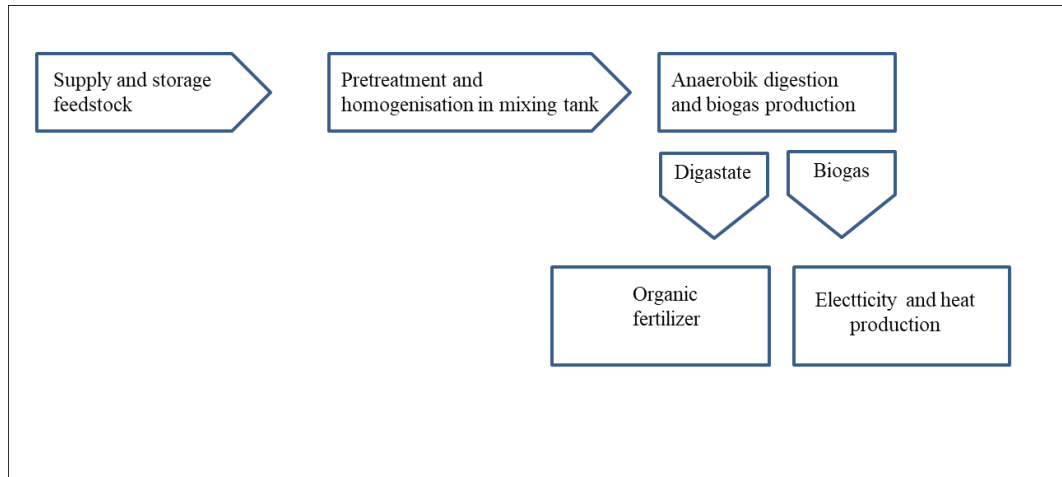


Figure 2.4 Process of agricultural biogas facility

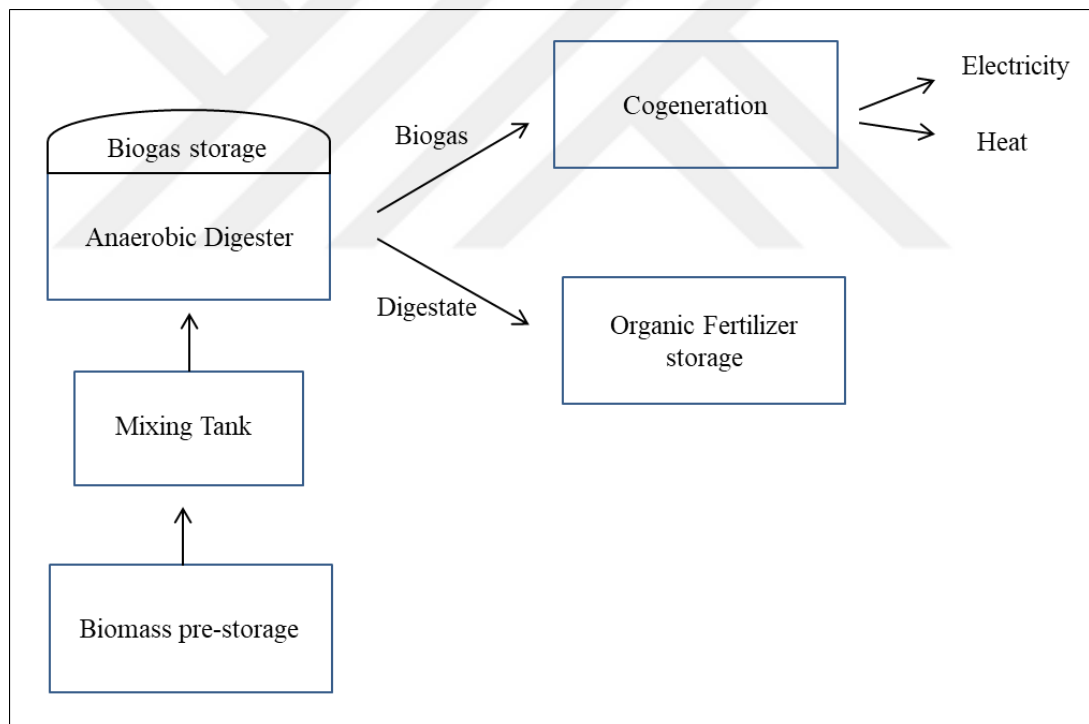


Figure 2.5 Main components and general flow of biogas facility

In storage, the wastes brought from the farms to the facility are firstly accepted to the facility by registering the information such as the amount and the source of the waste in the reception area. Then, the waste is stored until it is used in production. Depending on the type of biomass used in the facility, the storage types may vary.

The liquid biomasses are stored in the equilibration tanks, and solid wastes are stored in the solid storage area.

In the mixing tank, wastes are kept in mixture by continuous mixing. In this way, substances such as sand in the waste accumulate at the bottom of the tank. Waste is pumped from this area to the digesters.

In anaerobic digester, wastes are decomposed by anaerobic microorganisms and biogas is obtained. Anaerobic digester processes are mentioned in Section 2.2. Electricity and heat generation are obtained in cogeneration. CHP is a utilization stage of biogas obtained from anaerobic digester for energy generation. Approximately 35% electricity and 65% heat are generated at this stage.

CHAPTER THREE

LITERATURE REVIEW ABOUT SUSTAINABLE BIOMASS SUPPLY CHAIN

3.1 Introduction

This chapter presents a comprehensive literature review to highlight sustainability evaluation on BSC. Besides that, this chapter aims to help to future sustainable BSC research with evaluation and classification scheme to improve the concept of sustainability. For this purpose, a comprehensive literature research was conducted with limitations and specific keywords.

In the reminder of the chapter, section 3.2 states research methodology, and in Section 3.3, some previous literature reviews on BSC are presented to better comprehending of this field. In section 3.4, fifty-six papers obtained from literature search are analyzed and compared in different aspects. Table 3.10 presents basis classifications of papers as a basic guide.

3.2 Research Methodology

Table 3.1 gives information about research, selecting and sorting criteria. The articles on sustainable BSC, written in English language and published peer reviewed journals, were collected for the period 2010 to November 2018 in online databases. The specific keywords were used for this research; “sustainable BSC”, “sustainability”, “bioenergy supply chain”, “biomass” etc. The keywords of biomass, supply chain, bioenergy and types of biofuels were searched in keyword and title. Especially, the words of sustainable BSC and sustainability were searched both keyword/title and abstract. In consequence of this literature research, unexpectedly about a hundred articles were obtained. Ten times of this numbers could be reached, if only BSC was searched. This result shows that the number of papers, evaluating BSC under the sustainability concept, is low, whereas, nearly all of papers indicate that biomass is a sustainable energy source. At the end of the material collection, 56 papers are obtained from this research filtering quantitative methods. The papers

including qualitative analysis and presenting conceptual research were excluded in order not to go out of the field. Furthermore, in the material collection stage, some previous literature reviews were selected to be evaluated with the aim of making more accurate and effective the scope and classification of this work. And also, previous literature reviews are analyzed to distinguish our research from others. These previous research studies are evaluated and analyzed in section 3 in terms of field of research, time horizon, and the number of reviewed papers, objectives and conclusions. As a result of research methodology, 56 papers related sustainable BSC and 6 previous literature reviews on BSC and 5 previous literature reviews on sustainable BSC are obtained.

Table 3.1 Research and selection criteria

Keyword groups	• “biomass”, “sustainability”, “sustainable supply chain”, “biomass supply chain” • “sustainable supply chain”, “sustainability”, “waste management” • “bioethanol”, biodiesel”, “bioenergy”, “biofuel”, “supply chain”, “sustainability”, “sustainable biomass supply chain”
Time Period	2010-2018
Search Space	Title, keywords, abstract
Article Type	peer reviewed journals in English language
Inclusion Criteria	The articles should include quantitative biomass supply chain assessment under the concept of sustainability.
Sorting	Quantitative papers and previous literature reviews

3.3 Previous Literature Review

The aim of this section is to present more detailed information about the scope, scheme, and gaps on the field. Therefore, some previous literature reviews are analyzed and the differences and the shortcomings of the existed literature are revealed and its important aspects are displayed. These previous reviews are selected from the review papers published since 2010. In order to better understanding of this section, some characteristics of these previous literature reviews are illustrated and briefly information regarding the scope, characteristics. For example, time horizon and number of reviewed papers, and conclusions of reviews are presented in Table 3.2.

BSC reviews commonly describe general structure and processes of supply chain design. Gold and Seuring (2011), present a literature review about supply chain structure, management and logistics issue of bio-energy production. They classify articles with years, journals and region. Then, they analyzed the articles in terms of their research design, supply chain models and feedstock. Sharma et al. (2013), describe the energy needs, energy trends, bioenergy feedstock and conversion processes. They present a review on BSC design and modeling. They classify articles in terms of years and the journals, and decision levels, supply chain structure, modeling approach, and quantitative performance measurement are also included in the articles. Meyer et al. (2014) present an overview of the optimization methods and models of biomass- for-bioenergy supply chain by focusing on decisions regarding design and management. They analyze the articles with their objectives, and modeling approach. And also they classify strategic decisions in terms of location, size and type of facility, and biomass sourcing and allocation. Similarly, Ghaderi, Pishvae, & Moini (2016) provide a framework of the previous works and, a comprehensive review on BSC network design. They first analyze years and the journals. They classify the literature according to their strategic decision, multi feedstock and multi products, modeling approach, bioenergy generations, objectives, sustainability and uncertainty parameters, their data and region. Mafakheri & Nasiri (2014), present a review of existing literature and they analyze the use of mathematical models to describe design, planning and management decision on BSC. Their review considers the relation of different operational stages on BSC; harvesting, storage, transport, energy conversion. Yue, Slivinsky, Sumpter, & You, 2014, elucidate the key challenges and opportunities in modeling and optimization of BSC with a comprehensive review and classification of contributions on BSC. They present a potential perspective for future research.

In the second stage of the investigation of previous works, the reviews, especially covering on the sustainable BSC, are considered. Awudu and Zhang (2012), present general structure, decision making levels of the biofuel supply chain and describe sustainability concepts. Besides that, they elucidate biofuel generations according to similarities, differences and sustainability aspects. Palmeros Parada, Osseweijer, & Posada Duque (2017), present and analyze sustainability methods and metrics with

regard to different aspects. And they identify the advances of the incorporation of sustainability on biorefinery design. Espinoza Pérez, Camargo, Narváez Rincón, & Alfaro Marchant (2017), review the literature review on biorefinery supply chain optimization, designing and management. This review presents the differences of previous papers in terms of sustainability perspective. They analyze 72 published research articles to highlight the sustainability dimensions. Cambero and Sowlati (2014), review of the articles that cover economic, environmental and social optimizations of forest BSC. They aim to highlight assessment economic, environmental and social criteria, by discussing modeling approaches used, on the design of forest BSC. Hong et al. (2016), provide the understanding of the sustainability concept on BSC management and they identify the characteristics of integrated sustainable BSC. They present an overview of BSC synthesis and optimization methods.

After a detailed analysis of these previous literature reviews, some inferences are obtained. These reviews generally point out that the sustainable BSC should be assessed in economic, environmental and social aspects. Moreover, these reviews add that the numbers of research on development of BSC models will gradually increase because of the benefits of using biomass in the bioenergy production. Only one review (Awudu & Zhang, 2012) evaluates bioenergy generations in terms of sustainability and differences. Ghaderi et al. (2016) and Gold & Seuring (2011) analyze the type of feedstock used in the papers. Decision levels are studied by nearly all previous reviews. While, Cambero & Sowlati (2014), Espinoza Pérez et al. (2017) and Palmeros Parada et al.(2017) assess the objectives of the papers in sustainability dimensions, Ghaderi et al.(2016) categorize both objective functions and, analyze the papers that consider sustainability concept. The aim of the analysis of previous literature reviews is a better understanding and observation to evaluate criteria and classifications of the field of BSC.

Table 3.2 Previous literature reviews

References	Field of Research	Time Horizon	Number of reviewed papers	Objective	Conclusion
Gold & Seuring (2011)	Supply chain and logistics of bioenergy production	2000-2009	54	Structuring supply chain management (SCM) and logistics issues of bio-energy production	Academic research on relationship-focused management aspects and empirical analyses in bioenergy chain should be improved.
Sharma et al. (2013)	BSC design and analysis	1997-2011	32	Presenting energy trends, increasing focus on biomass, detailed review of mathematical modeling of BSC and the importance of SCM	Uncertainty should be incorporated into model formulation. Economic, environmental and social components should be incorporated. Large-scale case studies and computational complexities should be addressed.
De Meyer et al. (2014)	BSC Design and Management	1997-2012	71	Presenting a review of methods and models on optimization, designing and management of BSC	BSC optimization is essential to overcome uncertainties and to enhance sustainable bioenergy market. Sustainable SCM should be integrated with economic, environmental and social aspects.
Mafakheri & Nasiri (2014)	Modelling BSC	1997-2013	107	Providing a review of existing literature, analyzing design, and planning and management decision in BSC and also, presenting existing gaps in modeling of BSC.	Supply chain models, incorporating the uncertainties and dynamism, have to be investigated. There is a limited amount of research that focuses on the integrated socioeconomic-environmental evaluation of bioenergy production supply chains. The quantify impacts model should be developed with regard to health and ecosystem protection.
Yue et al. (2014b)	Biofuel supply chain optimization	2003-2013	143	Elucidating opportunities and key challenges in modeling and optimization of BSC. Presenting an overview and BCS classification.	Biofuels would grow rapidly because of economic, environmental and social benefits. Usage of cellulosic and algae biomass have more advantages over ethanol and biodiesel.

Table 3.2 continues

References	Field of Research	Time Horizon	Number of reviewed papers	Objective	Conclusion
Ghaderi et al. (2016)	BSC network design	1997-2016	146	Making a framework and a comprehensive overview regarding BSC design and models.	The models combining all sustainability concepts can be a future direction in this field. Multi-stage stochastic approaches and robust optimization techniques can be considered instead of traditional stochastic programming models to cope with uncertainty.
Awudu & Zhang (2012)	Uncertainties and sustainability in biofuel SCM	1988-2011	75	Evolution general structure, decision making levels of the biofuel supply chain. Describing uncertainties and sustainability concepts.	Uncertainty and sustainable concepts should be applied in biofuel SCM and also combination of all aspects of sustainability can be future direction in BSC models.
Cambero & Sowlati (2014)	Forest BSC in economic, environmental and social aspects.	1984-2014	91	Assessment of forest BSC with optimizing economic, environmental and social criteria.	Decision support tools are needed to quantify and optimize the all aspects (economic, environmental and social) of forest BSC simultaneously.
Hong et al. (2016)	Sustainable BSC	1998-2016	131	Presenting a general overview the concept and modeling sustainable BSC.	BSC undoubtedly near to commercialization and sustainability. New ideas should be supported for improvement in sustainable BSC.
Palmeros Parada et al. (2017)	Sustainability in bio refinery design	2005-2016	84	Analyzing sustainability methods and metrics regards to different aspects in bio refinery design.	Incorporated sustainability is increasingly considered in the design of bio refinery. However some challenges are found in sustainability incorporation for bio refinery design.
Perez et al. (2017)	Bio refinery SC design and management	2006-2015	72	Surveying the recent researches on designing and management bio refinery SC and highlighting the sustainability dimensions.	Bio refinery SC design and management must integrate the constraints and requirements of sustainability and decision making levels to sustainable industrialization.

3.4 Classification Scheme

Fifty six published papers (2010-2018) are analyzed and classified with regard to classification scheme, presented in Figure 3.1. The classification scheme is formed based on various classifications proposed by Awudu & Zhang (2012), Ghaderi et al. (2016) and Palmeros Parada et al. (2017). First of all, the papers are classified in terms of sustainability dimensions; economic, environmental and social aspects. Second, solution methodologies applied in the papers are analyzed. In following, bioenergy generations are assessed depending on biomass types and sustainability consideration. The decision levels of the articles are assessed and classified. Then, the types of data used in the papers are evaluated. The distribution of the articles according to years is shown in Figure 3.2. There is an increase in the number of papers in recent years.

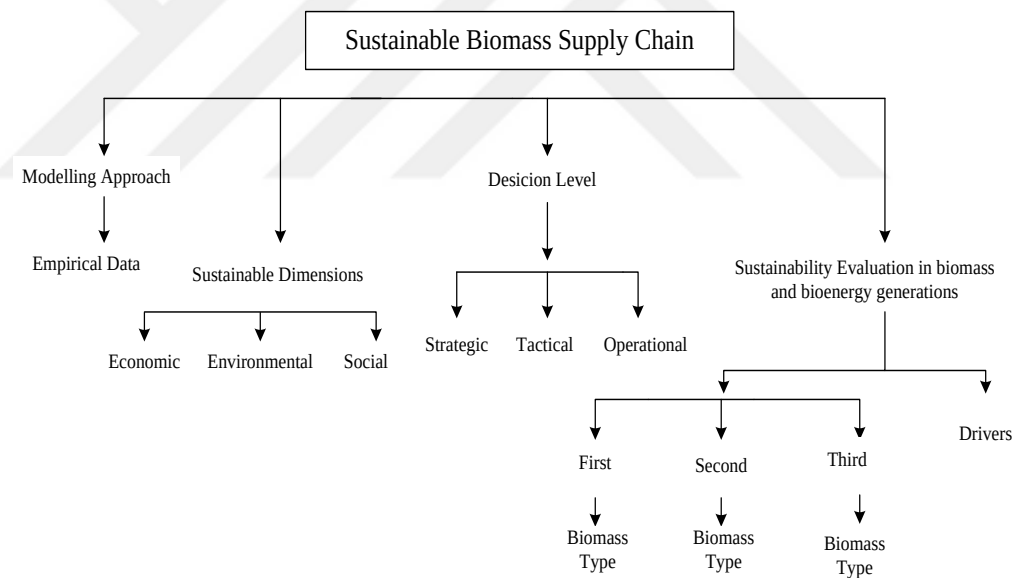


Figure 3.1 Classification scheme of sustainable BSC

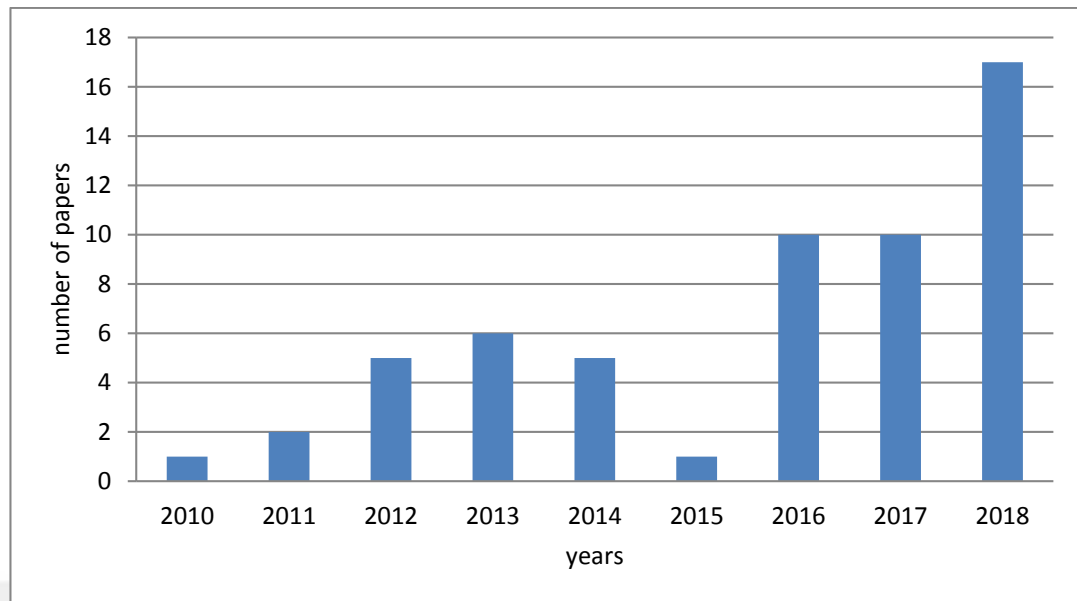


Figure 3.2 Distributions of papers according to years

3.4.1 Objective Functions Evaluation according to Sustainable Dimensions

Sustainability is defined as the meeting present needs with preserving the ability of meeting future needs. Literature on sustainable SCM has received increasing attention from research community in recent years. According to Espinoza Perez et al. (2017), the developments on economics, environmental and social aspects are composed as “the three pillars of sustainability: The Triple Bottom Line (TBL)”. Especially in the energy sector, sustainability becomes a well-known concept, with concerns about limited fossil resources and adverse environmental impacts. Supply chain design is a complex structure and each element in the chain is affected by each other. Thus, the designing a sustainable supply chain is a challenge on the bioenergy field. In addition, BSC includes many decisions (facility location, distribution road, supplier selection etc.) and different segments from the harvesting to end users, and sustainable BSC is considered in three dimensions (Hong et al. 2016; Rajeev et al. 2017; Seay & Badurdeen, 2014).

On the BSC literature, sustainability issue gains more attention recently. Most of the published papers discuss sustainability on environmental or economic aspects, whereas, the number of papers, covering social sustainability, is less than the others.

In Table 3.10, 17 papers evaluate all dimensions of sustainability. The following sections identify and analyze the literature in terms of its sustainability dimensions; economic, environmental and social. The distribution of the papers according to their sustainability dimensions is illustrated in Figure 3.3.

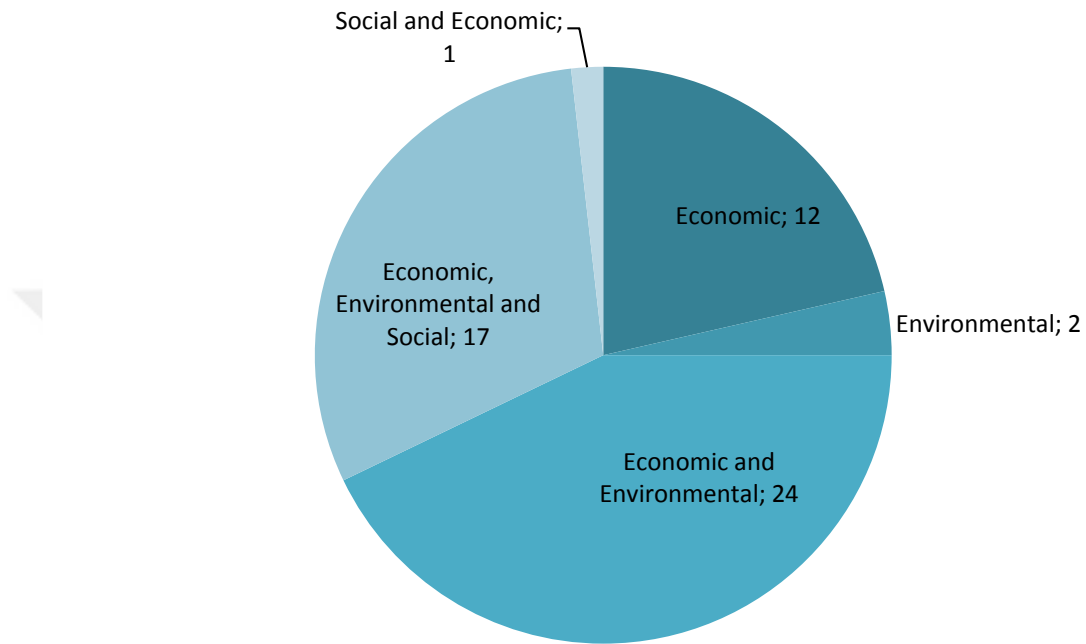


Figure 3.3 Distributions of 56 papers according to sustainability dimensions

3.4.2 Economic Dimension

Economic dimension of sustainability is the most popular objectives in BSC design. In Table 3.10, almost all of the papers (54 of 56) assess economic sustainability. Economic sustainability is related to profitability and cost reduction in the different segments of the chain such as feedstock type, distribution route, and facility location. In addition, economic sustainability is considered as long term benefits by using the resources in effective and efficient way. That is, economic sustainability necessitates that the use of resources, such as land, capital and labor, must be managed wisely and prospectively to ensure that the work continues for a period of several years in a healthy manner. There are some metrics to measure economic performance; net present value (NPV) and annual total cost generally are

the most common. Economic measurement considers the revenues of the system and the costs related to the processes like; investment, transportation, production (Ghaderi et al. 2016; Parada et al. 2017; Yue et al. 2014)

Profitability is one of the economic objectives. In 28 of the 54 articles, an economic profitability was targeted. In Table 3.3, papers are classified depend on profitability objectives. 17 papers aim to maximize overall annual profit. The annual profit is calculated by subtracting all costs from the sum of all sales. In these papers, annual total revenues from sales of final product, by products or biomass main crops are calculated, and then, different cost indicators are considered and calculated as total cost Bairamzadeh, Pishvae, & Saidi-Mehrabad (2016), Costa, Duarte, & Sarache (2017), and Domínguez-García, Gutiérrez-Antonio, De Lira-Flores, & Ponce-Ortega, (2017) calculate annual gross profit to measure profitability. Osmani & Zhang (2017) aim to maximize net expected profit, and they calculate total revenue considering sales and production tax credits. 11 papers use Net Present Value (NPV) metric to assess the value of supply chain project in a long term.

Cost minimization also is the main topic of economic sustainability. There are many cost indicators in BSC network; harvesting, distribution, storage, capital, labor costs etc. In general, optimization models aim to minimize the total cost in BSC. In Table 3.3, the papers are classified according to cost indicators. Transportation cost, investment cost, operation cost, production cost, storage cost, biomass related cost and inventory holding cost are considered. Transportation cost is the most calculated, and the papers generally consider more than one cost indicator.

Table 3.3 Classifications of papers according to economic dimensions

Economic dimensions		References
Cost minimization	Transportation cost	(Ahmed & Sarkar 2018; Akgul et al. 2012; Babazadeh et al. 2017b; Babazadeh et al. 2017a; Huang et al. 2010; Matindi et al. 2018; Mirkouei et al. 2017; Mohseni & Pishvae 2016; Petridis et al. 2018; Santibanez-Aguilar et al. 2013b; Yazan et al. 2016; Yilmaz Balaman & Selim 2016; Yue et al. 2014; Zhang et al. 2013; Rabbani et al. 2018)
	Investment/capital cost	(Akgul et al. 2012; Correll et al. 2014; Khishtandar et al. 2017; Mohseni & Pishvae 2016; Santibanez-Aguilar et al. 2013b; Yilmaz Balaman & Selim 2016; You et al. 2011; Yue et al. 2014a; Yue et al. 2013; Petridis et al. 2018; Yilmaz Balaman et al. 2018; Rabbani et al. 2018)
	Operation cost	(Correll et al. 2014; Khishtandar et al. 2017; Miret et al. 2016; Mohseni & Pishvae 2016; Santibanez-Aguilar et al. 2013b; Yilmaz Balaman & Selim 2016; You et al. 2011; Yue et al. 2014a; Yue et al. 2013; Zhang et al. 2013; Matindi et al. 2018)
	Production cost	(Akgul et al. 2012; Babazadeh et al. 2017a; Babazadeh et al. 2017b; Mirkouei et al. 2017; Yazan et al. 2016; Matindi et al. 2018; Ahmed & Sarkar 2018; Rabbani et al. 2018)
	Storage Cost	(Correll et al. 2014; Miret et al. 2016; Mirkouei et al. 2017; Ahmed & Sarkar 2018)
	Biomass Related Cost (land rental, harvesting, cultivation etc.)	(Correll et al. 2014; Mata et al. 2013; Mirkouei et al. 2017; Santibanez-Aguilar et al. 2013b; Yue et al. 2014a; Zhang et al. 2013; Zhong et al. 2016; Matindi et al. 2018; Petridis et al. 2018; Ahmed & Sarkar 2018; Rabbani et al. 2018)
	Inventory holding cost	(Babazadeh et al. 2017a; Babazadeh et al. 2017b; Rabbani et al. 2018)
NPV		(Cambero and Sowlati 2016; Giarola et al. 2012; Hombach et al. 2016; Pérez-Fortes et al. 2012; Zamboni et al. 2011; Akhtari et al. 2018; Berry & Sessions 2018; Wheeler et al. 2018; How et al. 2018; Chavez et al. 2018)
Max profit		(Bairamzadeh 2016; Costa et al. 2017; Čuček et al. 2012; Domínguez-García et al. 2017; How et al. 2016; Osmani & Zhang 2013, 2014, 2017; Perrin et al. 2017; Santibanez-Aguilar et al. 2014; Santibanez-Aguilar et al. 2013a; Torkkeli 2014; Ulonska et al. 2018; Mohamed Abdul Ghani et al. 2018; How & Lam 2018; Yilmaz Balaman et al. 2018; Kesharwani et al. 2018)

3.4.3 Environmental Dimension

In the recent literature, environmental dimension is the issue that gained more attention due to the increasing negative environmental impacts of energy use. Environmental sustainability requires designing operations or processes by preserving resources of today and tomorrow from potential harms. There are several issues of the environmental sustainability; such as; air and soil quality, water resources quality, waste management, greenhouse gas (GHG) emission, protection of wildlife, energy efficiency. Climate change and global warming potential (GWP) are those of the main drivers of environmental sustainability; therefore businesses should give attention to the causes of climate change GWP. Sustainability strategies should be develop to reduce GHG emissions, carbon footprint and to improve air quality (Hoang Duc & Do Ba, 2016; Kolk & Pinkse, 2004). Out of 56 papers, 43 papers (76%) consider environmental sustainability in different aspects; GWP, climate change, waste management etc. In Table 3.4, the papers, covering environmental sustainability, are classified depends on the issues.

In terms of GWP, carbon-dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) are an important consideration of net GHG emissions. Comparing the traditional fuels, GHG emissions from the use of biofuels are less in the atmosphere. As a substitution of fossil resources, biomass reduces the impacts of fossil energy use on the GWP. As seen in Table 3.4, the most of papers (33 of 43) on environmental sustainability consider impacts on GWP. It is clear that, global warming has an important place in sustainable BSC. Some papers use the most common technique Life cycle analysis (LCA) to evaluate the environmental impacts of products from raw material to the end products (Cambero & Sowlati, 2016; Costa et al., 2017; Čuček et al., 2012; de la Fuente, Athanassiadis, González-García, & Nordfjell, 2017; Giarola et al., 2012; You, Fengqi; Tao, Ling; Graziano, Diane J.; Snyder, 2011; Yue et al., 2013; Zamboni et al., 2011). This analysis is used to measure the global warming potential of bioenergy products with the total GHG emissions throughout their entire life cycle (Hall & Scrase, 1998; Solomon, 2010; Zokaï & Manikas, 2014).

Moreover, sustainability requires that consideration of water and soil quality; levels of nutrients and organic matter in soils and the water resources usage (Reijnders, 2006). Some papers consider soil and water quality and assess emissions and toxic emissions (Bairamzadeh et al., 2016; Khishtandar et al., 2017; Mata, Martins, Sikdar, & Costa, 2011; Miret et al., 2016; Perrin et al., 2017; Santibañez-Aguilar, González-Campos, Ponce-Ortega, Serna-González, & El-Halwagi, 2014). Fresh water is an important resource for biomass production. Similarly, fresh water is an indispensable source for all humanity and the efficient use of scarce fresh water is an important issue for present and future (Reijnders, 2006). Santibaez-Aguilar et al. (2013b) aim to obtain clean water in bioenergy generation by using water hyacinth as biomass. Besides, it is discussed that stump harvesting, as a feedstock for bioenergy, can diminish the sequestration and storage of carbon in soils (Alam, Kellomäki, & Kilpeläinen, 2013).

Solid waste management is essential to contribute different environmental problems such as climate change, resource depletion, ecosystem and human health damages (Laurent et al., 2014). In BSC, the management of increased waste generation is addressed to move more sustainable society in respect to environment. Čuček et al. (2012) and Santibaez-Aguilar et al. (2013a) use waste materials as biomass to bioenergy generation.

On the other hand, the impacts of large scale biofuels production on biodiversity are discussed, where focusing on forest and grassland species. The increased of land use, water requirements and various feedstock species is assessed for potential biodiversity impacts as sustainability (Solomon, 2010). Among the papers aiming environmental sustainability, Khishtandar et al. (2017) considers the BSC impacts on biodiversity.

Table 3.4 Classifications of papers according to environmental dimensions

Environmental dimensions		References
GWP	GHG emission	(Cambero & Sowlati 2016; Costa et al. 2017; Čuček et al. 2012; Giarola et al. 2012; Hombach et al. 2016; Khishtandar et al. 2017; de la Fuente et al. 2017; Mata et al. 2013; Miret et al. 2016; Osmani & Zhang 2017, 2014; You et al. 2011; Yue et al. 2014a; Yue et al. 2013; Zamboni et al. 2011; Zhong et al. 2016; Yılmaz Balaman et al. 2018; Kesharwani et al. 2018; How et al. 2018; Stougie et al. 2018; Rabbani et al. 2018)
	CO2 emission	(Domínguez-García et al. 2017; Giarola et al. 2012; How et al. 2016; Mirkouei et al. 2017; Pérez-Fortes et al. 2012; Perrin et al. 2017; Torkkeli 2014; Yazan et al. 2016; Muhamed Abdul Ghani et al. 2018; Petridis et al. 2018; Yılmaz Balaman et al. 2018; Ahmed & Sarkar 2018; Chavez et al. 2018)
climate change		(Bairamzadeh et al. 2016; Khishtandar et al. 2017; de la Fuente et al. 2017; Santibanez-Aguilar et al. 2014; Wheeler et al. 2018)
Waste management		(Čuček et al. 2012; Santibanez-Aguilar et al. 2013)
Clean water		(Santibanez-Aguilar et al. 2013b; Wheeler et al. 2018; How & Lam 2018)
Resource use		(Bairamzadeh et al. 2016; Miret et al. 2016; Perrin et al. 2017; Santibanez-Aguilar et al. 2014; Wheeler et al. 2018; Stougie et al. 2018)
Land use		(Khishtandar et al. 2017; Mata et al. 2013; Perrin et al. 2017; Zhong et al. 2016; Wheeler et al. 2018; Stougie et al. 2018; How & Lam 2018)
Biodiversity loss		(Khishtandar et al. 2017)
water and soil emissions/ toxic emission		(Bairamzadeh et al. 2016; Khishtandar et al. 2017; Mata et al. 2013; Miret et al. 2016; Perrin et al. 2017; Santibanez-Aguilar et al. 2014; Wheeler et al. 2018; How & Lam 2018; How et al. 2018)

3.4.4 Social Dimension

Social sustainability is related the issues increasing and enhancing social welfare such as employment opportunities, poverty reduction, social resources security and technological developments. And also, it covers social rights, working conditions, health issues, fresh water and food security (Espinoza Pérez et al., 2017; Hombach et al., 2016; Srinivasan, Ikuma, Shakouri, Nahmens, & Harvey, 2016). Table 3.10 shows that 18 of 56 papers (33%) work on social sustainability. In the some previous literature reviews on BSC, the ratio of the papers on social sustainability is less than that of the present study. It can prove that, the importance given social dimension

increase in sustainable BSC. In Table 3.5, the papers are classified depends on social issues.

Increase employment is defined that biomass and bioenergy generation provides job opportunities in both agricultural and biorefineries in rural areas. It makes no differences whether it is a large scale or a small scale; biomass generation contributes to employment on these areas. Therefore it increases the quality of life on the communities (Awudu & Zhang, 2012; Fytili & Zabaniotou, 2017). In the present, most of papers on social dimensions aim to increase employment (Bairamzadeh et al. 2016; Cambero and Sowlati 2016; Mata et al. 2013; Miret et al. 2016; Osmani & Zhang 2017; Pérez-Fortes et al. 2012; Santibanez-Aguilar et al. 2014; You et al. 2011; Yue et al. 2014).

Food security is another issue of social sustainability and one paper consider food security issue (Khishtandar et al. 2017). There is a criticism about the use of food crops, as biomass feedstock for bioenergy generation, increases food prices due to the emergence of competition between food sector and energy sector (Meyer et al. 2014; Palmeros Parada et al. 2017).

Energy security also effects social sustainability, namely, increased social developments like new technologies need more energy use. The increased energy needs create a competition between energy prices, and also increase the use of energy resources. These issues reveal the ability to meet demand and maximization of service level (Yılmaz Balaman & Selim 2016). It is claimed that the biomass use is able to decrease energy costs and foreign energy resources dependency, and to preserve future energy security (Awudu & Zhang 2012; Hong et al. 2016; Palmeros Parada et al. 2017)

Table 3.5 Classifications of papers according to social dimensions

Social Dimensions	References
Increase employment	(Bairamzadeh et al. 2016; Cambero & Sowlati 2016; Mata et al. 2013; Miret et al. 2016; Osmani & Zhang 2017; Pérez-Fortes et al. 2012; Santibaez-Aguilar et al. 2014; You et al. 2011; Yue et al. 2014a; Petridis et al. 2018; How & Lam 2018; How et al. 2018; Chavez et al. 2018; Rabbani et al. 2018)
Maximization service level / meet demand	(Yılmaz Balaman & Selim 2016; Kesharwani et al. 2018)
Food security	(Khishtandar et al. 2017; Chavez et al. 2018)
Improvement rural/economic development	(Khishtandar et al. 2017; Petridis et al. 2018; How et al. 2018)

3.4.5 Solution Methodology

The present study considers quantitative research on sustainable BSC. These quantitative papers use different solution methodologies depending on objectives, decisions, uncertainty parameters and type of applications. In this section, different solution methodologies are analyzed and then, they are classified as optimization methods, simulation, hybrid methods, Multi criteria decision making (MCDM), fuzzy optimization, Life Cycle Assessment (LCA), stochastic methods. In Table 3.6, MILP and stochastic methods have widely usage in sustainable BSC.

Optimization methods are deterministic mathematical models. These models consist of constraints, objective functions, decision variables and parameters. These models aim to obtain optimal solution for objective functions. The parameters, used in these model, are certain and fixed. In this study, optimization methods are analyzed and classified within themselves depends on the decision variables in Table 3.6. According to results of this study, MILP models are the most used approach (19 of 56). This approach generally is applied to maximize net profit and to minimize total cost with binary and continuous decision variables. 4 of 19 papers have single objective. Single objective MILP models purpose to minimize total cost (Akgul et al. 2012; Huang et al. 2010; Zhang et al. 2013; Akhtari et al. 2018). Other MILP models consider multi objective optimization. 7 of 19 papers include economic and

environmental optimization (Čuček et al. 2012; Domínguez-García et al. 2017; Hombach et al. 2016; Santibanez-Aguilar et al. 2013a; Zamboni et al. 2011; Zhong et al. 2016; Muhamed Abdul Ghani et al. 2018). Remained articles consider economic-environmental and also social objective (Cambero & Sowlati 2016; Miret et al. 2016; Pérez-Fortes et al. 2012; Santibanez-Aguilar et al. 2014; You et al. 2011; Petridis et al. 2018; Chavez et al. 2018; Rabbani et al. 2018). Mixed integer non-linear programming models (MINLP) include nonlinear constraints or objective functions. Table 3.6 shows that 5 of 56 papers present MINLP models and all of these papers are multi objective consideration. Some papers study under uncertain parameters such as demand, market, and price. Uncertainty is considered frequently in BSC. To overcome the different uncertain parameters, stochastic approach is used in 8 papers. Only one paper, Correll et al.(2014) use a simulation model with variety conditions. Two papers propose a fuzzy MILP model, comprising multiple biomass types and system uncertainties, with the objectives of cost and unmet demand minimization. In addition, Babazadeh et al. (2017a) present fuzzy optimization with economic and environmental objectives. Costa et al. (2017) use a hybrid approach presenting simulation-optimization framework to achieve economic goals with environmental and social issues. Babazadeh et al. (2017b) also integrate hybrid approach using a data envelopment analysis (DEA) and mathematical programming techniques with an economic objective. Khishtandar et al. (2017) use multi criteria decision making (MCDM) for sustainable BSC. They present multi criteria economic, environmental, technical and social dimensions. de la Fuente et al. (2017) and Perrin et al. (2017) use LCA perspectives to assess sustainability. They compare alternative biomass supply chain scenarios and evaluate resource and energy consumption, and emissions to air, water and soil. In supply chain design, GIS are used to determine the transport distance, to select the location of the facility, to determine the supply and demand points. Sánchez-García et al. (2017) and Woo et al. (2018) use GIS to minimize transportation distance and cost by determining the optimum facility location. Nivala et al. (2015) determines supply points with GIS to provide minimum distance in entire supply chain. F. Zhang et al. (2016) uses GIS to design biofuel supply chain and to determine facility locations. Sahoo & Mani (2015) use GIS to design transportation flows with minimum cost.

For the validation of the proposed methods and the consistency of the article, the suitability and accuracy of the data used in the article is crucial. In the literature, the data can be used from case studies application. For quantitative papers, data sometimes are collected from related past studies or real data, or are derived with the aid of software. In Figure 3.4, nearly all of the papers apply their proposed models with a case study.

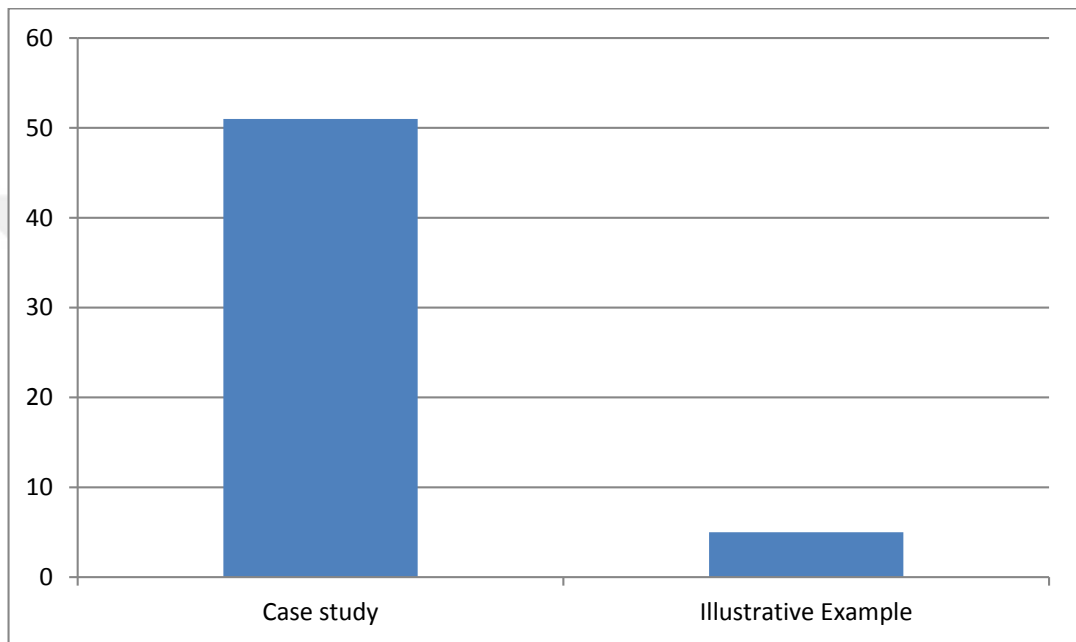


Figure 3.4 Number of papers according to data type

Table 3.6 Classifications of papers according to solution methodologies

Solution Methodology		References
Optimization method	MILP	(Akgul et al. 2012; Cambero & Sowlati 2016; Čuček et al. 2012; Domínguez-García et al. 2017; Hombach et al. 2016; Huang et al. 2010; Miret et al. 2016; Pérez-Fortes et al. 2012; Santibanez-Aguilar et al. 2014; Santibanez-Aguilar et al. 2013a; You et al. 2011; Zamboni et al. 2011; Zhang et al. 2013; Zhong et al. 2016; Akhtari et al. 2018; Muhamed Abdul Ghandi et al. 2018; Petridis et al. 2018; Chavez et al. 2018; Rabbani et al. 2018; Berry & Sessions 2018; Ahmed & Sarkar 2018)
	MINLP	(How et al. 2016; Santibanez-Aguilar et al. 2013b; Yue et al. 2014a; Yue et al. 2013; Kesharwani et al. 2018)
	NLP	(Torkkeli 2014; Ulonska et al. 2018)
Simulation Method		(Correll et al. 2014)
Hybrid		(Babazadeh et al. 2017a; Costa et al. 2017; Matindi et al. 2018)
MCDM		(Khishtandar et al. 2017; Wheeler et al. 2018; How & Lam 2018; How et al. 2018)
Stochastic		(Babazadeh et al. 2017a; Bairamzadeh et al. 2016; Giarola et al. 2012; Mirkouei et al. 2017; Mohseni & Pishvae 2016; Osmani and Zhang 2013, 2014, 2017)
GIS		(Nivala et al., 2015; Sahoo & Mani, 2015; Sánchez-García et al., 2017; Woo et al., 2018; F. Zhang et al., 2016)
LCA		(de la Fuente et al. 2017; Perrin et al. 2017; Stougie et al. 2018)
Fuzzy Programming		(Yilmaz Balaman & Selim 2016; Yilmaz Balaman et al. 2018)
Others/ analytical		(Mata et al., 2013; Yazan et al., 2016)

3.4.6 Bioenergy Generations and Sustainability Evaluations

Different types of feedstock are used in bioenergy generation. According to type of biomass used and related generation processes, bioenergy currently is classified into three generations. Bioenergy generations of papers are presented in Table 3.7; papers are categorized according to their biomass feedstock. In the present study, most of papers use second generation bioenergy, while, only two paper study on third generation bioenergy. The reason of this finding can be attributed the fact that third generation bioenergy is a newly developed subject compared to others. In Figure 3.5, the number of papers is showed in terms of considered bioenergy generations.

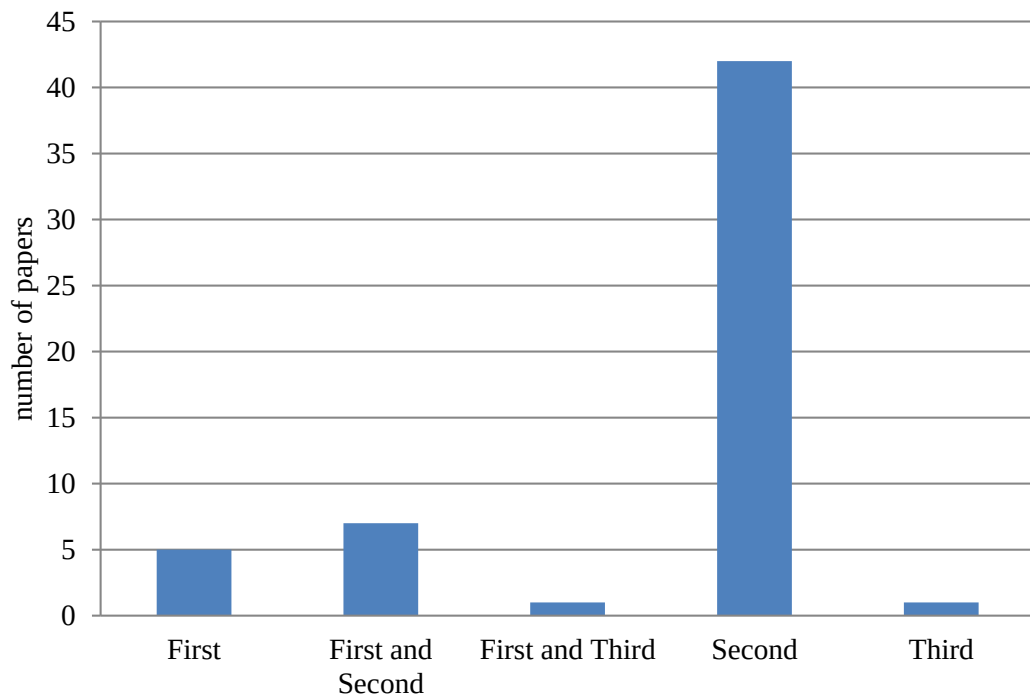


Figure 3.5 Number of papers according to bioenergy generations

First generation is widely commercialized with the well-developed processes and technology. Thus, the first generation bioenergy is the most common one and is a mature field in the bioenergy production. The common biomasses in first generation are agricultural crops, animal wastes oil plants and plant silage as feedstock; sugars and vegetable oils are the most widely used ones. Despite of the fact that first generation bioenergy is well developed; it is not much preferred under the concept of sustainability. The reason is that these biomasses can be used as food source for humanity as well. This creates a competition between food sector and energy sector, and leads to increase food prices and also, the use of agricultural materials in energy generation endanger the food supply. This adverse effect leads the second generation bioenergy become popular. In addition, there are competitions on land and fresh water use for food production and are some concerns about impacts on biodiversity. Conversely, the benefits on mitigation of GHG and enhancing domestic energy security are main sustainability characteristics of the first generation bioenergy (Correa et al., 2017; Ghaderi et al., 2016; Naik et al., 2010).

The second generation bioenergy is obtained from nonfood feedstock; agricultural residues, woody crops, lignocellulose biomass with an advanced technology. Nonfood sources are abundant and they are obtained from plants. However, there are some barriers in the commercialization of second generation bioenergy. Its production process is more difficult than first generation. Production cost, technological developments and infrastructures are challenges. To commercialize in the second generation bioenergy, a new infrastructure is needed over the BSC design from harvesting to final products of biomass (Antizar-Ladislao; Turrion-Gomez, 2008; Sims, Mabee, Saddler, & Taylor, 2010).

Third generation biofuels are derived from algae and microalgae. In the respect of food security, microalgae can be obtained from sea water or waste water such as industrial. And third generation has potential to be possible solution for energy sector. Currently, third generation technologies use algae and cyanobacteria with high oil mass content, which grown in ponds. In other words, feedstock in the third generation biofuels does not require any land that can be use also in food production. However, the research on technological development are ongoing and more research is required to commercialize in third generation (Carneiro et al. 2017; Singh et al. 2011).

Table 3.7 Classifications of the papers according to feedstock and bioenergy generations

Bioenergy Generation	Feedstock	References
First generation	Agricultural (wheat, corn, sugar cane, starch)	(Akgul et al. 2012; Giarola et al. 2012; How et al. 2016; Khishtandar et al. 2017; Mata et al. 2013; Miret et al. 2016; Santibanez-Aguilar et al. 2014; Torkkeli 2014; Yue et al. 2013; Zamboni et al. 2011; Wheeler et al. 2018; Kesharwani et al. 2018)
	Animal waste	(Čuček et al. 2012; Mata et al. 2013; Yılmaz Balaman & Selim 2016; Yılmaz Balaman et al. 2018; Stougie et al. 2018)
	Plant silage	(Čuček et al., 2012)
	Oil plants (sunflower, soybean, canola, palm oil)	(Costa et al. 2017; Khishtandar et al. 2017; Mata et al. 2013; Santibanez-Aguilar et al. 2014; Torkkeli 2014)
Second generation (lignocellulosic biomass)	Agricultural waste (Corn stover, rice straw, wheat straw)	(Bairamzadeh et al. 2016; Correll et al. 2014; Giarola et al. 2012; Hombach et al. 2016; How et al. 2016; Huang et al. 2010; Khishtandar et al. 2017; Osmani & Zhang 2013, 2017; Pérez-Fortes et al. 2012; You et al. 2011; Yue et al. 2014a; Matindi et al. 2018; Muhamed Abdul Ghandi et al. 2018; How & Lam 2018; Ahmed & Sarkar 2018; Chavez et al. 2018; How et al. 2018)
	Forest/wood residues	(Cambero & Sowlati 2016; Hombach et al. 2016; Huang, Chen, & Fan 2010; Khishtandar et al. 2017; Santibanez-Aguilar et al. 2014; You et al. 2011; Akhtari et al. 2018; Berry & Sessions 2018)
	Municipal Solid Waste	(Babazadeh et al. 2017b; Huang et al. 2010; Khishtandar et al. 2017; Santibanez-Aguilar et al. 2013a)
	Cotton residues	(Huang et al. 2010)
	Energy crops (switchgrass, miscanthus, poplar, jatropha)	(Akgul et al. 2012; Babazadeh et al. 2017a; Babazadeh et al. 2017b; Correll et al. 2014; Domínguez-García et al. 2017; Giarola et al. 2012; Hombach et al. 2016; Khishtandar et al. 2017; Osmani & Zhang 2017, 2013, 2014; Perrin et al. 2017; Santibanez-Aguilar et al. 2014; Torkkeli 2014; Yılmaz Balaman & Selim 2016; You et al. 2011; Yue et al. 2013; Zhang et al. 2013; Zhong et al. 2016; Rabbani et al. 2018)
	Forest / woody	(Giarola et al. 2012; de la Fuente et al. 2017; Miret et al. 2016; Mirkouei et al. 2017; Osmani & Zhang 2014, 2017; Torkkeli 2014; Yazan et al. 2016; Ulonska et al. 2018; Petridis et al. 2018; How & Lam 2018)
	Water hyacinth	(Santibanez-Aguilar et al. 2013b)
Third generation	Microalgae	(Mata et al., 2013; Mohseni & Pishvae, 2016)

3.4.7 Decision Levels

SCM is a complex and comprehensive issue which comprising of all movements from the raw materials to end users. SCM aims to provide a more effective flow and network between chains. The more effective management requires some decision such as locations, road, distribution centers, shipment, inventory levels etc. In BSC, decision levels classified in three levels (strategic, tactical and operational), as in the SCM (Eskandarpour et al. 2015; Papageorgiou 2009; Shabani et al. 2013).

3.4.7.1 Strategic Decision Level

Strategic decision level considers long term decisions which are usually over one year. It interests the financial investment and development of the system. In general, number, location and capacities of facility and distribution centers, network design, and supply and demand contracts are some examples of strategic decision types. In BSC, type and source of biomass, location and size of bio refineries, conversion technology selection, distribution patterns are the key strategic decisions (Ba et al. 2016; Iakovou et al. 2010; Lin et al. 2014). Table 3.8 shows that BSC considers mostly strategic level decision. Facility (pre-processing site, processing site, biorefinery, etc.) decisions are most common one in BSC strategies. Selection of location, capacity or size of facilities is long-term issue and affects effective and economic execution of supply chain in the long run. These decisions are usually stated as binary variable in the mathematical models. It is important that facilities should be close to resources and consumers in location decisions. In Table 3.8, the papers classified in terms of their strategic decisions. Figure 3.6 shows the number of most used decisions, and, facility related decisions are clearly the most considered ones in the strategic decisions. Most papers determine facility location, capacity and technology, because these decisions directly impact investment, transportation cost and performance. Biomass related decisions also affect BSC costs and productivity. Selection of biomass type and determining the annual amount of biomass need are related expected cost and expected final product quantity. Annual transportation schedule is also considered in some papers. These decisions are flow rate or quantity

of materials (biomass, byproducts or final products) among nodes (harvesting site, refinery or demand points etc.), and help to determine supply chain capacity, type of vehicle used, transportation route, distance and cost.

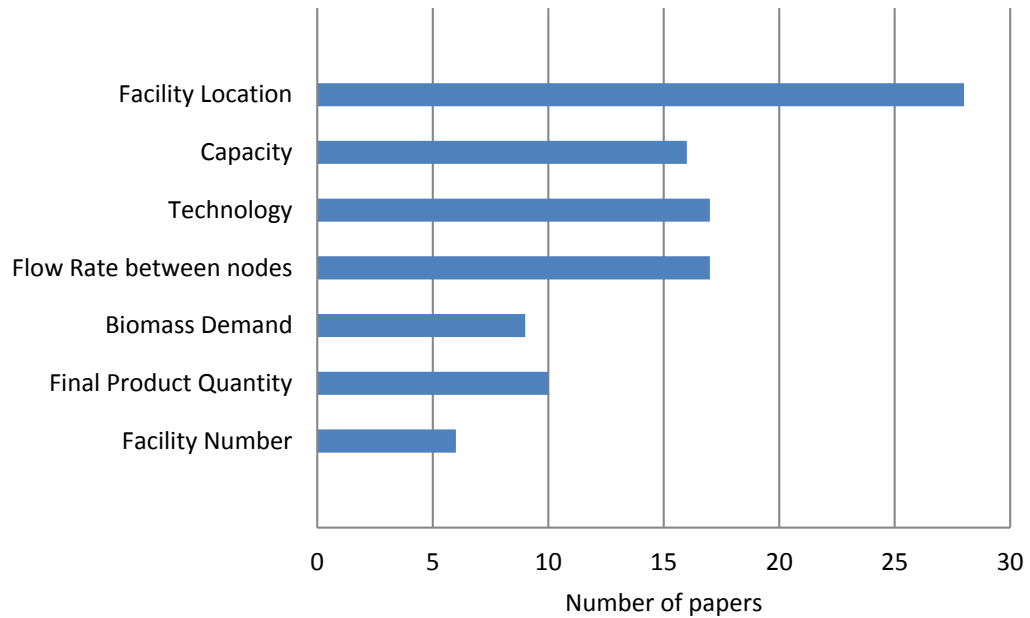


Figure 3.6 Number of papers according to strategic decisions

Table 3.8 Classifications of the papers according to strategic decisions

Strategic decisions		References
Facility Related	Location	(Akgul et al. 2012; Babazadeh et al. 2017a; Babazadeh et al. 2017b; Bairamzadeh et al. 2016; Costa et al. 2017; Giarola et al. 2012; Huang et al. 2010; de la Fuente et al. 2017; Miret et al. 2016; Mohseni & Pishvaei 2016; Osmani & Zhang 2013, 2014, 2017; Pérez-Fortes et al. 2012; Yazan et al. 2016; Yılmaz Balaman & Selim 2016; You et al. 2011; Yue et al. 2014a; Yue et al. 2013; Zhang et al. 2013; Akhtari et al. 2018; Uloska et al. 2018; Petridis et al. 2018; Yılmaz Balaman et al. 2018; Kesharwani et al. 2018; How et al. 2018; Chavez et al. 2018; Rabbani et al. 2018)
	Capacity	(Babazadeh et al. 2017a; Babazadeh et al. 2017b; Bairamzadeh et al. 2016; Huang et al. 2010; Miret et al. 2016; Mohseni & Pishvaei 2016; Osmani & Zhang 2013, 2014, 2017; Pérez-Fortes et al. 2012; Torkkeli 2014; Yılmaz Balaman & Selim 2016; You et al. 2011; Yue et al. 2013; Yılmaz Balaman et al. 2018; Rabbani et al. 2018)
	Number	(Babazadeh et al. 2017a; Babazadeh et al. 2017b; Hombach et al. 2016; Yue et al. 2014a; Yılmaz Balaman et al. 2018; Rabbani et al. 2018)
	Size	(Huang et al. 2010; Yue et al. 2014)
	Technology	(Bairamzadeh et al. 2016; Cambero and Sowlati 2016; Giarola et al. 2012; Hombach et al. 2016; Khishtandar et al. 2017; Miret et al. 2016; Pérez-Fortes et al. 2012; Perrin et al. 2017; You et al. 2011; Yue et al. 2014a; Yue et al. 2013; Akhtari et al. 2018; Wheeler et al. 2018; How and Lam 2018; Yılmaz Balaman et al. 2018; How et al. 2018; Stougie et al. 2018)
Biomass /feedstock related	Type	(Khishtandar et al. 2017; de la Fuente et al. 2017; Mata et al. 2013; Santibanez-Aguilar et al. 2014; Akhtari et al. 2018; Uloska et al. 2018; Stougie et al. 2018)
	Quantity/demand	(Akgul et al. 2012; Correll et al. 2014; Hombach et al. 2016; Osmani & Zhang 2013; Perrin et al. 2017; Torkkeli 2014; Yue et al. 2014a; Yue et al. 2013; Chavez et al. 2018)
	Sourcing	(Osmani and Zhang 2013; Zhang et al. 2013; Petridis et al. 2018; How & Lam 2018; Yılmaz Balaman et al. 2018)
	Allocation	(Osmani & Zhang 2013, 2017; Zhang et al. 2013; Matindi et al. 2018; Yılmaz Balaman et al. 2018; Stougie et al. 2018; Ahmed & Sarkar 2018)

Table 3.8 continues

Strategic Decisions		References
Final Product	Quantity/Product ion rate	(Akgul et al. 2012; Hombach et al. 2016; Huang et al. 2010; Osmani & Zhang 2013; Santibanez-Aguilar et al. 2013b; Yue et al.2013; Akhtari et al. 2018; Berry & Sessions 2018; Yilmaz Balaman et al. 2018; Rabbani et al. 2018)
	Type (bioethanol, biodiesel)	(Khishtandar et al. 2017; Santibanez-Aguilar et al. 2014; Akhtari et al. 2018; Ulonska et al. 2018; Stougie et al. 2018)
Annual Transportation schedule	Flow rate/Quantity between nodes	(Akgul et al. 2012; Costa et al. 2017; How et al. 2016; Huang et al. 2010; Mirkouei et al. 2017; Mohseni & Pishvae 2016; Osmani & Zhang 2013; Santibanez-Aguilar et al. 2013b; Yue et al. 2013; Matindi et al. 2018; Akhtari et al. 2018; Muhamed Abdul Ghani et al. 2018; Petridis et al. 2018;Yilmaz Balaman et al. 2018; Ahmed & Sarkar 2018; Chavez et al. 2018; Rabbani et al. 2018)
	Transportation route	(Mirkouei et al. 2017; Yazan et al. 2016; Matindi et al. 2018; Berry & Sessions 2018; Petridis et al. 2018; How & Lam 2018; Kesharwani et al. 2018; Yilmaz Balaman et al. 2018; Ahmed & Sarkar 2018)

3.4.7.2 Tactical and Operational Decision Level

Tactical decisions relate to medium-short term horizon; monthly or a few months such as production planning, inventory management, transportation methods in certain periods. Especially in BSC, biomass harvesting decision in short period can be related to tactical decisions such as which source is used to harvest or how much biomass is harvested (Ba et al. 2016; Iakovou et al. 2010).

Operational decisions consider short term time horizon. These decisions are related hourly, daily or weekly issues. For instance, daily production scheduling, start times of operations, daily harvest scheduling are examples of operational decisions (An et al. 2011; Ba et al. 2016).

3.4.8 Sustainability Drivers of Biomass

Especially since the 2000s, biomass has a many causes for being preference and potential solution of energy sector. Environmental problems emerged by the use of fossil fuels are the primary of these causes. Also, the importance given to the use of renewable resources has increased in all over the world. However, besides biomass, it is available in other renewable sources that can be used to generate energy, such as the sun and wind. In this section, we investigate the reasons why biomass is preferred for energy production. For this purpose, in the present study, the preference reasons of biomass in sustainable energy supply are defined as “sustainability drivers of biomass”. This study also has the characteristic of distinguishing of biomass from different renewable and environmental friendly sources. To analyze sustainability drivers of biomass, the following questions are investigated in the reviewed papers.

- Why biomass use is recommended for sustainable energy supply?
- For which features, the papers use biomass in energy generation?

As a result of this analysis, one of the most important reasons of the preference biomass use is that biomass is a renewable resource for energy generation. The second common reason is its positive impacts on GHG emissions. Papers mention generally positive environmental effects of biomass; GWP, Climate change potential (CCP). Besides that, the security of energy supply is among the important reasons of biomass use. When considered increasing energy consumption, biomass use provides continuous energy supply for next generation. Especially, because of its vast domestic supply, biomass can be available easily almost every rural and urban area from forest, waste or agricultural materials. Besides that, eight papers indicate that the biomass use in energy industry strengthens the economic development in rural areas increasing employment and job opportunities. Some papers specify that biomass reduce oil dependence. One paper chooses biomass use in energy generation because biomass reduces dependence of energy import. Finally, some papers considering second generation biomass, forest biomass consider in terms of the food

security issue. Table 3.9 classifies the papers according to the sustainability drivers mentioned above.

Table 3.9 Classifications of the papers according to sustainability drivers

Reducing GHG emission	(Bairamzadeh et al. 2016; Cambero and Sowlati 2016; Costa et al. 2017; Čuček et al. 2012; Domínguez-García et al. 2017; Hombach et al. 2016; Huang et al. 2010; de la Fuente et al. 2017; Mohseni & Pishvae 2016; Osmani & Zhang 2017, 2014; Pérez-Fortes et al. 2012; Perrin et al. 2017; Santibanez-Aguilar et al. 2014; You et al. 2011; Zamboni et al. 2011; Kesharwani et al. 2018; Stougie et al. 2018; Rabbani et al. 2018)
Renewable Resource	(Babazadeh et al. 2017b; Bairamzadeh et al. 2016; Čuček et al. 2012; Giarola et al. 2012; Khishtandar et al. 2017; Mata et al. 2013; Mirkouei et al. 2017; Perrin et al. 2017; Santibanez-Aguilar et al. 2014; Yazan et al. 2016; Yilmaz Balaman & Selim 2016; Yue et al. 2014a; Yue et al. 2013; Ulonska et al. 2018; Muhamed Abdul Ghandi et al. 2018; Petridis et al. 2018; Yilmaz Balaman et al. 2018; Kesharwani et al. 2018; Ahmed & Sarkar 2018; Chavez et al. 2018)
Food Security	(Akgul et al. 2012; Hombach et al. 2016; Osmani & Zhang 2017; Yazan et al. 2016; Yue et al. 2014a; Zhang et al. 2013)
Economic Development	(Bairamzadeh et al. 2016; Cambero and Sowlati 2016; Correll et al. 2014; Santibanez-Aguilar et al. 2014; You et al. 2011; Akhtari et al. 2018; How & Lam 2018)
Vast Domestic Supply	(Khishtandar et al. 2017; Miret et al. 2016; Mirkouei et al. 2017; Santibanez-Aguilar et al. 2013a; Santibanez-Aguilar et al. 2013b; Yue et al. 2013; Matindi et al. 2018)
Energy Supply Security	(Akgul et al. 2012; Correll et al. 2014; Pérez-Fortes et al. 2012; Zhong et al. 2016; Akhtari et al. 2018; Berry & Sessions 2018; How et al. 2018; Chavez et al. 2018)
Reduce Oil Dependence	(Huang et al. 2010; Mohseni and Pishvae 2016; You et al. 2011; Stougie et al. 2018)
Environmental Impacts	(Babazadeh et al. 2017; Santibanez-Aguilar et al. 2013a; Yue et al. 2013; Wheeler et al. 2018; How & Lam 2018; Yilmaz Balaman et al. 2018; How et al. 2015; Rabbani et al. 2018)
Reducing GWP	(Giarola et al. 2012; Torkkeli 2014; Ulonska et al. 2018; Ahmed & Sarkar 2018; Rabbani et al. 2018)
Reducing CCP	(de la Fuente et al., 2017)
Reducing Dependence of Energy Import	(Čuček et al. 2012; Berry & Sessions 2018)

Table 3.10 Classifications of the papers in main categories

References	Sustainability Dimension			Drivers	Decision Levels		Bioenergy Generation			Data
	Economic	Environmental	Social		Strategic	Tactical and Operational	First	Second	Third	
Huang et al. 2010	x			OD, GHG	x			x		CS
You et al. 2011	x	x	x	OD, GHG, ED	x	x		x		CS
Zamboni et al. 2011	x	x		GHG	x	x	x			CS
Čuček et al. 2012	x	x		RR, GHG, DEI	x	x		x		CS
Giarola et al. 2012	x	x		RR, GWP	x	x	x	x		CS
Pérez-Fortes et al. 2012	x	x	x	ES, GHG	x	x		x		CS
Akgul et al. 2012	x			ES, FS	x		x	x		CS
Osmani & Zhang 2013	x			ID	x	x		x		CS
Mata et al. 2013	x	x	x	RR	x		x		x	CS
Yue et al. 2013	x	x		RR, VDS, EI	x	x		x		CS
Zhang et al. 2013	x			FS	x	x		x		CS
Santibanez-Aguilar et al. 2013b	x	x		VDS	x			x		CS
Santibanez-Aguilar et al. 2013a	x	x		VDS, EI	x			x		CS
Torkkeli 2014	x	x		GWP	x		x	x		CS
Yue et al. 2014a	x	x	x	FS, RR	x	x		x		IE/ CS
Correll et al. 2014	x			ES, ED	x	x		x		IE
Osmani & Zhang 2014	x	x		GHG	x			x		CS
Santibanez-Aguilar et al. 2014	x	x	x	RR, GHG, ED		x	x	x		CS
Nivala et al. 2015	x			RR	x			x		CS
Bairamzadeh et al. 2016	x	x	x	RR, GHG, ED	x	x		x		CS
Yazan et al. 2016	x	x		FS, RR	x			x		CS
Zhang et al. 2016	x	x		OD, CCP	x			x		CS
Hombach et al. 2016	x	x		GHG, FS	x			x		CS
How et al. 2016	x	x		ID	x	x		x		CS

Table 3.10 continues

References	Sustainability Dimension			Drivers	Decision Levels		Bioenergy Generation			Data
	Economic	Environmental	Social		Strategic	Tactical and Operational	First	Second	Third	
Miret et al. 2016	x	x	x	VDS	x	x	x	x		CS
Zhong et al. 2016	x	x		ES		x		x		IE
Camero & Sowlati 2016	x	x	x	ED, GHG	x	x		x		CS
Yilmaz Balaman & Selim 2016	x		x	RR	x	x		x		CS
Mohseni and Pishvae 2016	x			OD, GHG	x	x			x	CS
Perrin et al. 2017	x	x		RR, GHG	x			x		CS
Khishtandar et al. 2017	x	x	x	RR, VDS	x		x	x		CS
Domínguez-García et al. 2017	x	x		ID, GHG	x	x		x		CS
Babazadeh et al. 2017a	x	x		EI	x	x		x		CS
Babazadeh et al. 2017b	x			RR	x	x		x		CS
Mirkouei et al. 2017	x	x		VDS, RR	x			x		CS
de la Fuente et al. 2017		x		CCP, GHG	x			x		CS
Osmani & Zhang 2017	x	x	x	FS, GHG	x	x		x		CS
Costa et al. 2017	x	x		GHG	x		x			CS
Sánchez-García et al. 2017	x	x		RR, ID, EI	x			x		CS
Akhtari et al. 2018	x			ED, ES	x	x		x		CS
Matindi et al. 2018	x			VDS	x			x		CS
Berry & Sessions 2018	x			ES, DEI,	x			x		CS
Wheeler et al. 2018	x	x		EI	x		x			CS
Ulonska et al. 2018	x			RR, GWP	x			x		CS
Mohamed Abdul Ghani et al. 2018	x	x		RR,	x			x		CS

Table 3.10 continues

References	Sustainability Dimension			Drivers	Decision Levels		Bioenergy Generation			
	Economic	Environmental	Social		Strategic	Tactical and Operational	First	Second	Third	Data
Petridis et al. 2018	x	x	x	RR,	x			x		IE
How & Lam 2018	x	x	x	ED, VDS, EI	x			x		CS
Yilmaz Balaman et al. 2018	x	x		RR, EI	x		x			CS
Kesharwani et al. 2018	x	x	x	GHG, RR,	x		x			CS
Woo et al. 2018	x	x	x	RR, EI	x			x		CS
Sahoo & Mani 2015	x	x		GHG, ES	x			x		CS
How et al. 2018	x	x	x	ES, EI	x			x		CS
Stougie et al. 2018		x		OD	x		x			CS
Ahmed & Sarkar 2018	x	x		RR, GWP	x			x		IE
Chávez et al. 2018	x	x	x	RR, ES	x			x		CS
Rabbani et al. 2018	x	x	x	GHG, EI, GWP	x	x		x		CS

OD: Oil Dependence, GHG: Greenhouse Gas, ED: Economic Development, RR: Renewable Energy, DEI: Dependence of Energy Import, GWP: Global Warming Potential, ES: Energy Supply Security, FS: Food Security, ID: Increase Demand, VDS: Vast Domestic Supply, EI: Environmental Impact, CCP: Climate Change Potential, CS: Case Study, IE: Illustrative Example

3.5 Conclusions

Recently, the sustainability concept become crucial in energy supply when future generations' energy needs and environmental issues are considered. Increased trend in energy consumption accelerate searches for new resources. Renewable energy resources and global warming issues gain importance in the course of time. By conducting a literature research, this study aims to find out how the concept of sustainability is evaluated in previous papers, and to investigate motivations for acceptance of biomass as sustainable. Following inferences are observed at the end of this study. The number of papers designing the BSC in terms of sustainability has increased compared to previous years, but the number of these papers is still not sufficient. Most of the papers evaluate sustainability in economic and environmental aspects, but few papers cover social sustainability with increasing employment and economic development. More BSC studies should be done covering all aspects of sustainability. In other respects, 88 percentages of the papers use the second generation biomass, and the first generation biomass is not popular in sustainable BSC in terms of food security. The papers on third generation bioenergy in sustainable BSC are still limited. Third generation bioenergy is a topic that will continue to develop in the future.

CHAPTER FOUR

BIOMASS SUPPLY CHAIN OPTIMIZATION: ELECTRICAL ENERGY GENERATION FROM POULTRY FARM WASTE

4.1 Introduction

The rise in energy consumption has led to the struggle to meet the energy demand worldwide. In order to meet the growing demand, energy generation has increased with needs of new resources and production facilities. In today's growing energy sector, long term strategic plans are needed for increasing and changing needs. This indicates the importance of supply chain management. Supply chain management includes all processes from the source of energy to the production and delivery to the consumer. Therefore, a well-designed supply chain is a challenging issue in the current competitive energy industry.

Supply chain design is a complex structure and each element in the chain is affected by each other. Thus, the designing a sustainable supply chain is a challenge on the bioenergy field (Hong et al. 2016; Rajeev et al. 2017; Seay and Badurdeen 2014). Traditional biomass supply chain has main components such as harvesting or collection (biomass resources), pretreatment, storage, transportation, energy conversion and distribution. And also, many strategic, tactical and operational decisions are among significant issues of biomass supply chain such as numbers and locations of biorefineries, biomass resources, types and transportation schedules, warehouses capacities to be needed. These many components and decisions make biomass supply chain a complex structure because each decision impacts the efficiency of supply chain. An effective biomass supply chain should be well designed and well managed, and should be able to respond to changing conditions and needs of time. In other words, the biomass supply chain design must be long-term because it requires large financial investments. An effective biomass supply chain provides also reducing the costs of supply, transportation and operation.

Depending on the structure of the supply chain and the biomass type, the biomass supply chain design has some challenges. There are some uncertain parameters in the biomass supply chain. Some changes may occur in long-term planning depending on the type of biomass used or the width of its logistic network. Prices or availability of biomass due to seasonality, biofuel demands, changes of economic parameters are main uncertainty issues in biomass supply chain.

The objectives, expected from well-designed supply chain, can be different and contradictory in many times. Globally, it is desirable to obtain the optimum economic return in the energy sector by making the right investments for the future. For this, the burden of economic parameters in the supply chain is evaluated and optimum supply chain is designed by reducing cost. In general, the decisions on plant locations and numbers are also affected by cost. On the other hand, supply chain designs with environmental objectives have increased considerably in recent years. From the procurement of biomass to the delivering of the final product to the consumer, environmental impacts are measured at many stages of the supply chain. In addition, the biomass supply chain includes many social objectives, such as job creation, economic development, and rural development.

Optimization of a supply chain, which involves multiple opposing objectives such as minimizing environmental impact while maximizing profits, is a challenging and complex task. In such cases, various solution methods can be used to obtain the optimum result from the objective functions and to increase the accuracy of the solution. In this study, multi-stage solution methodology is proposed. In this way, an optimum supply chain with many objectives has been designed. The proposed multi-stage solution methodology will be described in detail in the following section.

In this study, the subject of obtaining electricity generation by using poultry farm waste as biomass resource is handling. There are quite a lot of farm wastes available in rural areas. Available energy potential in rural areas is utilized with the use of farm waste as a biomass resource in the generation of bioenergy. In this way, the beneficial use of the waste, which is present continuously in sufficient quantity, is

provided. Biogas plants that generate electricity using farm waste are expected to support the economy in their rural areas. From a wider perspective, the reduction of energy imports can be supported by using a domestic resources existing abundantly.

The advantages of waste utilization in energy production are as follows:

- Wastes are easily accessible and can be found sufficiently in all periods of the year.
- When compared with energy crops, the potential for uncertainty arising from the seasonality is ignored.
- It is thought that the use of agricultural waste supports the producer economically in the long term. Thus, agricultural producers and rural areas can be developed.
- Generating energy by using waste is recycling and, a useful and necessary product is obtained.

4.2 Problem Definition

This study aims to develop biomass supply chain optimization model with a real case problem. In this problem, it is desired to produce electrical energy by using the wastes of poultry farms in İzmir region. Laying poultry farms in İzmir region is used as biomass sources. Waste biomass is converted to electrical energy and organic fertilizer. Laying chicken manure is used as waste biomass. Every poultry farm has daily waste capacity. Laying chicken manure is transported daily from poultry farms to biogas facilities by farmers. In biogas facilities, firstly, laying chicken manure is transformed into biogas, and then electrical energy is generated from biogas. Generated electrical energy is sold to national grid in the region, and also, organic fertilizer is sold to nearby agricultural lands.

4.2.1 Problem Region

The problem is performed in İzmir region. İzmir is located to the west of Turkey and is the third largest province in terms of population density. In the Figure 4.1, the map of the İzmir is illustrated and colored according to the waste capacity of the provinces; from dark colors to light colors respectively. İzmir is a developed province in the agricultural and industrial sectors, and it is one of the most prominent provinces in terms of utilization and development of renewable energy resources. Considering the agriculture and livestock potential of İzmir province, poultry farming is rapidly evolving and have an important share. Poultry farms are considered as laying and broiler. Total number of poultry farms in İzmir province is 348. In this study, only laying poultry farms are used. Because it is difficult process to separate manure from materials which are spread under chickens in broiler farms. And also, this process is reduced the methane content of manure. Number of laying poultry farms in İzmir and their daily waste capacity percentages in terms of number of animals are shown in Figure 4.2 and Figure 4.3, respectively.

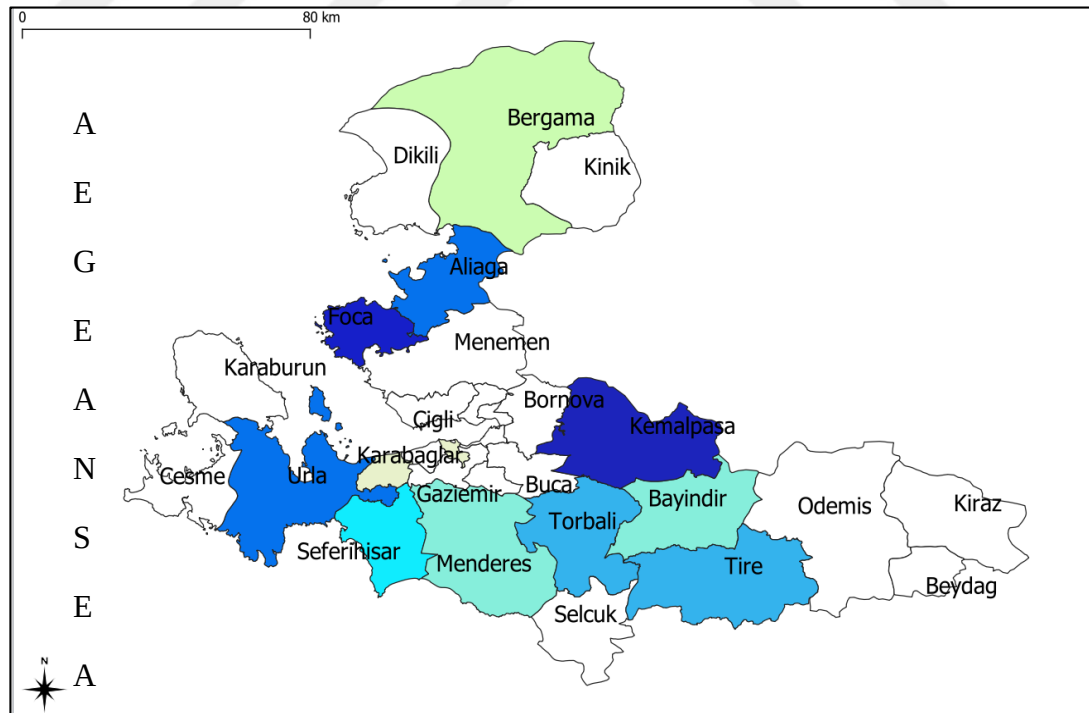


Figure 4.1 The map of İzmir colored by waste capacity

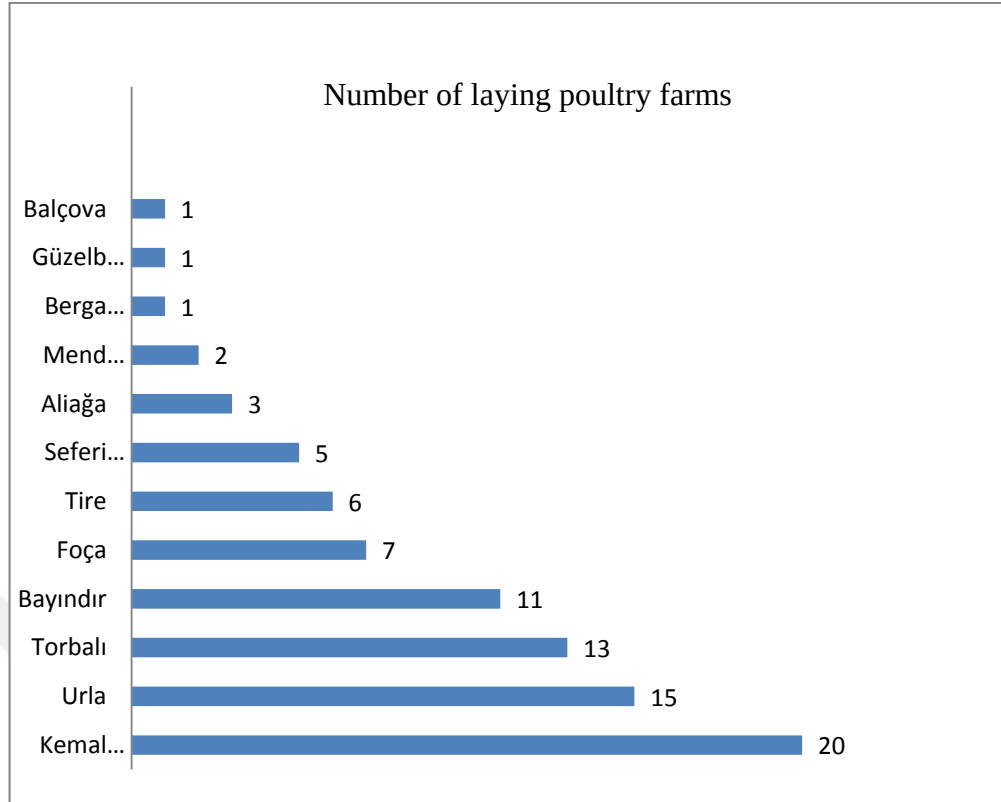


Figure 4.2 Number of laying poultry farms according to county of İzmir

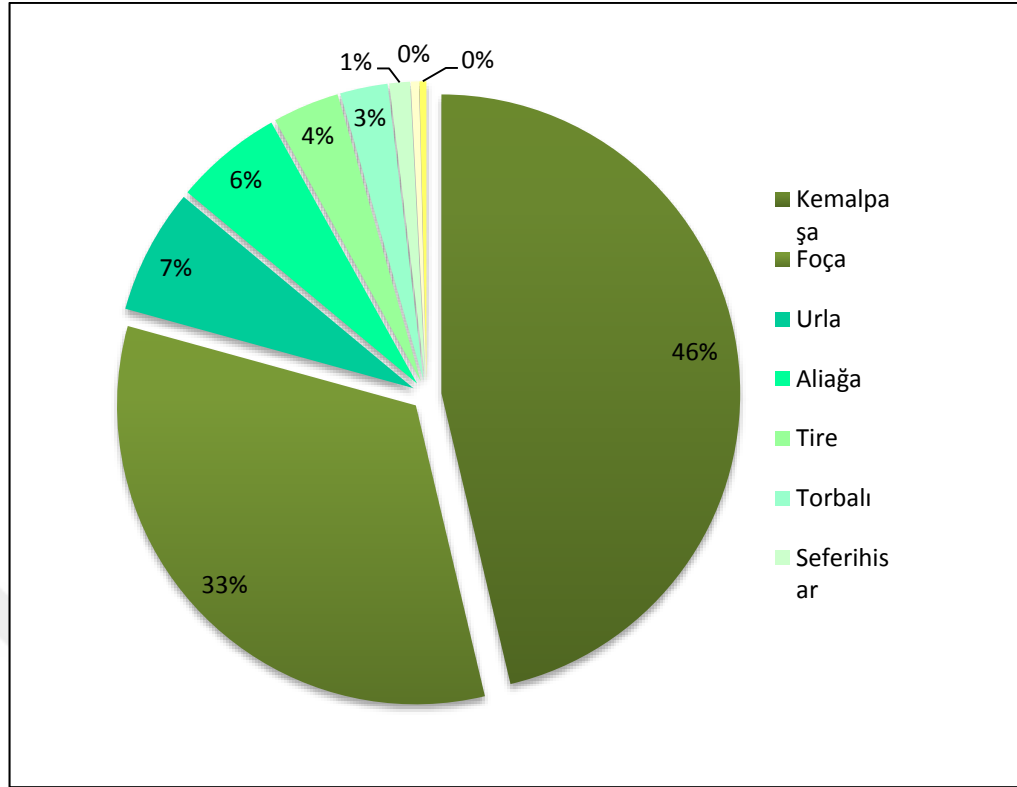


Figure 4.3 Daily waste capacities of laying poultry farms according to counties of İzmir

4.2.2 Biomass Source of The Problem

There is a single type of waste as a biomass source in this problem. Namely, only laying chicken manure is used as a biomass source. The number of farms available and the number of livestock available in İzmir are gathered from provincial directorate of food, agriculture and livestock. The locations and daily waste capacities of the poultry farms, which considered in this problem, are illustrated in Figure 4.4. The biomass capacity obtained from livestock is calculated according to the official sources.

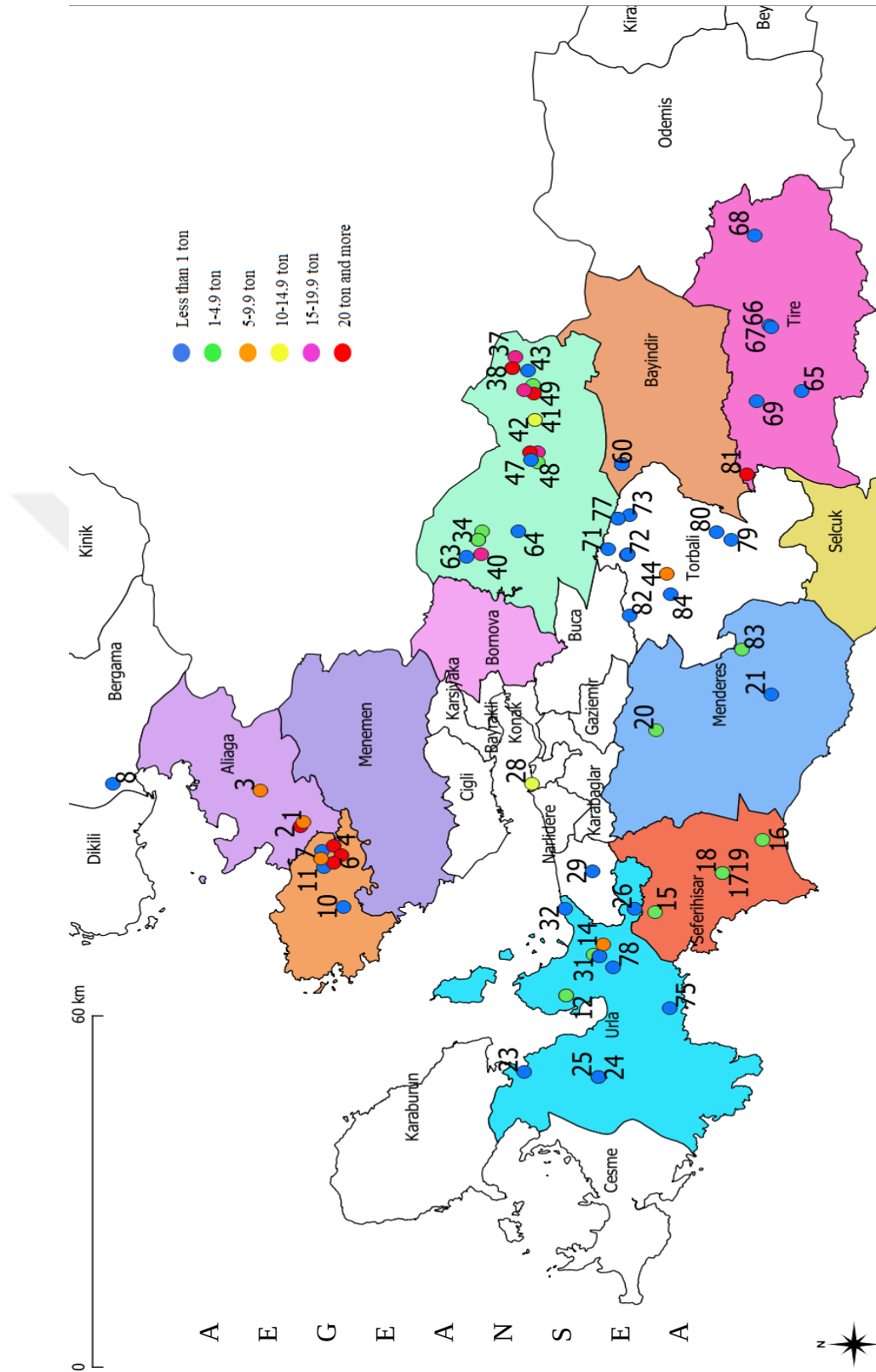


Figure 4.4 Locations of the poultry farms

4.2.3 Type of bioenergy product

Electricity energy is generated in biogas plants and all generated electricity is fed into the national electricity grid. In addition to electricity generation, organic fertilizer which obtained from digestion residue is produced and is sold to agricultural lands.

4.2.4 Transport within the Supply Chain

Biomass is transported from farms to biogas plants in the problem. Transport is carried out daily with the vehicles belonging to farmers. The cost of transporting biomass to the facilities does not in charge of the facilities. However, in the problem, the total transportation distance should be minimized for reducing the transportation cost burden of farmers.

4.2.5 Storage

In this problem, each biogas facility has its own warehouse. In a biogas facility, waste transported from farms, and fertilizers obtained from production are stored separately in the warehouses. Warehouses have 3-day waste storage and 6-month fertilizer storage capacity. Storage capacities of warehouses are determined according to facility capacities in the problem. Table 4.1 shows warehouse capacities.

Table 4.1 Warehouse capacities

Capacity level of biogas facility	Biomass storage capacity	Fertilizer storage capacity
150 kWh	39.6 ton	19000 ton
500 kWh	132 ton	63360 ton
1000 kWh	264 ton	126720 ton

4.2.6 Biogas Facilities

Biogas facilities generate electricity with the poultry farms waste. Biogas facilities are established at locations to be determined in the problem. There are three different biogas plants according to production capacity. Production capacities are 150 kWh, 500 kWh, and 1000 kWh respectively. Production capacities are determined by professional expert opinions and the waste capacities of poultry farms. The aim of the proposed model is to determine the capacity of the biogas facilities besides the location of biogas facilities. Product flows in a biogas facility are shown in Figure 4.15.

4.2.7 Problem Objectives

The problem has economic and environmental considerations. Firstly, the locations and capacities of the biogas facilities that generate electricity are determined. Besides, the total distance to be taken within the entire supply chain is to be minimum. In addition, the environmental damage must be minimum when determining the locations of biogas plants. In order to achieve the environmental objective, there are some ecological constraints to be considered in the problem. These ecological constraints are specified in the following sections.

4.2.8 Economics

Facility opening cost, operational cost and purchasing cost are considered. Facility opening cost is capital investment cost and changes according to capacities of biogas facilities. Table 4.2 shows cost values according to capacity levels. Operational cost represents all included cost in a biogas facility and annual operational cost is equal 15 % of investment cost. Operational Cost components are presented in Table 4.3. In the basic model, purchasing cost of biomass is ignored. Under current conditions, local farms do not receive any money from waste, but in the next few years, farmers are estimated to receive approximately 5 \$/ton for waste.

All generated electricity are fed into the national grid with the price of 0.133 \$/kWh (Ministry of Energy and Natural Resources). Fertilizer is sold as organic digestion residue to the agricultural areas with the price of 7.55 \$/ton. These opening costs, operational costs and fertilizer price values are obtained from professional expert opinions and recent feasibility reports. The planning horizon is five years and during this time the supply chain is desired to amortize itself. The annual working hours of a biogas facility is 7800 hours.

Table 4.2 Cost values of Supply chain according to biogas facility levels

Capacity Level	Facility Cost (\$/kW)	Operational Cost (\$/kW)	Purchasing Cost (\$/ton)	Electricity Sales Price (\$/kW)	Fertilizer Sales Price (\$/ton)
150 kWh	5600	840	-	0.133	7.55
500 kWh	4300	645	-	0.133	7.55
1000 kWh	3750	562.5	-	0.133	7.55

Table 4.3 Operational cost components

Operational Cost Components;
• Staff cost • Maintenance cost • Insurance cost • Own electricity consumption • Water consumption • Other operational costs

4.3 Proposed Solution Methodology

In this study, multi-objective biomass supply chain optimization is handled. Considering the results of literature review on biomass supply chain and the objectives of the problem, a multi-stage and multi-objective solution methodology is

proposed. This study aims to develop a supportive, integrated and extensive solution methodology to design the optimum biomass supply chain.

In the first stage, GIS is used to determine suitable locations within the framework of the ecological constraints of the problem. In the second stage, ecologically suitable locations are reduced by using AHP method. In this way, the final candidate biogas facility locations are obtained. In the final stage of the problem, a MOMILP is developed to optimize the biomass supply chain design.

4.3.1 Geographic Information Systems

In the first stage of the problem, GIS is used. GIS provide the ability to collect, update, control, analyze and view the information of the earth for a specific purpose in the computer environment. GIS can be considered as maps system because it base on earth's geographic coordinates. The information contained in GIS may not be information that is only positionally expressed. The attribute information describing these spatial information or symbologies is also included in GIS. The first definition of GIS in the modern sense was made by Burrough (1998). According to Burrough, GIS is all of the tools that perform the functions of collecting, storing, querying, transferring and displaying the real data of the earth with a specific purpose. If a general definition is made, GIS can be defined as a decision support system that helps solve problems containing geographical content.

In this problem, GIS is used to achieve environmental objective. The problem is developed in open source software QGIS developed by Gary Sherman in 2002. It is aimed to prevent some ecological units from being damaged in terms of environmental while establishing biogas plant. These ecological units are water resources, protected areas, important natural areas, wetland areas, coasts, agricultural lands. For this purpose, the minimum distance between a biogas facility and ecological units is considered. In other words, when determining biogas plant locations, firstly the locations which are environmentally appropriate must be determined. Ecological units and the desired distance are obtained from Application

and Research Centre for Environmental Studies, Ege University, and are specified in Table 4.4.

For environmental objective, QGIS 3.2.2 software is used. Thanks to GIS, the geographic data in the problem is created, modified and visualized. Besides, some of the data in the problem is stored in QGIS software, in the attributes table of each geographic unit. In other words, both the environmental objective is achieved with GIS in this problem, and GIS is used like a data source throughout the problem.

Firstly, the ecological units, taken into account in the problem, are located on the map of İzmir in the QGIS software basing on coordinate reference system (CRS). Namely, ecological units are digitizing and overlaying on map and, their geographical features are saved as shape files. Water resources and coasts, protected areas, important natural areas and wetland areas, and agricultural lands in İzmir are shown in Figures 4.5, 4.6, 4.7, 4.8, respectively. To determine appropriate areas for biogas facilities, buffering analyze is used to surround ecological areas at intended distances. Thus, unsuitable areas, in terms of environmental objective, for biogas facilities are visualized by coloring on the map, that is, ecologically appropriate areas are left for establishing a biogas plant.

Secondly, the locations of the poultry farms are mapped with QGIS software. And, county / neighborhood where the poultry farms are located, number of animals, waste capacity and type of farms are stored in the attribute tables with QGIS software. In this way, the waste capacity and the number of farms of the each county are mapped.

After obtaining the locations of ecological areas and farms on the map, the candidate locations where can be established biogas facilities are determined randomly by evaluating the minimum distance intended for ecological areas and farm capacities. In this process, in order to minimize the environmental damage in setting up the biogas facility, it is desirable to determine the optimum distant points to the ecological areas. In addition, in order to ensure that designing an effective supply

chain, it is paid attention that candidate locations are near the areas with high waste capacity. These candidate locations and ecologically suitable regions are shown on the map of İzmir in Figures 4.9 and 4.10. In these figures, the candidate facility locations are indicated by red dots, and also, ecologically suitable regions for biogas facilities are colored in white. By using QGIS software, 72 candidate biogas facility locations were obtained.

Table 4.4 Ecological constraints

Ecological constraints		Intended Minimum Distance
Water Resources	Absolute Protection Area (Lake / Dam etc.)	3000 m
	Other Water Surfaces	200 m
	Water Reserves	1000m
Protected Areas	Archeological Site (Natural, Urban etc.)	50 m
	Wildlife Development Area	
	Nature Park	
	Natural Monument	
	Special Environmental Protection Area	
	Waterfowl Habitat	
Important Nature Areas	Important Nature Areas	50 m
Wetland Area	Wetland Areas	50 m
Coast	Coastal Areas	100 m
Important Agricultural Lands	Absolute Agricultural Area	50 m
	Planted Areas	
	Special Product Areas	
	Grassland	

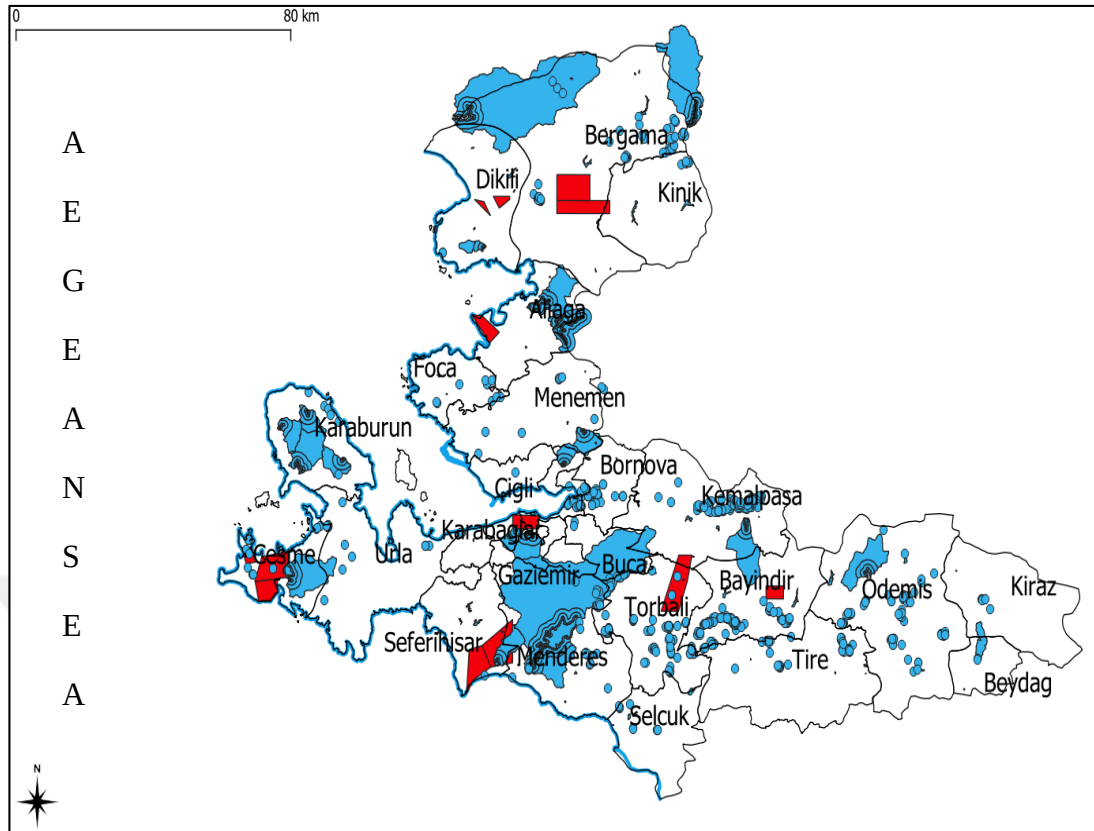


Figure 4.5 Water resources; absolute protection zone, water surfaces, water reserves and coastal sides of İzmir

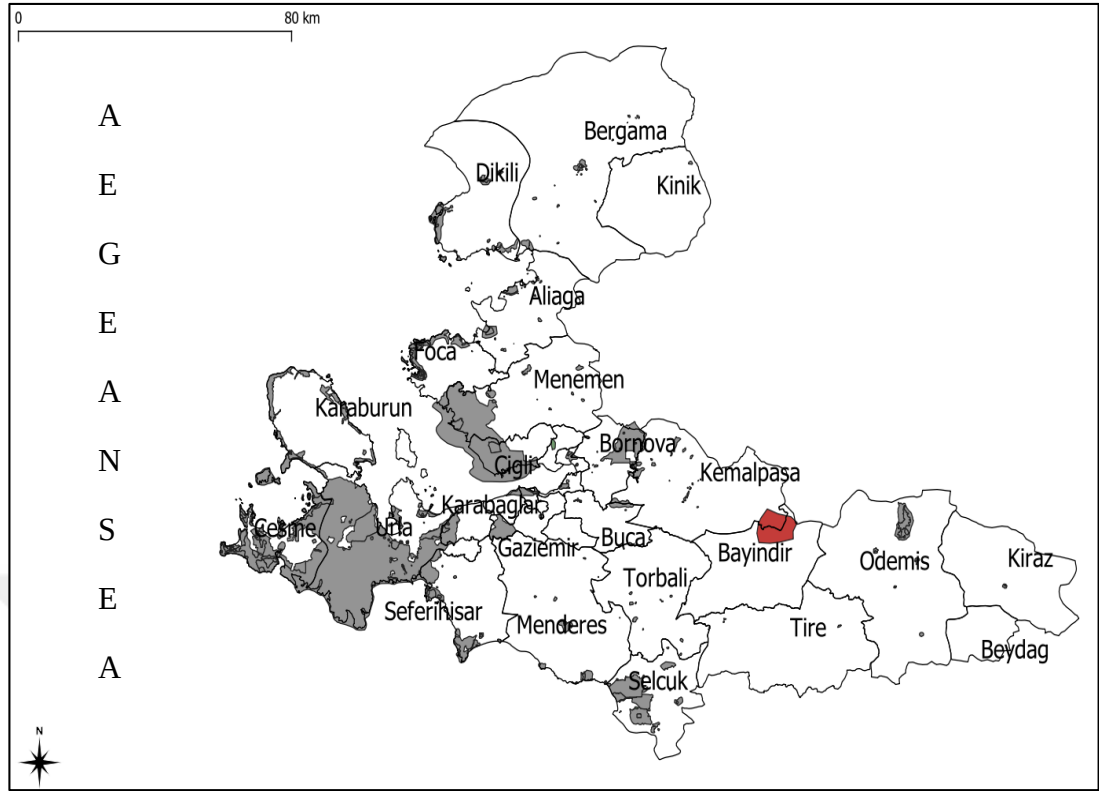


Figure 4.6 Protected Areas; natural, urban and archaeological sites, wildlife development area, natural parks, special environmental protection zone of İzmir

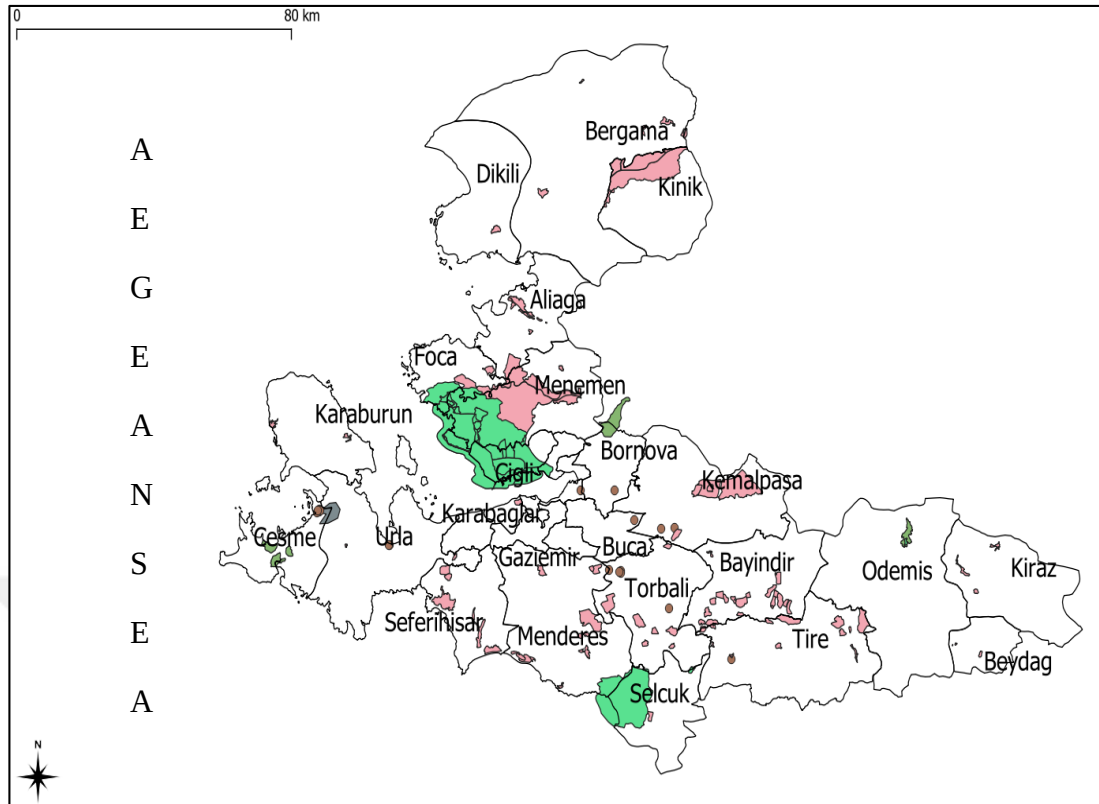


Figure 4.7 Important nature areas, wetlands of İzmir

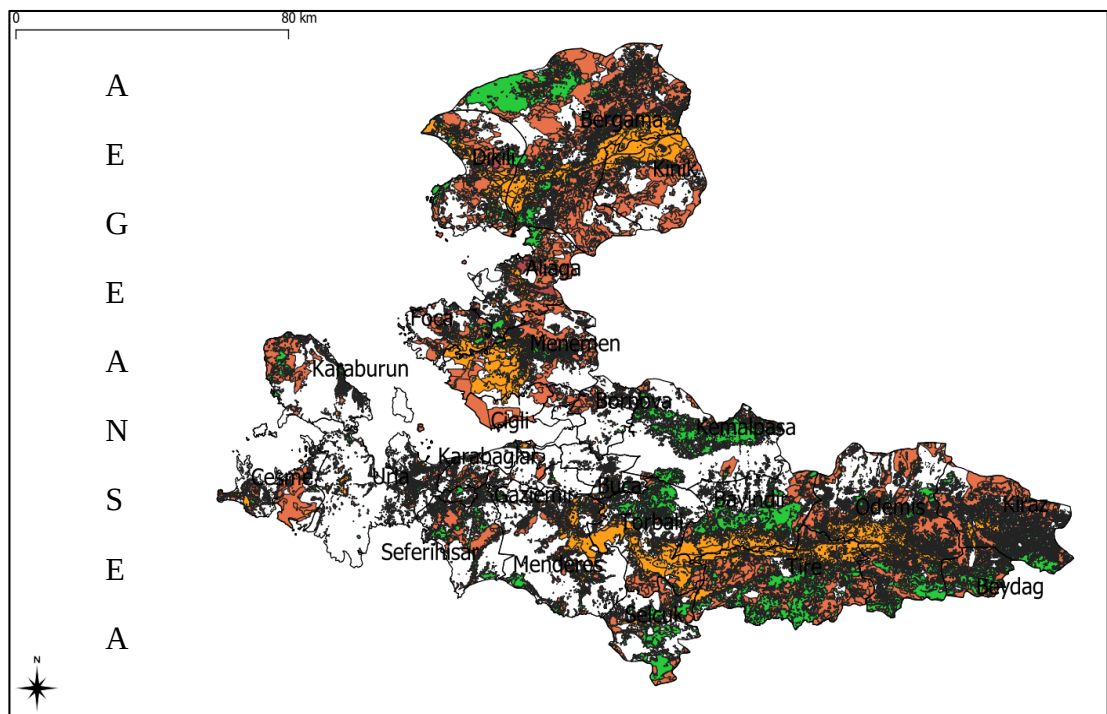


Figure 4.8 Areas of agricultural importance of İzmir

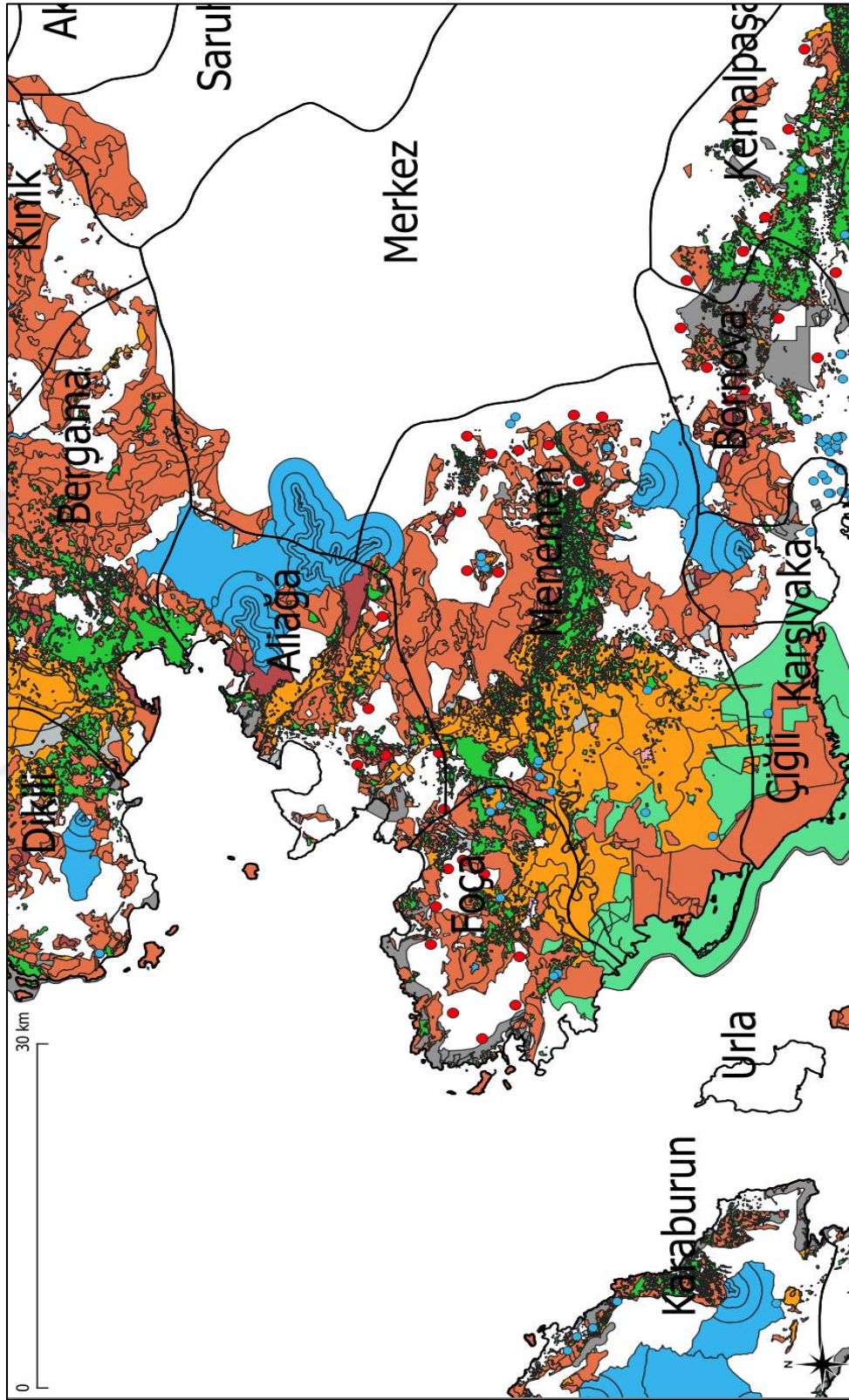


Figure 4.9 Candidate biogas facility locations determined in QGIS in Northern part of İzmir

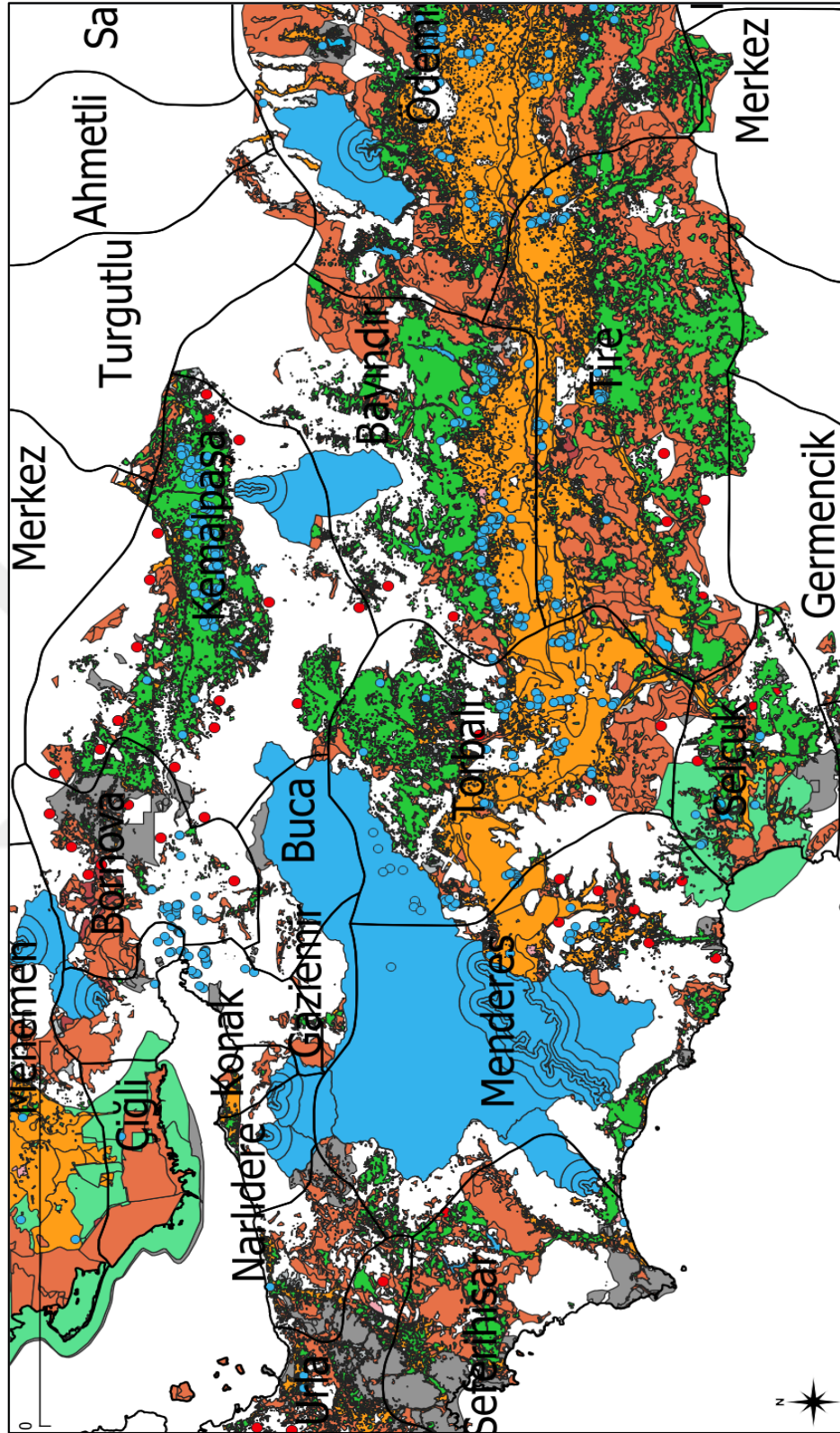


Figure 4.10 Candidate biogas facility locations determined in QGIS in Southern part of Izmir

4.3.2 *Analytic Hierarchy Process*

AHP is a multi-criteria decision making method, firstly proposed by Saaty (1980). The method is used to select from a large number of alternatives by evaluating multiple criteria. AHP is a numerical method to sort alternatives and select one of them according to the specified multiple criteria (Saaty, 1980)

The AHP method consists of the following steps;

- Creation of hierarchy model
- Creation preference matrices (pairwise comparison)
- Determination of superiorities
- Integration (synthesis)

In this study, AHP method is used to improve the candidate facility locations obtained with QGIS and to make the results more accurate and appropriate. In the problem, biogas facilities are asked to be close to residential areas and main roads in order to make transportation easier. Five main considered are created to implement AHP method and the AHP hierarchy is shown in Figure 4.11. These criteria are distance to water resources, distance to protected areas, distance to agricultural areas, distance to settlements and distance to main roads. The distances between the candidate biogas facility locations and the criteria are measured by using the distance matrix algorithm included in the QGIS software.

While at this stage of the problem, the distance between the candidate facilities locations and ecological areas are asked to be high, on the contrary, it is desired to be close to residential areas and main roads. For this purpose, comparison matrices are created by considering real distances and importance assessment scale shown in Table 4.5. The comparison matrices are shown in the Appendices 2, 3, 4, 5, 6. Also, the criteria have importance assessments among themselves. The importance assessment matrix of the criteria is shown in Table 4.6. These values have been obtained from experts' opinions on biogas plant installation and supply chain.

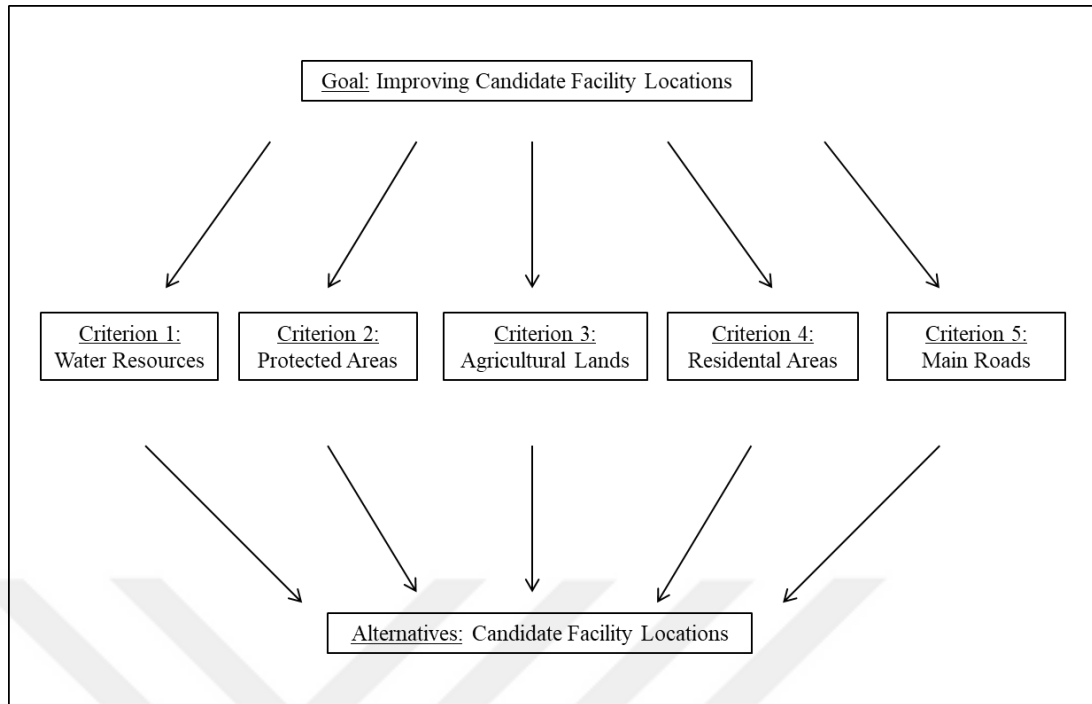


Figure 4.11 AHP hierarchy

Table 4.5 Importance assessment scale of AHP

Value	Interpretation
1	Alternative 1 and Alternative 2 are equally important
3	Alternative 1 is slightly more important than Alternative 2
5	Alternative 1 is strongly more important than Alternative 2
7	Alternative 1 is very strongly more important than Alternative 2
9	Alternative 1 absolutely more important than Alternative 2

Table 4.6 The importance assessment matrix of the criteria

	Water Resources	Protected Areas	Agricultural Lands	Residential Areas	Main Roads
Water Resources	1	3	1	5	5
Protected Areas	1/3	1	3	7	7
Agricultural Lands	1	1/3	1	5	5
Residential Areas	1/5	1/7	1/5	1	1
Main Roads	1/5	1/7	1/5	1	1

In this study, in order to facilitate the problem and to make better analyses, İzmir region is separated into two parts because there are many candidate facilities. Expert Choice 11 software is used to perform AHP method. Comparison matrices are created as input in Expert Choice software.

AHP method is performed in two stages as south and north region of İzmir. The results obtained from the Expert Choice software are shown in the Figures 4.12 and Figures 4.13 with inconsistency 0.02. According to the AHP results, Priority sequence by weights is made between the candidate facilities. The weighted averages of the candidate facilities are taken by using the weights shown in the following results and the candidate facilities which are below this value are eliminated. Figure 4.12 shows the results of 25 candidate facilities in the northern part of İzmir. The weighted average of these results is 0.039. Accordingly, candidate facilities with a weight less than 0.039 are eliminated and the number of candidate facilities is reduced from 25 to 16. Figure 4.13 shows the results of a total of 47 candidates in the southern part of İzmir. The weighted average of these results is 0.021. Accordingly, the candidate facilities with a weight of less than 0.021 are eliminated and the number of candidate facilities is reduced from 47 to 27. The distances between the reduced and improved candidate facility locations and poultry farms are shown in Appendix 1.

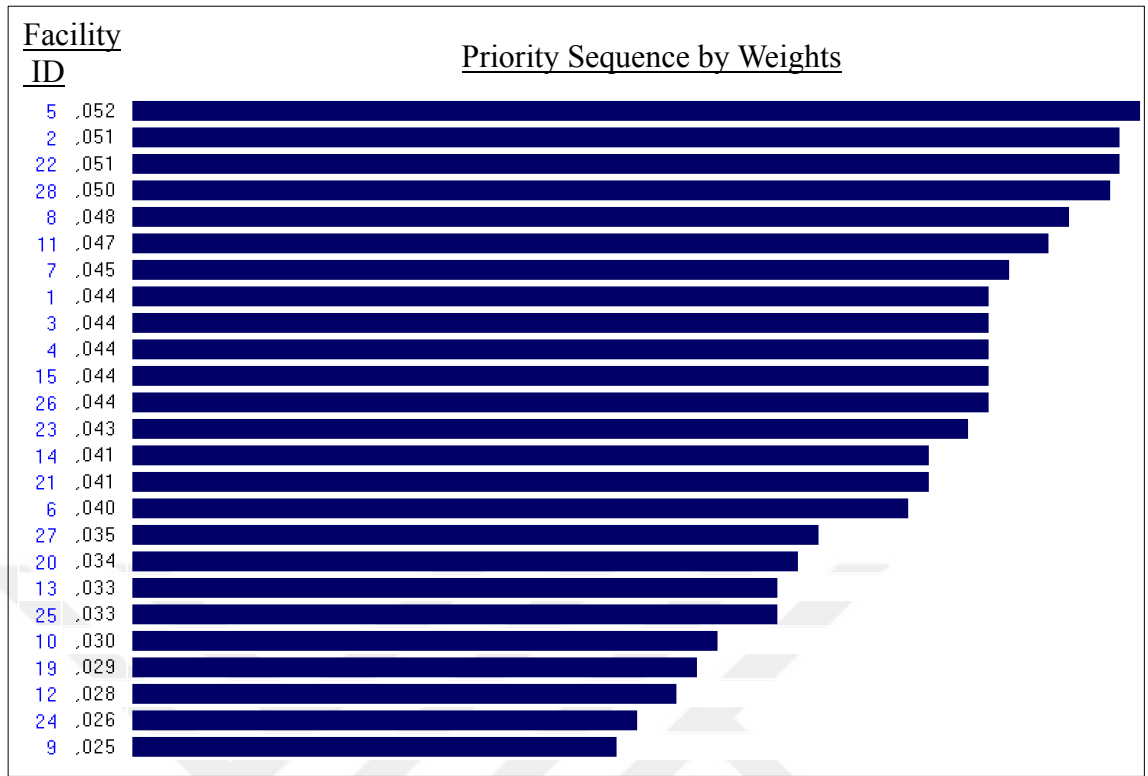


Figure 4.12 AHP results of northern part of İzmir

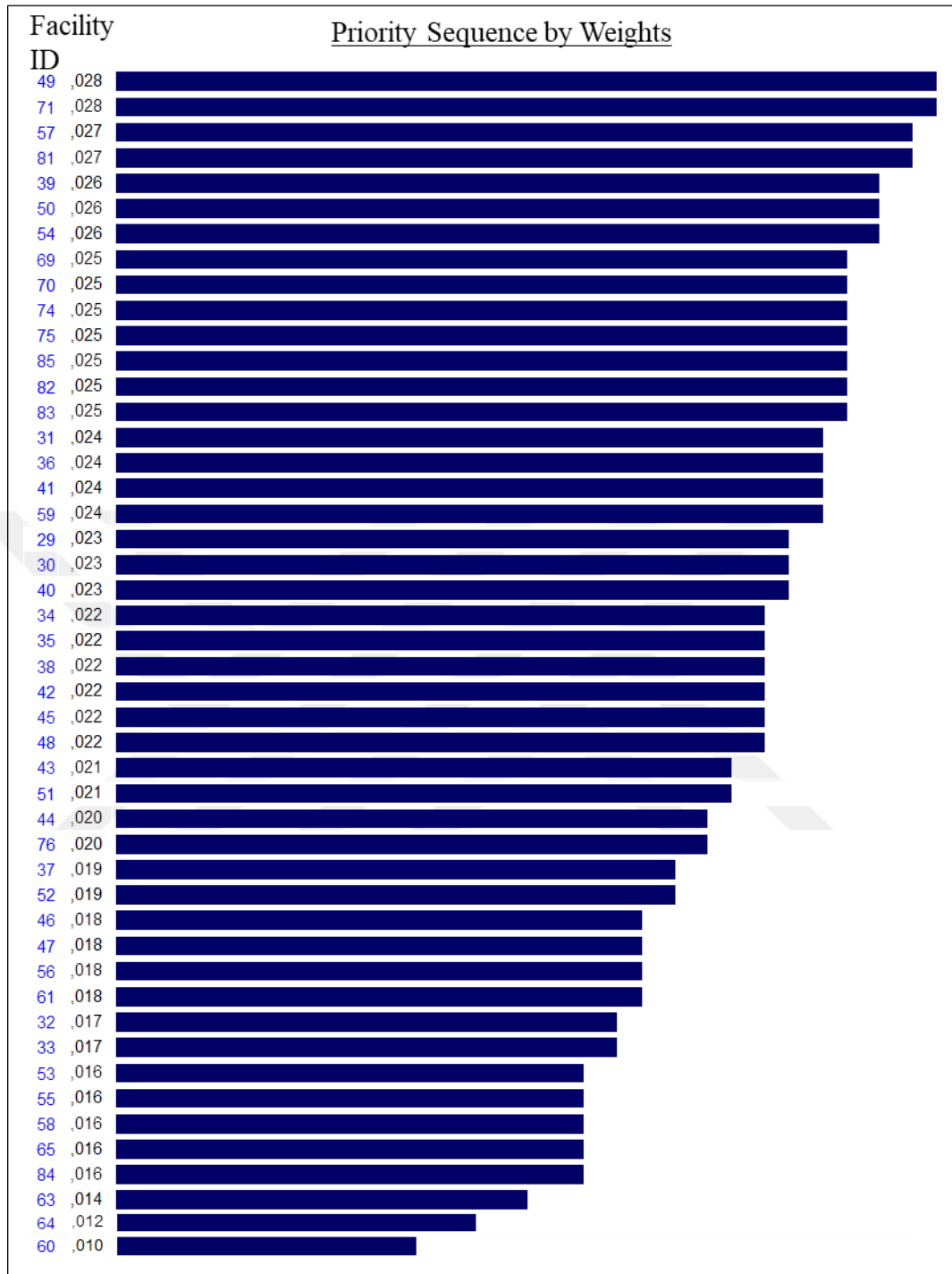


Figure 4.13 AHP results of southern part of İzmir

4.3.3 Multi-Objective Mixed Integer Linear Programming

In this section, a MOMILP model is developed to optimize biomass supply chain design. Integrated results of QGIS software and AHP method are used as candidate biogas facility locations. The objective of the model is to maximize the profit and to minimize the distance of the entire supply chain.

The main constraints are those that include facility opening constraints, flow constraints, production capacity constraints, and warehouse capacity constraints. The model has strategic and tactical decisions. Main strategic decisions are the determination of the numbers, locations and capacities of biogas facilities. Transportation network and amount of waste transported between farms and facilities, warehouse capacities for both waste and fertilizer, production quantities of facilities for both electricity and fertilizer are also other decision variables of the model.

In the scope of this problem, biogas facilities will be established to generate electrical energy. The most suitable locations to establish biogas facility and the capacity levels of these facilities are determined under economic and ecological constraints. In addition, in this problem, it is required that the distance taken within the whole supply chain should be at a minimum. In determining the locations and capacities of biogas plants, waste capacities and locations of poultry farms in the region of the problem are evaluated. The characteristics of the problem and the structure of the supply chain are given in the following sections. In Figure 4.14, supply chain structure is illustrated. Materials flows in a biogas facility are shown in Figure 4.15.

In the multi-objective programming, all objective functions are simultaneously optimized. A single optimum result does not optimize all objective functions simultaneously. Therefore, the ε -constraint method is used to address MOMILP in Section 4.3.3.2.

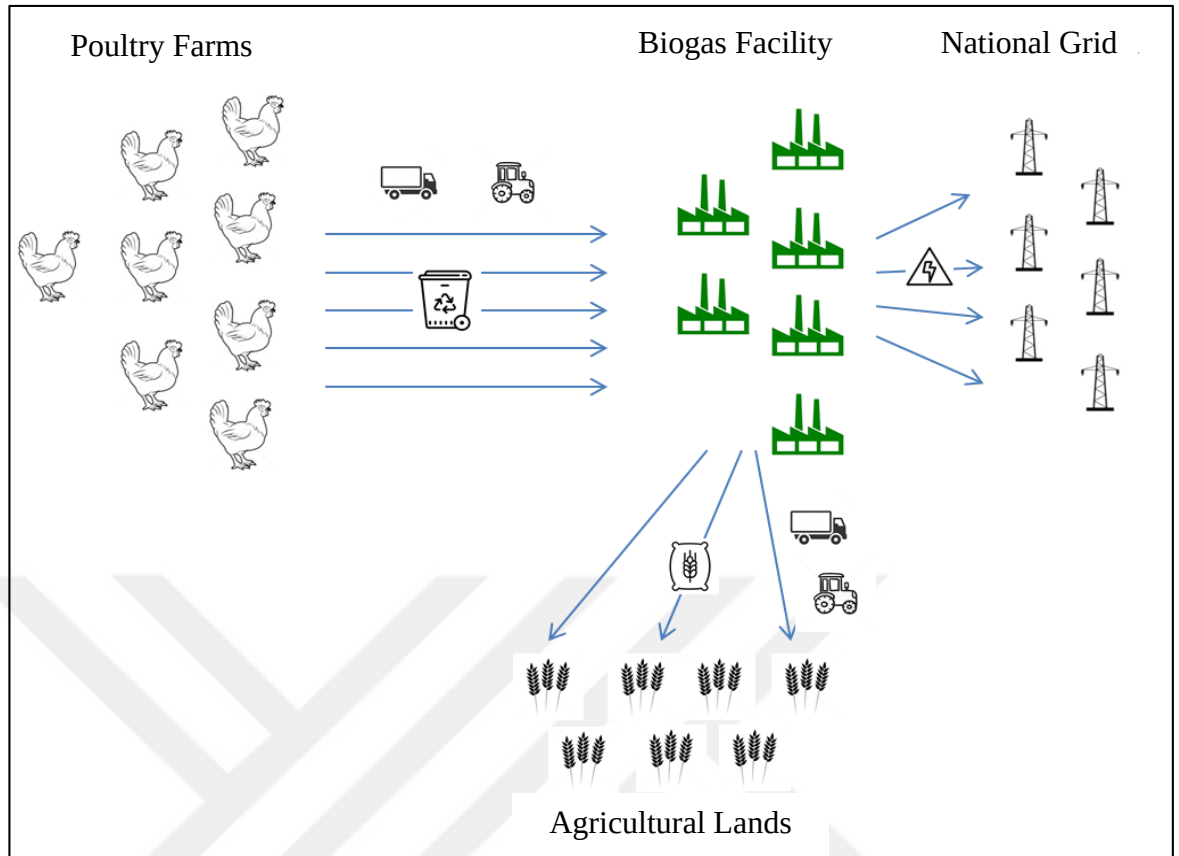


Figure 4.14 Supply chain structure of the problem

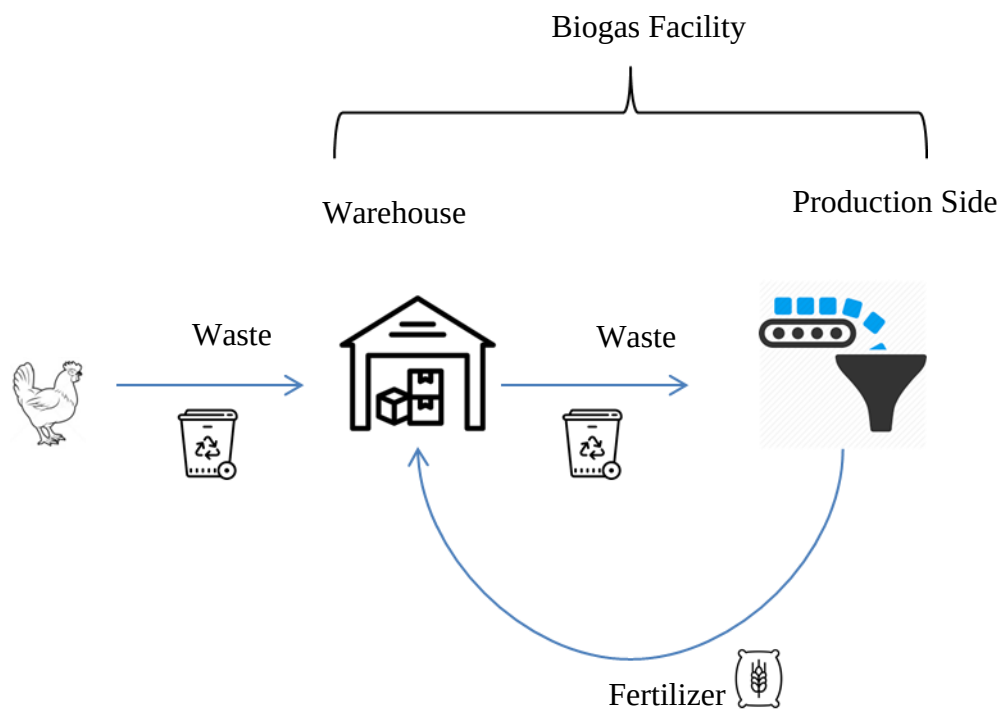


Figure 4.15 Materials flows in a biogas facility

4.3.3.1 Formulation of Mathematical Model

Notations, parameters and decision variables are presented in the following.

Nomenclature:

Indices:

i : (candidate) biogas facility locations

j : poultry farm location (biomass resources)

d : production capacity levels of biogas facilities

t : time period

Parameters:

B_j : Daily waste capacities of farms (ton),

P_d : The minimum electricity amount that a facility must generate to pay back itself in a desired period according to production capacity (kW),

A_d : The minimum fertilizer amount that a facility must sell to pay back itself in a desired period according to production capacity (ton),

EG_d : Maximum electricity amount which a biogas facility can generate in total period according to capacity d (kW),

Ww_d : The maximum amount of waste that can be stored according to capacities (ton),

Wf_d : The maximum amount of fertilizer that can be stored according to capacities (ton),

α : Biomass to biogas conversion rate (m^3 /ton),

β : Biogas to electrical energy conversion rate (kW/ m^3),

θ : Biomass to fertilizer conversion rate (ton)

D_{ji} : Distance between farms and facilities (km),

Y_{ji} : Binary parameter, if the distance between facility i and farm j is equal or less than $maxdis$ (50 km), 1; otherwise 0,

FC_d : Biogas facilities opening cost according to capacities (\$),

OC_d : Biogas facilities operation cost per kW (\$/electricity production),

PC : Biomass purchasing cost (\$/ton),

P_f : Fertilizer sales price (\$/ton),

P_e : Electricity sales price (\$/kW)

$maxdis$: The maximum distance that must be between the plant and the farm to transport waste from the farm (km). $Maxdis$ is determined evaluating the distance between farms and candidate facilities,

$maxwaste_d$: Maximum waste amount that can be used in facilities according to capacity d (ton).

Decision Variables:

Binary Variables:

T_{id} : If facility i is to be opened with capacity d, 1; otherwise 0,

X_{ji} : If waste transport flow is established between the farm j and the facility i, 1; otherwise 0.

Continuous Variables:

Q_{jit} : The waste amount that transport from farm j to facility i per time t (ton/t),

R_{it} : The amount of biomass used in facility i per time t (ton),

E_i : The amount of electricity produced in facility i in total period (kW),

G_i : The amount of biogas produced in facility i in total period (m^3)

F_{it} : The amount of fertilizer produced in facility i per time t (ton/t),

Z_{it} : The fertilizer amount that transport from facility i per time t (ton/t).

Objective Functions:

First objective function is to maximize profit. Maximization of profit consists of two components; total sales revenue and total cost. The following equations are presented maximum profit function. Eqs. 4.1 and 4.2 present total sales revenue and total cost. Total sales revenue is value from electricity and fertilizer sales. Total cost is divided into three terms; facility opening cost, operational cost and purchasing cost.

$$\text{maxprofit} = \text{total sales revenue (TR)} - \text{total cost (TC)}$$

$$TR = \sum_i P_e \cdot E_i + \sum_{i,t} P_f \cdot Z_{it} \quad (4.1)$$

$$TC = \sum_{i,d} FC_d \cdot T_{id} + \sum_{i,d} OC_d \cdot T_{id} + \sum_{i,j,t} PC \cdot Q_{jit} \quad (4.2)$$

Second objective function is to minimize total distance of the entire supply chain. Eq. 4.3 presents the function of minimizing total distance.

$$\min \sum_{j,i} D_{ji} \cdot X_{ji} \quad (4.3)$$

Constraints:

Facility Opening Constraints:

$$\sum_d T_{id} \leq 1 \quad \forall i \quad (4.4)$$

Constraint 4.4 enforces that each facility i can only be opened at one capacity level d .

$$T_{id} \cdot \text{maxwaste}_d \leq \sum_j B_j \cdot Y_{ji} \quad \forall i, d \quad (4.5)$$

Constraint 4.5 guarantees that the availability of sufficient amount of biomass in the area covered by *maxdis* in location i , depending on the capacity level of the facility to be opened. Namely, to open a facility in any candidate location i , the daily total waste capacity of all farms in *maxdis* of location i , must be equal or more than the daily maximum waste requirement (*maxwaste*) of the facility.

Flow Constraints:

$$\sum_i X_{ji} = 1 \quad \forall j \quad (4.6)$$

Constraint 4.6 limits that each farm j must carry waste to only one facility i .

$$X_{ji} \cdot D_{ji} \leq \text{maxdis} \quad \forall j, i \quad (4.7)$$

Maxdis is determined as 50 km in this model. Constraint 4.7 ensures that each farm j must supply waste to a facility i if only located in *maxdis* of this facility.

Flow Conservation Constraints between Farms and Facilities:

$$X_{ji} \cdot B_j \geq Q_{jit} \quad \forall j, i, t \quad (4.8)$$

Constraint 4.8 enforces that farms do not carry more waste than their capacity. Each farm j cannot supply waste to a facility i more than its capacity.

$$\sum_j Q_{jit} \geq R_{it} \quad \forall i, t \quad (4.9)$$

Constraint 4.9 ensures that each facility i cannot produce more than the total amount that supplied from farms j in time t .

Production Capacity Constraints:

$$\sum_t R_{it} \cdot \alpha \cdot \beta \leq \sum_d EG_d \cdot T_{id} \quad \forall i \quad (4.10)$$

$$\sum_t R_{it} \cdot \alpha \cdot \beta \geq \sum_d P_d \cdot T_{id} \quad \forall i \quad (4.11)$$

Constraints 4.10 and 4.11 enforce that the minimum and maximum electricity production capacity, respectively.

$$\sum_t Z_{it} \geq \sum_d A_d \cdot T_{id} \quad \forall i \quad (4.12)$$

Constraint 4.12 guarantees that there should be minimum amount of fertilizers to be sold during the time periods.

$$E_i = \sum_t R_{it} \cdot \alpha \cdot \beta \quad \forall i \quad (4.13)$$

Constraint 4.13 calculates the total electricity production in facility i .

$$G_i = \sum_t R_{it} \cdot \alpha \quad \forall i \quad (4.14)$$

Constraint 4.14 calculates the total biogas production in facility i.

$$\sum_t F_{it} = \sum_t R_{it} \cdot \theta \quad \forall i \quad (4.15)$$

Constraint 4.15 calculates the total fertilizer production in facility i.

$$\sum_t F_{it} \geq \sum_t Z_{it} \quad \forall i \quad (4.16)$$

Constraint 4.16 ensures that the amount of fertilizers produced must be greater than the amount of fertilizer sold in facility i.

Warehouse Capacity Constraints:

Each facility i has a warehouse capacity for both biomass and fertilizer. Constraints 4.17 and 4.18 address that the total amount of the products in the warehouse at time t cannot exceed warehouse capacity. Constraint 4.17 addresses biomass storage capacity constraint. Constraint 4.18 addresses fertilizer storage capacity.

$$\sum_j Q_{jit} - R_{it} + \sum_j Q_{jit-1} - R_{it-1} \leq \sum_d W_{wd} \cdot T_{id} \quad \forall i, \quad (4.17)$$

$$F_{it} - Z_{it} + (F_{it-1} - Z_{it-1}) \leq \sum_d W_{fd} \cdot T_{id} \quad \forall i, \quad (4.18)$$

A novel MOMILP model is developed to solve sustainable BSC. Besides the classical constraints such as single sourcing, capacity requirements, conservation of biomass flows, we take into account covering constraints (constraints 4.5 and 4.7), and define maximum distance and maximum waste amount parameters. By using these parameters, we have written constraints: one guarantees that each farm must supply waste to a facility if only located in *maximum distance* of this facility, and the other one ensures that the sufficient amount of poultry farm waste should be available in the locations that a biogas facility is opened.

4.3.3.2 The ε -constraint Method

Assume the following MOMP problem:

$$\begin{aligned} \max \quad & (f_1(x), f_2(x), \dots, f_n(x)) \\ \text{st} \quad & x \in S \end{aligned}$$

where $\mathbf{x}$ is the vector of decision variables, $f_1(x), f_2(x), \dots, f_n(x)$ are the n objective functions and S is the feasible region.

In the ε -constraint method we optimize one of the objective functions using the other objective functions as constraints, incorporating them in the constraint part of the model as shown below (Mavrotas, 2009)

$$\begin{aligned} \max \quad & f_1(x) \\ \text{st} \quad & \\ & f_2(x) \geq \varepsilon_2 \quad (\text{for maximum functions}) \\ & f_3(x) \leq \varepsilon_3 \quad (\text{for minimum functions}) \\ & \dots \\ & f_n(x) \geq \varepsilon_n, \end{aligned}$$

$$x \in S.$$

By determining the range of objective functions ε_i , $i \in \{1, \dots, n\}$, the optimal solutions of the problem is obtained.

4.4 Computational Results

The mathematical model is programmed and solved in IBM ILOG CPLEX Optimization Studio. The experiments were performed on an Intel Core i7-4700HQ CPU 2.40 GHz processor with 12 GB RAM on 64-bit under Windows 10 environment.

The optimum solution is determined with ε -constraint method which is mentioned in Section 4.3.3.2. Payoff values of each objective functions are presented in payoff table in Table 4.7. After calculating payoff table, the range of objective functions is divided into four equal intervals. The model is solved with 5 different ε_2 values of objective functions.

Table 4.7 Payoff table

	f_1 (maximum profit)	f_2 (minimum distance)
$\max f_1$	7,704,453.538 \$ /year	1779.401 km
$\min f_2$	1,278,792.442 \$/year	697.367 km

According to results of this model, maximum profit and minimum distance value of entire supply chain are 7,323,244.9 \$/year and 1006 km, respectively. Furthermore, the entire supply chain amortizes itself in 3 years with the current efficiency. In İzmir province, it is decided to establish 12 biogas facilities in total. The candidate facility locations and biogas facilities that are decided to be opened are shown on the map of İzmir in Figures 4.16 and 4.17.

The counties and capacities of the biogas facilities are shown in Table 4.8. In the county of Aliağa, it is decided to establish two facilities with the first and third capacity levels. Both in Bayındır and Bornova, one biogas facility is established with third capacity level. Two facilities with third capacity level is opened in Foça. And

also, in Kemalpaşa, three biogas facilities with third capacity level are established. With first capacity level, a facility is opened in Seferihisar, and two facilities are opened in Urla.

Table 4.8 Locations, Capacities and Numbers of Facilities to be opened

County	Facility ID	Capacity Level	Facility Number
Aliağa	3	150 kWh	1
	6	1000 kWh	1
Bayındır	54	1000 kWh	1
Bornova	39	1000 kWh	1
Foça	7	1000 kWh	1
	8	1000 kWh	1
Kemalpaşa	36	1000 kWh	1
	40	1000 kWh	1
	49	1000 kWh	1
Seferihisar	74	150 kWh	1
Urla	71	150 kWh	1
	75	150 kWh	1
Total Facility Number			12

Table 4.9 shows Economic Results of Entire Supply Chain. Total electricity sales revenues is 8,658,667.08 \$/year, and total fertilizer sales revenue is 10,340,577.8 \$/year. Total revenue of entire supply chain is 18,999,244.9 \$/year. As seen in table, total cost value is 11,676,000 \$/year.

Table 4.9 Economic results of entire supply chain

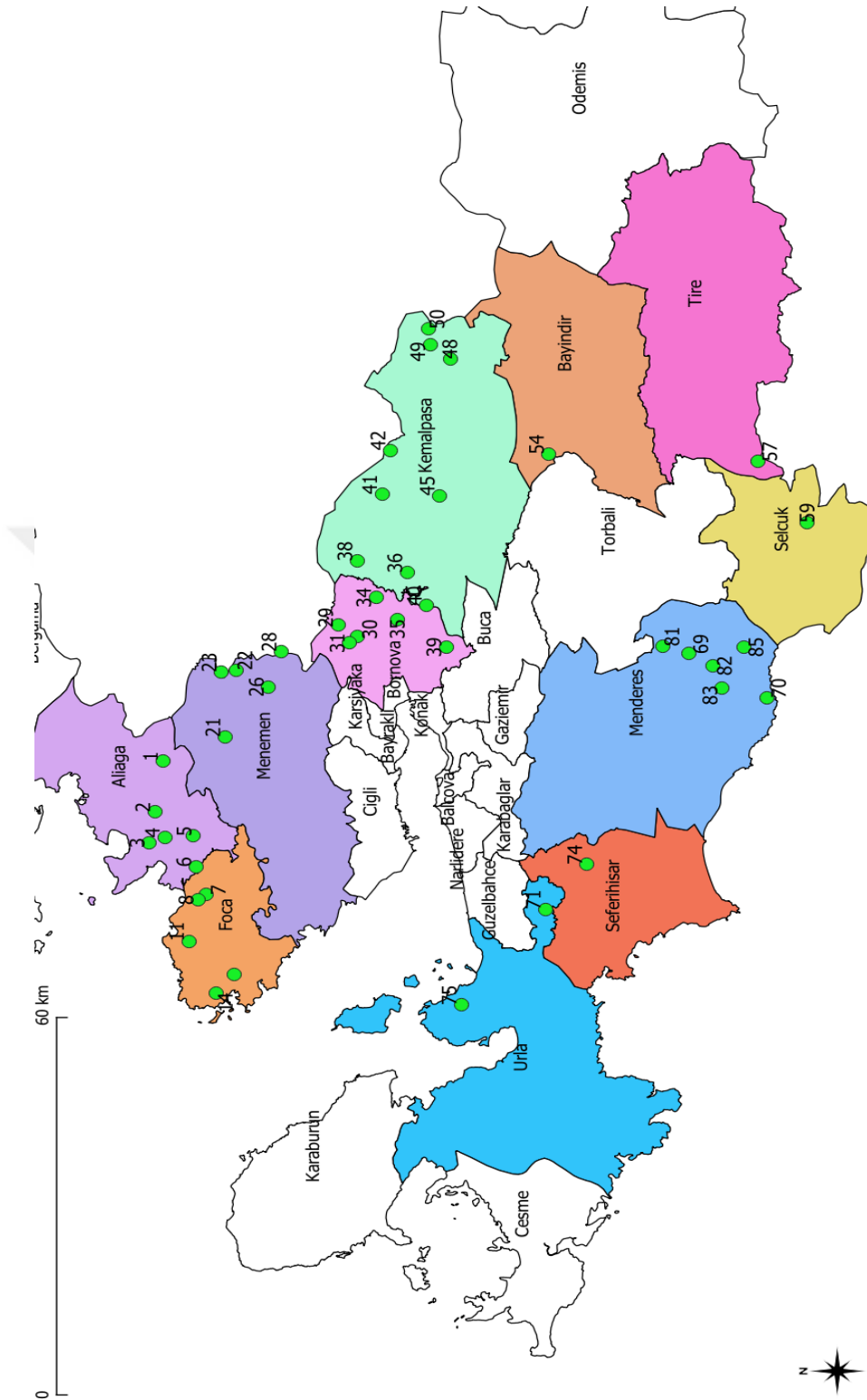
Incomes	Value (\$)
Electricity Sales	8,658,667.08 \$/year
Fertilizer Sales	10,340,577.8 \$/year
TOTAL REVENUE	18,999,244.9 \$/year
Expenses	Value (\$)
Capital Investment Cost	33,360,000 \$
In Horizon Planing Time	6,672,000 \$/year
Facility Operational Cost	5,004,000 \$/year
Total Cost	11,676,000 \$/year
PROFIT	7,323,244.9 \$/year
Payback period	3 years

Electricity and fertilizer amount sold in biogas facilities according to countries are shown in Table 4.10. In the entire supply chain, annually, 65,102,160 kW electricity is generated and fed into national grid and 1,420,605.84 tons organic fertilizer is sold to agricultural lands.

Table 4.10 Electricity and fertilizer amount sold in biogas facilities from counties

County	Facility ID	Capacity Level	Electricity Amount	Fertilizer Amount
Aliağa	3	150 kWh	1,170,000 kW/year	25,531.92 ton/ year
	6	1000 kWh	7,800,000 kW/year	170,212.8 ton/ year
Bayındır	54	1000 kWh	7,096,000 kW/year	154,857.6 ton/ year
Bornova	39	1000 kWh	7,370,000 kW/year	160,833.6 ton/ year
Foça	7-8	1000 kWh	15,600,000 kW/year	340,423.92 ton/ year
Kemalpaşa	36-40-49	1000 kWh	22,556,160 kW/year	492,148.8 ton/ year
Seferihisar	74	150 kWh	1,170,000 kW/year	25,532.4 ton/ year
Urla	71-75	150 kWh	2,340,000 kW/year	51,064.8 ton/ year
Total			65,102,160 kW/year	1,420,605.84 ton/ year

The results of main strategic decision, which are facility location and capacity and flows between farms and facilities, are presented in Table 4.11.



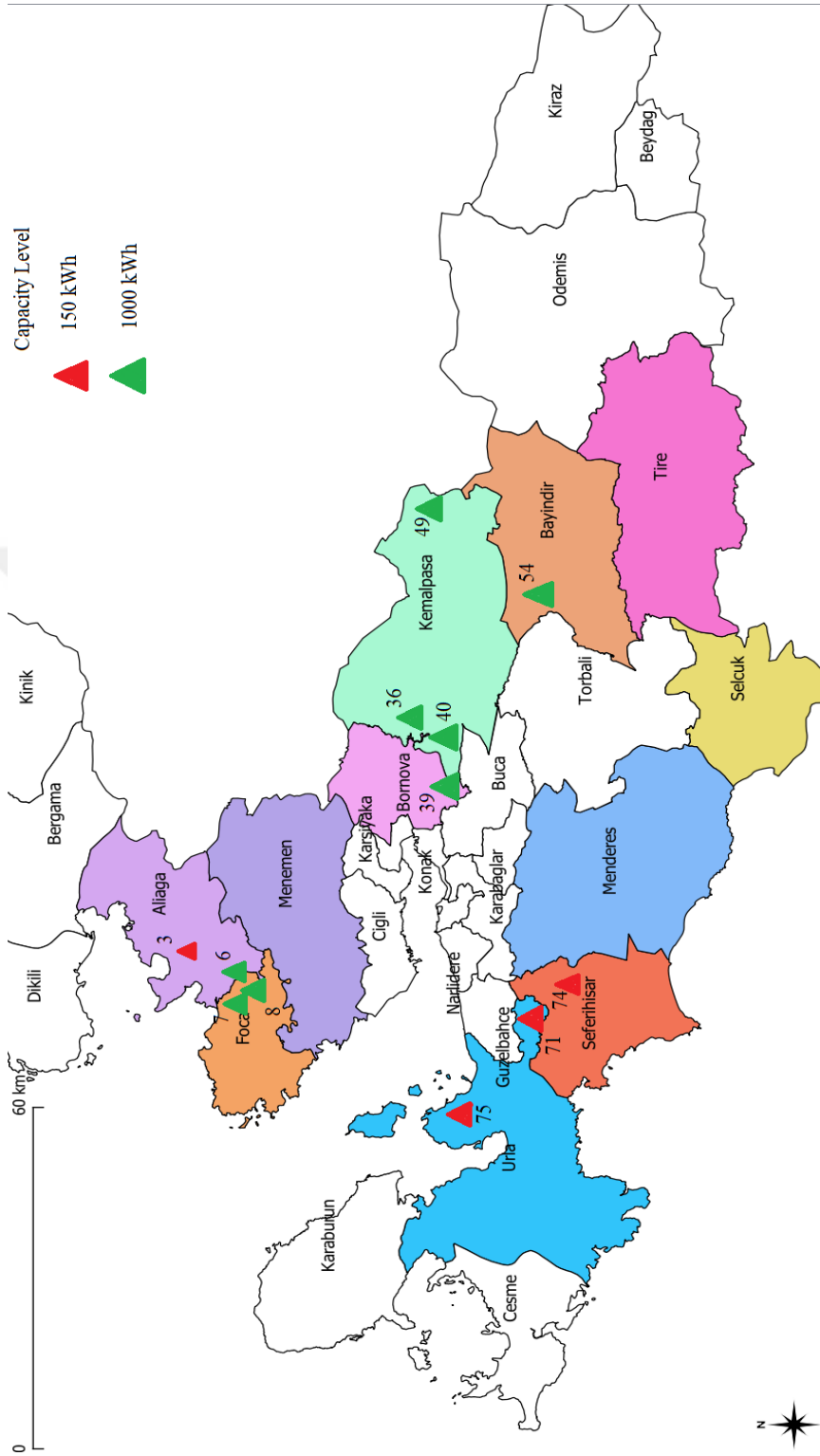


Figure 4.17 Illustration of biogas facilities on the map of İzmir

Table 4.11 Main strategic decisions

Locations and Capacities, T_{id}	$T_{3,1} = 1, T_{6,3} = 1, T_{7,3} = 1, T_{8,3} = 1, T_{36,3} = 1, T_{39,3} = 1,$ $T_{40,3} = 1, T_{49,3} = 1, T_{54,3} = 1, T_{71,1} = 1, T_{74,1} = 1, \text{ and}$ $T_{75,1} = 1$
Established flows between farms and facilities, X_{ji}	$X_{1,6} = 1, X_{2,8} = 1, X_{3,3} = 1, X_{4,7} = 1, X_{5,6} = 1, X_{6,8} = 1,$ $X_{7,6} = 1, X_{8,3} = 1, X_{9,6} = 1, X_{10,3} = 1, X_{11,7} = 1, X_{12,75} =$ $1, X_{13,71} = 1, X_{14,75} = 1, X_{15,74} = 1, X_{16,71} = 1, X_{17,71} =$ $1, X_{18,74} = 1, X_{19,71} = 1, X_{20,74} = 1, X_{21,74} = 1, X_{22,71} =$ $1, X_{23,75} = 1, X_{24,75} = 1, X_{25,75} = 1, X_{26,75} = 1, X_{27,74} =$ $1, X_{28,74} = 1, X_{29,74} = 1, X_{30,74} = 1, X_{31,75} = 1, X_{32,75} =$ $1, X_{33,36} = 1, X_{34,36} = 1, X_{35,36} = 1, X_{36,36} = 1, X_{37,49} =$ $1, X_{38,39} = 1, X_{39,49} = 1, X_{40,36} = 1, X_{41,54} = 1, X_{42,54} =$ $1, X_{43,49} = 1, X_{44,39} = 1, X_{45,36} = 1, X_{46,39} = 1, X_{47,49} =$ $1, X_{48,49} = 1, X_{49,40} = 1, X_{50,49} = 1, X_{51,49} = 1, X_{52,54} =$ $1, X_{53,54} = 1, X_{54,54} = 1, X_{55,54} = 1, X_{56,54} = 1, X_{57,54} =$ $1, X_{58,54} = 1, X_{59,54} = 1, X_{60,54} = 1, X_{61,54} = 1, X_{62,54} =$ $1, X_{63,36} = 1, X_{64,36} = 1, X_{65,54} = 1, X_{66,54} = 1, X_{67,54} =$ $1, X_{68,54} = 1, X_{69,54} = 1, X_{70,54} = 1, X_{71,54} = 1, X_{72,54} =$ $1, X_{73,54} = 1, X_{74,54} = 1, X_{75,54} = 1, X_{76,54} = 1, X_{77,54} =$ $1, X_{78,39} = 1, X_{79,54} = 1, X_{80,54} = 1, X_{81,54} = 1, X_{82,39} =$ $1, X_{83,39} = 1, X_{84,54} = 1$

CHAPTER FIVE

CONCLUSIONS

There is a growing trend in the energy sector on issues of sustainability and renewable energy sources. Increasing energy consumption of the world and limited availability of current energy sources have caused concerns about the security of energy supply. The importance of renewable energy sources for energy production has increased. For a long time, most of the energy needs are met by fossil fuels. The use of fossil fuels has adverse effects on the environment. In particular, greenhouse gas emissions have accelerated in the atmosphere and global warming effects have been observed. Global warming in the world has aroused great influence for the continuation of the ecosystem. Therefore, it is emphasized that the resources used in energy production should be environmentally sustainable.

As biomass is both environmentally friendly and renewable energy source, it has attracted more attention in recent years. Biomass can be easily obtained everywhere as an energy source. In addition, biomass supports domestic energy production and the reduction of energy imports. As biomass can be easily found in rural areas and agricultural areas, bioenergy plants in rural areas both support the development of agriculture and create a new job opportunities. With these positive impacts, biomass is regarded as sustainable in economic, environmental and social dimensions.

In this thesis, a comprehensive literature review on sustainability BSC is presented. In this literature review, firstly, previous literature reviews on sustainable BSC is analyzed. The objectives and conclusions, and time horizon, research fields of previous literature reviews are investigated to better comprehend developments of sustainable BCS. Classification and assessment criteria of the previous literature reviews are also examined.

Then, quantitative papers on sustainable BSC are investigated. A classification scheme is proposed to better assessment of previous papers. According to this classification scheme, sustainability dimensions of the previous papers are analyzed

in detailed in terms of economic, environmental and social. According to this, economic and environmental aspects are more common sustainability dimensions. Then, the previous papers are analyzed according to solution methodologies. Optimization methods and stochastic approaches are the most commonly used solution methods. Bioenergy generations and sustainability evaluations of previous papers are also investigated and second generation bioenergy is seen to regards as more sustainable. Decision levels of papers on sustainable BSC are analyzed and, results show that BSC considers mostly strategic level decision. Finally, the preference reasons of biomass in sustainable energy supply are defined as “sustainability drivers of biomass”, and sustainability drivers of previous papers are investigated.

In this thesis, we have developed multi-stage solution methodology and MOMILP model to solve sustainable BCS network design with a real case problem. The real case study is about electrical energy generation by using poultry farm wastes in İzmir region. For this purpose, it is planned to establish biogas facilities generate electricity in suitable locations for both economically and environmentally. In multi-stage solution methodology, firstly, GIS is used to determine suitable locations under environmental constraints. In the second stage, environmentally suitable locations, obtained by GIS, are improved and reduced by using AHP method. By this stage, final candidate plant locations are determined. Then, a novel MOMILP model is developed to solve sustainable BSC with maximizing total profit and minimizing total distance of the entire supply chain. Single sourcing, conversation flow, capacity requirement constraints are taken into account in this model. Besides that, covering constraints are considered by defining, maximum distance and maximum waste amount parameters.

5.1 Future Research Directions

In chapter three, a number of evaluations are presented according to the classification scheme in Figure 3.1. Some considerations are obtained about importance points and gaps of sustainable BSC in the literature. Table 3.10 shows papers' characteristics regarding some basic classification topics. By deducing from all these evaluations, the following points that need to be investigated are suggested.

- In recent years, the number of BSC studies has increased considerably, nevertheless, more studies still would be needed which addressing BSC issue by emphasizing sustainability concept.
- Sustainability concept is mostly associated with the environmental friendly features of biomass. Biomass supply chain management in terms of social dimension has received little attention. Therefore, more attention should be paid to social dimension.
- However, there is a continuous and stable employment opportunity in bioenergy production sector. That is, the use of biomass in energy production can be considered to also support social sustainability dimension in economic terms.
- The increased trend in the first generation bioenergy studies, in time, has shifted towards second generation bioenergy production due to competition in food products. However, energy production from agricultural waste and animal waste, which is in the first generation bioenergy, should be improved. Thus, waste management should be assessed within the sustainability concept.
- More investigations on advantages and shortcomings between third generation bioenergy and second generation bioenergy should be conducted to clearly understand motivations of third generation bioenergy.

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APPENDIX

Appendix 1. Distance (meter) between candidate biogas facilities and poultry farms within maximum distance 80 km

Farms ID/ FacilityID	1	2	3	4	5	6	7	8	9	10	11
1	11208	11208	5595	16391	16415	16362	16418	36823	16432	23592	17583
2	6888	6889	923	12167	12200	12132	12174	35564	12202	18893	13011
3	6471	6473	4708	10861	10900	10825	10851	35186	10880	16734	11293
4	4376	4378	4351	9215	9252	9180	9214	37223	9246	15624	9873
5	981	980	6863	6259	6288	6228	6279	41192	6298	13374	7361
6	2855	2856	9768	3653	3693	3617	3639	42212	3677	9993	4156
7	6529	6530	13349	3112	3135	3101	3054	44465	3089	6437	1987
8	6987	6988	13391	4360	4386	4346	4303	43555	4341	6955	3291
9	12154	12155	17649	9308	9324	9304	9250	44117	9278	7352	7906
10	18748	18749	24960	14547	14544	14560	14496	50464	14507	8483	13052
11	17117	17118	23926	12383	12372	12402	12339	51651	12341	5568	10961
12	13906	13905	13216	17249	17252	17235	17299	45944	17289	24059	18744
13	22315	22314	20438	25637	25638	25626	25689	49418	25676	32283	27139
14	21625	21623	19105	25295	25300	25281	25344	47366	25336	32134	26783
15	22049	22047	21917	24415	24408	24410	24470	53218	24450	30469	25911
16	26756	26754	26251	29120	29113	29116	29176	56173	29155	35067	30614

Appendix 1. Continues

Farms ID/ FacilityID	12	13	14	15	16	17	18	19	20	21	22	23
17	53452	53449	50504	50546	56434	54096	54082	54088	35574	50606	48266	61550
18	51129	51127	47928	47575	53275	50993	50984	50985	32414	47576	45424	29291
19	50765	50762	47745	47698	53884	51421	51411	51413	33201	48613	45482	59013
20	55059	55056	51364	50059	53893	52356	52347	52347	32468	46190	48136	64037
21	51739	51737	47795	46171	49854	48311	48302	48302	28466	42561	44312	61064
22	57194	57191	52950	50616	52536	51742	51733	51732	30917	43084	48958	66780
23	60153	60151	56578	55331	58800	57477	57468	57468	37263	50161	53412	68905
24	47295	47292	42633	39862	42307	41096	41087	41087	20826	35113	38275	57478
25	52743	52740	48297	45730	47751	46831	46823	46822	26149	39095	44115	62616
26	67440	67437	63317	60958	61963	61663	61655	61653	40425	50642	59337	76763
27	72625	72622	68304	65497	65345	65548	65540	65537	44042	52712	64011	82136
28	69859	69856	64703	60359	57443	58681	58674	58670	37080	42995	59324	80350
29	83185	83182	78163	73904	70368	71986	71979	71975	50467	54693	72869	93451
30	85106	85103	80251	76290	73258	74694	74687	74683	53111	57840	75165	95168
31	87058	87055	82207	78231	75081	76578	76571	76567	55008	59507	77113	97107
32	72013	72010	66128	60214	53829	56456	56451	56445	35825	36910	59731	83252
33	80964	80960	73998	65119	50818	56721	56720	56711	43836	31616	66035	93034
34	78341	78337	71240	61727	45574	52208	52209	52199	43160	27828	63077	90373
35	55314	55310	48269	39165	25562	30886	30884	30875	20006	6062	40203	67386
36	57968	57965	50868	40865	23344	30438	30440	30429	28295	10688	42697	69757
37	17527	17523	10475	4538	20207	13317	13309	13317	21419	33012	2876	29591
38	25510	25506	18397	9299	13334	8220	8211	8214	15763	25019	10233	37526
39	3137	3135	7164	17290	36039	28596	28590	28600	36399	49754	15004	13542
40	54240	54236	47285	38605	26610	31205	31202	31194	17674	8015	39371	66309
41	55998	55999	55995	55233	39444	53217	30400	30400	44200	22222	30969	40739
42	54662	54658	47542	37866	22032	28344	28345	28335	22510	4768	39347	66636
43	60570	60571	60568	56936	43824	55062	34283	34284	27232	10191	45267	72564

Appendix 1. Continues

Farms ID/ FacilityID	24	25	26	27	28	29	30	31	32	33	34	35
17	65376	65368	48265	50590	25777	40521	50784	50777	42759	12751	12775	12788
18	63033	63025	45424	48014	23067	37750	48203	48195	40247	13035	13057	13075
19	62684	62676	45482	47831	22994	37737	48024	48017	40014	14152	14174	14190
20	66887	66879	48135	51451	26440	40746	51625	51617	43873	7769	7789	7808
21	63499	63491	44311	47882	22971	37032	48050	48042	40417	10640	10655	10678
22	68860	68852	48957	53036	28386	41972	53193	53184	45751	5795	5799	5822
23	72011	72003	53411	56665	31638	46009	56842	56834	49043	4737	4762	4768
24	58757	58750	38274	42718	18785	31500	42863	42854	35716	16561	16567	16590
25	64319	64311	44115	48383	24002	37237	48534	48525	41225	10723	10728	10750
26	79161	79153	59337	63403	38640	52365	63563	63554	56057	5153	5135	5114
27	84276	84268	64010	68390	43817	57242	68542	68533	61168	10689	10669	10649
28	81032	81024	59323	64786	41702	53419	64906	64897	58239	15113	15089	15086
29	94462	94454	72868	78247	54756	66889	78372	78362	71571	24031	24008	23993
30	96494	96486	75164	80336	56511	69002	80467	80458	73513	24755	24733	24716
31	98449	98441	77112	82291	58456	70957	82423	82413	75467	26565	26543	26526
32	82460	82453	59730	66206	45569	54991	66289	66278	60559	25537	25515	25516
33	88770	88764	66034	74053	61516	64694	74039	74028	71144	53672	53652	53658
34	85025	85019	63077	71285	62220	62987	71239	71229	69451	59831	59814	59824
35	62790	62784	40203	48319	39525	39624	48291	48281	46096	45615	45605	45622
36	63410	63405	42697	50901	47806	44354	50815	50806	50559	57782	57773	57790
37	25963	25956	2876	10527	20491	6422	10508	10498	10482	51966	51975	51998
38	32962	32956	10233	18441	22471	12339	18391	18381	18026	50143	50148	50171
39	14988	14980	15004	7162	26057	15309	7327	7333	9289	59554	59568	59591
40	62283	62276	39371	47341	36806	38075	47331	47321	44546	41876	41867	41883
41	68032	62889	20679	48944	41915	40861	48897	48887	47293	49259	49249	49266
42	61103	61097	39347	47583	42188	40039	47523	47513	46405	51499	51490	51507
43	67073	67067	45266	53497	46916	45709	53441	53431	52117	52804	52793	52808

Appendix 1. Continues

Farms ID/ FacilityID	36	37	38	39	40	41	42	43	44	45	46	47
17	12767	37489	35873	35873	11405	30816	30836	36406	34853	26647	26647	26648
18	13056	38134	36510	36510	11753	30935	30959	36847	32429	26491	26491	26492
19	14171	39200	37577	37577	12844	32136	32159	37970	33778	27749	27750	27751
20	7793	32848	31225	31225	6583	25476	25500	31472	29026	21002	21002	21003
21	10668	35101	33490	33490	9716	27170	27200	33490	26493	22410	22411	22411
22	5822	29209	27605	27605	5471	21211	21240	27550	24476	16465	16466	16466
23	4745	29084	27467	27467	3459	22562	22581	28015	31534	18642	18643	18643
24	16588	38609	37067	37067	16043	29951	29987	36609	21175	24974	24974	24975
25	10750	33258	31685	31685	10294	24839	24872	31399	22130	19909	19909	19909
26	5127	20121	18499	18499	6327	13734	13748	19003	29650	10413	10413	10414
27	10665	14534	12915	12915	11912	9005	9009	13540	30833	7411	7411	7411
28	15108	17174	15893	15894	16371	8236	8277	14711	20598	4379	4378	4379
29	24013	4815	4576	4576	25363	6149	6119	2253	32384	11053	11053	11052
30	24734	1487	1892	1891	26049	7973	7934	1341	35469	12907	12907	12906
31	26544	1637	3165	3164	27848	9923	9885	3240	37184	14862	14862	14862
32	25538	23061	22398	22398	26664	16186	16220	20361	15401	14921	14920	14920
33	53679	49862	49741	49741	54589	45029	45056	47436	28478	44364	44363	44363
34	59843	59059	58791	58791	60594	53455	53486	56531	32426	52142	52142	52142
35	45635	54531	53650	53650	45948	46505	46545	51823	18318	43211	43211	43211
36	57802	66230	65430	65430	58072	58451	58490	63519	30521	55331	55330	55331
37	51994	73318	71866	71866	51274	64368	64407	71052	42453	59485	59485	59485
38	50170	69663	68293	68293	49639	60667	60708	67257	36578	55936	55936	55937
39	59580	83257	81700	81701	58574	74622	74657	81284	56634	69644	69644	69644
40	41896	51368	50436	50436	42202	43191	43231	48667	14831	39760	39759	39760
41	49278	57944	57093	57093	49581	50012	50052	48898	24439	21932	46791	46790
42	51519	60867	59993	59993	51764	52853	52893	58159	24616	49532	49532	49532
43	52822	59642	58906	58906	53215	52099	52137	53455	27823	24812	49233	49233

Appendix 1. Continues

Farms ID/ FacilityID	48	49	50	51	52	53	54	55	56	57	58	59
17	26647	34192	34195	34196	34798	34799	34807	34811	34804	34798	34790	34793
18	26491	34526	34529	34530	33589	33591	33598	33601	33594	33588	33580	33584
19	27750	35677	35679	35681	35004	35006	35013	35016	35009	35003	34995	34999
20	21002	29118	29121	29122	28475	28477	28484	28488	28481	28475	28467	28470
21	22411	31034	31037	31037	28106	28108	28116	28118	28110	28104	28097	28101
22	16466	25083	25086	25087	23126	23127	23135	23138	23131	23125	23117	23120
23	18643	25830	25833	25835	28167	28167	28175	28179	28174	28168	28159	28160
24	24974	34049	34052	34052	27024	27027	27034	27035	27025	27020	27015	27021
25	19909	28867	28870	28870	24135	24138	24145	24147	24138	24132	24126	24131
26	10413	16838	16840	16842	21921	21919	21926	21932	21929	21923	21913	21913
27	7411	11526	11528	11530	20173	20169	20175	20182	20182	20177	20167	20164
28	4379	12208	12211	12210	9113	9111	9118	9124	9122	9116	9106	9105
29	11053	2680	2678	2676	16764	16757	16758	16765	16772	16770	16764	16757
30	12907	3850	3847	3849	20019	20012	20014	20020	20028	20026	20019	20012
31	14862	5795	5792	5793	21565	21558	21559	21565	21573	21571	21566	21558
32	14921	18618	18620	18617	2126	2129	2123	2116	2116	2122	2132	2134
33	44364	46452	46453	46449	31571	31575	31569	31562	31562	31568	31577	31580
34	52143	55313	55315	55311	39444	39449	39444	39437	39435	39440	39449	39453
35	43212	49770	49772	49769	33163	33170	33169	33163	33155	33156	33162	33170
36	55331	61566	61568	61565	44774	44781	44779	44773	44765	44767	44774	44781
37	59485	68491	68494	68493	56846	56852	56857	56854	56843	56840	56840	56848
38	55937	64734	64737	64736	51788	51795	51798	51795	51784	51782	51782	51791
39	69644	78724	78727	78726	69469	69474	69480	69478	69467	69464	69461	69469
40	39760	46553	46556	46553	30129	30136	30136	30130	30121	30122	30127	30135
41	46791	46791	53218	53220	30390	36525	36532	36531	36524	36516	36518	36524
42	49533	56114	56116	56113	39478	39485	39484	39478	39470	39472	39477	39485
43	49233	49234	55063	55066	34274	38203	38209	38207	38201	38194	38196	38203

Appendix 1. Continues

Farms ID/ FacilityID	60	61	62	63	64	65	66	67	68	69	70	71
17	34801	34810	34815	9950	17200	62431	63413	63544	70190	56057	29715	27330
18	33593	33600	33606	10481	16538	60781	62217	62328	69453	54521	27580	25353
19	35008	35015	35021	11508	17875	62210	63634	63747	70826	55951	28983	26771
20	28479	28487	28492	5570	11098	56080	57104	57230	64088	49699	23611	21124
21	28112	28117	28124	9090	12110	54924	56654	56751	64299	48733	21597	19405
22	23129	23137	23143	5799	6190	50747	51760	51883	58900	44347	18717	16086
23	28168	28180	28182	1982	10308	56381	56467	56630	62557	49805	25587	22832
24	27033	27032	27042	15892	15338	51591	54615	54655	63411	45846	17662	16314
25	24142	24145	24153	10324	9830	50573	52541	52624	60509	44440	17157	14994
26	21917	21934	21932	7577	7158	50173	49135	49337	54341	43439	23210	20287
27	20165	20185	20180	13178	10632	47681	45663	45900	49966	40902	24422	21615
28	9108	9126	9123	17874	10032	37314	36670	36844	42985	30586	14556	12178
29	16748	16770	16756	26789	21281	38429	34178	34485	36589	31900	27133	25215
30	20004	20026	20012	27401	22746	41375	36669	36994	38217	34925	30050	27998
31	21549	21571	21557	29179	24676	41850	36708	37048	37623	35510	31855	29852
32	2133	2113	2118	28089	19771	26354	27039	27139	35334	19736	12258	12131
33	31579	31559	31565	55844	47714	11771	21834	21461	33770	14930	32837	35245
34	39455	39433	39441	61712	53957	21892	31949	31559	43588	25221	37952	40690
35	33179	33157	33171	46657	40542	35103	43605	43369	55737	33536	24691	27523
36	44789	44767	44781	58730	52782	40802	50382	50072	62643	41089	36928	39774
37	56861	56849	56863	50818	50711	71210	78135	78000	89411	67898	44683	45619
38	51804	51790	51804	49416	48004	64027	71361	71202	82898	61085	39671	41018
39	69482	69474	69487	57735	59862	86789	93059	92961	103852	82959	57621	57937
40	30145	30124	30138	42907	36836	34846	42794	42589	54754	32571	21122	23917
41	36532	36541	36519	36532	50276	5491	36316	45245	44983	57471	35380	28327
42	39494	39472	39486	52401	46579	39066	48130	47860	60376	38337	30942	33741
43	38210	38218	38195	38208	47522	34092	43503	43206	55775	34062	31272	34179

Appendix 1. Continues

Farms ID/ FacilityID	72	73	74	75	76	77	78	79	80	81	82	83	84
17	29761	32117	29752	62093	30354	30357	52997	45116	43253	50221	28697	45460	34924
18	27631	30366	27619	59343	28648	28652	50378	42804	41026	48276	25986	42561	32338
19	29033	31794	29021	59310	30077	30081	50230	44173	42411	49692	27248	43711	33641
20	23653	25798	23646	62275	24025	24028	53701	39120	37180	43941	23429	40550	29344
21	21648	24501	21635	58496	22814	22818	50078	36835	35043	42319	20286	37170	26504
22	18752	20542	18749	63211	18752	18754	55137	34289	32257	38739	19715	36973	25111
23	25617	26781	25618	67547	24962	24963	58934	41128	39011	44984	26877	44136	32263
24	17726	21828	17704	52538	20449	20455	44715	31697	30231	38320	13962	30087	20564
25	17208	20167	17196	58376	18515	18520	50433	32424	30612	37894	16246	33366	22266
26	23215	22599	23228	73595	20872	20870	65521	37880	35537	40043	27179	43873	31119
27	24411	22580	24431	78271	21056	21052	70443	37876	35440	38737	29742	45628	32698
28	14525	11604	14553	73387	10308	10303	66545	26696	24242	27543	21484	35652	22842
29	27086	22846	27119	86934	22234	22227	80044	35637	33227	33076	34694	47194	34966
30	30006	25936	30039	89294	25228	25221	82195	38948	36533	36373	37435	50350	38007
31	31811	27645	31843	91237	26995	26988	84149	40359	37964	37439	39305	52009	39751
32	12189	6987	12225	73187	7813	7806	67604	17364	14936	16458	20331	29408	18203
33	32790	30984	32800	76318	32803	32802	74436	17989	19445	13041	36112	27718	29522
34	37919	37373	37920	71880	39132	39133	71305	22392	24564	21246	39187	26416	32595
35	24703	27449	24682	50376	28560	28565	48565	15831	17714	23869	21240	4085	16481
36	36938	39449	36918	49848	40654	40659	50498	26247	28508	32480	33262	16035	28741
37	44749	49934	44712	17007	49578	49586	11102	48902	49324	58056	36550	35834	39763
38	39732	44799	39696	21766	44686	44694	18558	42013	42669	51166	31608	28337	33793
39	57691	62867	57656	17673	62170	62177	8853	64267	64375	73318	49760	52074	54148
40	21137	24147	21115	50341	25163	25169	47788	13977	15502	22685	17493	994	12841
41	31167	28337	62883	28317	50069	32124	32129	48991	18611	26010	24834	7584	20136
42	30957	33795	30935	48038	34893	34899	47479	21695	23747	29046	26936	9791	22663
43	31273	33260	31257	53971	34593	34598	53429	19377	21714	25367	28752	11883	23424

Appendix 2. The importance assessment matrix of the candidate facility locations in northern part of izmir according to criterion of water resources

Facility ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1	3	7	1/3	1/3	1/3	1	1/3	3	1/3	1	1	7	1/3	1	7	3	7	5	3	3	5	3	3	1/3
2	1/3	1	5	1/5	1/5	1/9	1/3	1/5	1	1/5	1/3	1/3	5	1/5	1/3	5	1	5	3	1	1	3	1	1	1/5
3	1/7	1/5	1	1/9	1/9	1/9	1/7	1/9	1/5	1/9	1/7	1/7	1	1/9	1/7	1	1/5	1/5	1	1/5	1/5	1/3	1/5	1/5	1/9
4	3	5	9	1	1	1	3	1	5	1	3	3	9	1	3	9	5	9	7	5	5	7	5	5	1
5	3	5	9	1	1	1	3	1	5	1	3	3	9	1	3	9	5	9	7	5	5	7	5	5	1
6	3	5	9	1	1	1	3	1	5	1	3	3	9	1	3	9	5	9	7	5	5	7	5	5	1
7	1	3	7	1/3	1/3	1/3	1	1/3	3	1/3	1	1	7	1/3	1	7	3	7	5	3	3	5	3	3	1/3
8	3	5	9	1	1	1	3	1	5	1	3	3	9	1	3	9	5	9	7	5	5	7	5	5	1
9	1/3	1	5	1/5	1/5	1/6	1/3	1/5	1	1/5	1/3	1/3	5	1/5	1/3	5	1	5	3	1	1	3	1	1	1/5
10	3	5	9	1	1	1	3	1	5	1	3	3	9	1	3	9	5	9	7	5	5	7	5	5	1
11	1	3	7	1/3	1/3	1/3	1	1/3	3	1/3	1	1	7	1/3	1	7	3	7	5	3	3	5	3	3	1/3
12	1	3	7	1/3	1/3	1/3	1	1/3	3	1/3	1	1	7	1/3	1	7	3	7	5	3	3	5	3	3	1/3
13	1/7	1/5	1	1/9	1/9	1/9	1/7	1/9	1/5	1/9	1/7	1/7	1	1/9	1/7	1	1/5	1/5	1	1/5	1/5	1/3	1/5	1/5	1/9
14	3	5	9	1	1	1	3	1	5	1	3	3	9	1	3	9	5	9	7	5	5	7	5	5	1
15	1	3	7	1/3	1/3	1/3	1	1/3	3	1/3	1	1	7	1/3	1	7	3	7	5	3	3	5	3	3	1/3
16	1/7	1/5	1	1/9	1/9	1/9	1/7	1/9	1/5	1/9	1/7	1/7	1	1/9	1/7	1	1/5	1/5	1	1/5	1/5	1/3	1/5	1/5	1/9
17	1/3	1	5	1/5	1/5	1/9	1/3	1/5	1	1/5	1/3	1/3	5	1/5	1/3	5	1	5	3	1	1	3	1	1	1/5
18	1/7	1/5	1	1/9	1/9	1/9	1/7	1/9	1/5	1/9	1/7	1/7	1	1/9	1/7	1	1/5	1/5	1	1/5	1/5	1/3	1/5	1/5	1/9
19	1/5	3	3	1/7	1/7	1/7	1/7	1/3	1/3	1/7	1/5	1/5	3	1/7	1/5	3	1/3	1	1	1/3	1/3	1	1/3	1/3	1/7
20	1/3	1	5	1/5	1/5	1/9	1/3	1/5	1	1/5	1/3	1/3	5	1/5	1/3	5	1	5	3	1	1	3	1	1	1/5
21	1/3	1	5	1/5	1/5	1/9	1/3	1/5	1	1/5	1/3	1/3	5	1/5	1/3	5	1	5	3	1	1	3	1	1	1/5
22	1/5	3	3	1/7	1/7	1/7	1/7	1/3	1/3	1/7	1/5	1/5	3	1/7	1/5	3	1/3	1	1	1/3	1/3	1	1/3	1/3	1/7
23	1/3	1	5	1/5	1/5	1/9	1/3	1/5	1	1/5	1/3	1/3	5	1/5	1/3	5	1	5	3	1	1	3	1	1	1/5
24	1/3	1	5	1/5	1/5	1/9	1/3	1/5	1	1/5	1/3	1/3	5	1/5	1/3	5	1	5	3	1	1	3	1	1	1/5
25	3	5	9	1	1	1	3	1	5	1	3	3	9	1	3	9	5	9	7	5	5	7	5	5	1

Appendix 3. The importance assessment matrix of the candidate facility locations in northern part of izmir according to criterion of protected areas

Facility ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1	1	5	7	9	5	1	5	3	9	9	5	1	9	9	1	1	1	1	1	1	1	1	1	1
2	1	1	5	7	9	5	1	5	3	9	9	5	1	9	9	1	1	1	1	1	1	1	1	1	1
3	1/5	1/5	1	3	5	1	1/5	1	1	5	5	1	1/5	5	5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5
4	1/7	1/7	1/3	1	3	1/3	1/7	1/3	1/3	3	3	1/3	1/7	3	3	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7
5	1/9	1/9	1/5	3	1	1/5	1/9	1/5	1/5	1	5	1/5	1/9	1	1	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9
6	1/5	1/5	1	3	5	1	1/5	1	1	5	5	1	1/5	5	5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5
7	1	1	5	7	9	5	1	5	3	9	9	5	1	9	9	1	1	1	1	1	1	1	1	1	1
8	1/5	1/5	1	3	5	1	1/5	1	1	5	5	1	1/5	5	5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5
9	1/5	1/5	1	3	5	1	1/5	1	1	5	5	1	1/5	5	5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5
10	1/9	1/9	1/5	3	1	1/5	1/9	1/5	1/5	1	5	1/5	1/9	1	1	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9
11	1/9	1/9	1/5	3	1	1/5	1/9	1/5	1/5	1	1	1/5	1/9	1	1	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9
12	1/5	1/5	1	3	5	1	1/5	1	1	5	5	1	1/5	5	5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5
13	1	1	5	7	9	5	1	5	3	9	9	5	1	9	9	1	1	1	1	1	1	1	1	1	1
14	1/9	1/9	1/5	3	1	1/5	1/9	1/5	1/5	1	5	1/5	1/9	1	1	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9
15	1/9	1/9	1/5	3	1	1/5	1/9	1/5	1/5	1	5	1/5	1/9	1	1	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9
16	1	1	5	7	9	5	1	5	3	9	9	5	1	9	9	1	1	1	1	1	1	1	1	1	1
17	1	1	5	7	9	5	1	5	3	9	9	5	1	9	9	1	1	1	1	1	1	1	1	1	1
18	1	1	5	7	9	5	1	5	3	9	9	5	1	9	9	1	1	1	1	1	1	1	1	1	1
19	1	1	5	7	9	5	1	5	3	9	9	5	1	9	9	1	1	1	1	1	1	1	1	1	1
20	1	1	5	7	9	5	1	5	3	9	9	5	1	9	9	1	1	1	1	1	1	1	1	1	1
21	1	1	5	7	9	5	1	5	3	9	9	5	1	9	9	1	1	1	1	1	1	1	1	1	1
22	1	1	5	7	9	5	1	5	3	9	9	5	1	9	9	1	1	1	1	1	1	1	1	1	1
23	1	1	5	7	9	5	1	5	3	9	9	5	1	9	9	1	1	1	1	1	1	1	1	1	1
24	1	1	5	7	9	5	1	5	3	9	9	5	1	9	9	1	1	1	1	1	1	1	1	1	1
25	1	1	5	7	9	5	1	5	3	9	9	5	1	9	9	1	1	1	1	1	1	1	1	1	1

Appendix 4. The importance assessment matrix of the candidate facility locations in northern part of İzmir according to criterion of agricultural lands

Facility ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1	1/3	1	1/3	1	1/3	1/3	1	1/3	1/3	1/3	1/5	1/3	1/7	1/5	1	1/5	1	1	1	1/3	1	1/3	1/3	1/3
2	3	1	3	1	3	1	1	3	1	1	1	1/3	1	1/5	1/3	3	1/3	3	3	3	1	3	3	3	3
3	1	1/3	1	1/3	1	1/3	1/3	1	1/3	1/3	1/3	1/5	1/3	1/7	1/5	1	1/5	1	1	1	1/3	1	1/3	1/3	1/3
4	3	1	3	1	3	1	1	3	1	1	1	1/3	1	1/5	1/3	3	1/3	3	3	3	1	3	3	3	3
5	1	1/3	1	1/3	1	1/3	1/3	1	1/3	1/3	1/3	1/5	1/3	1/7	1/5	1	1/5	1	1	1	1/3	1	1/3	1/3	1/3
6	3	1	3	1	3	1	1	3	1	1	1	1/3	1	1/5	1/3	3	1/3	3	3	3	1	3	3	3	3
7	3	1	3	1	3	1	1	3	1	1	1	1/3	1	1/5	1/3	3	1/3	3	3	3	1	3	3	3	3
8	1	1/3	1	1/3	1	1/3	1/3	1	1/3	1/3	1/3	1/5	1/3	1/7	1/5	1	1/5	1	1	1	1/3	1	1/3	1/3	1/3
9	3	1	3	1	3	1	1	3	1	1	1	1/3	1	1/5	1/3	3	1/3	3	3	3	1	3	3	3	3
10	3	1	3	1	3	1	1	3	1	1	1	1/3	1	1/5	1/3	3	1/3	3	3	3	1	3	3	3	3
11	3	1	3	1	3	1	1	3	1	1	1	1/3	1	1/5	1/3	3	1/3	3	3	3	1	3	3	3	3
12	7	5	7	5	7	5	5	7	5	5	5	1	5	1	3	1/7	3	7	7	7	7	7	7	7	7
13	3	1	3	1	3	1	1	3	1	1	1	1/3	1	1/5	1/3	3	1/3	3	3	3	1	3	3	3	3
14	7	5	7	5	7	5	5	7	5	5	5	3	5	1	3	1/7	3	7	7	7	7	7	7	7	7
15	5	3	5	3	5	3	3	5	3	3	3	1	3	1/3	1	1/5	1	5	5	5	5	5	5	5	5
16	5	3	5	3	5	3	3	5	3	3	3	1	3	1/3	1	1	1	5	5	5	5	5	5	5	5
17	1	1/3	1	1/3	1	1/3	1/3	1	1/3	1/3	1/3	1/5	1/3	1/7	1/5	1	1	1	1	1	1/3	1	1/3	1/3	1/3
18	1	1/3	1	1/3	1	1/3	1/3	1	1/3	1/3	1/3	1/5	1/3	1/7	1/5	1	1/5	1	1	1	1/3	1	1/3	1/3	1/3
19	1	1/3	1	1/3	1	1/3	1/3	1	1/3	1/3	1/3	1/5	1/3	1/7	1/5	1	1/5	1	1	1	1/3	1	1/3	1/3	1/3
20	1	1/3	1	1/3	1	1/3	1/3	1	1/3	1/3	1/3	1/5	1/3	1/7	1/5	1	1/5	1	1	1	1/3	1	1/3	1/3	1/3
21	3	1	3	1	3	1	1	3	1	1	1	1/3	1	1/5	1/3	3	1/3	3	3	3	1	3	3	3	3
22	1	1/3	1	1/3	1	1/3	1/3	1	1/3	1/3	1/3	1/5	1/3	1/7	1/5	1	1/5	1	1	1	1/3	1	1/3	1/3	1/3
23	3	1	3	1	3	1	1	3	1	1	1	1/3	1	1/5	1/3	3	1/3	3	3	3	1	3	1	3	3
24	3	1	3	1	3	1	1	3	1	1	1	1/3	1	1/5	1/3	3	1/3	3	3	3	1	3	3	1	3
25	3	1	3	1	3	1	1	3	1	1	1	1/3	1	1/5	1/3	3	1/3	3	3	3	1	3	3	3	1

Appendix 5. The importance assessment matrix of the candidate facility locations in northern part of İzmir according to criterion of residential areas

Facility ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1	1/3	1/3	1/3	1/3	1/3	1	1/3	5	3	1/3	3	3	1	1/3	7	7	3	1/3	3	5	3	1	3	1/3
2	3	1	1	1	1	1	3	1	7	5	1	5	5	3	1	9	9	5	1	5	7	5	3	5	1
3	3	1	1	1	1	1	3	1	7	5	1	5	5	3	1	9	9	5	1	5	7	5	3	5	1
4	3	1	1	1	1	1	3	1	7	5	1	5	5	3	1	9	9	5	1	5	7	5	3	5	1
5	3	1	1	1	1	1	3	1	7	5	1	5	5	3	1	9	9	5	1	5	7	5	3	5	1
6	3	1	1	1	1	1	3	1	7	5	1	5	5	3	1	9	9	5	1	5	7	5	3	5	1
7	1	1/3	1/3	1/3	1/3	1/3	1	1/3	5	3	1/3	3	3	1	1/3	7	7	3	1/3	3	1/5	3	1	3	1/3
8	3	1	1	1	1	1	3	1	7	5	1	5	5	3	1	9	9	5	1	5	7	5	3	5	1
9	1/5	1/7	1/7	1/7	1/7	1/7	1/5	1/7	1	1/3	1/7	1/3	1/3	1/5	1/7	3	3	1/3	1/7	1/3	1	1/3	1/5	1/3	1/7
10	1/3	1	1/5	1/5	1/5	1/5	1/3	1/5	3	1	1/5	1	1	1/3	1	3	1/5	1/5	1	1/5	1	3	1	1	1/5
11	3	1	1	1	1	1	3	1	7	5	1	5	5	3	1	9	9	5	1	5	1/7	5	3	5	1/5
12	1/3	1	1/5	1/5	1/5	1/5	1/3	1/5	3	1	1/5	1	1	1/3	1	3	1/5	1/5	1	1/5	1	3	1	1	1/5
13	1/3	1	1/5	1/5	1/5	1/5	1/3	1/5	3	1	1/5	1	1	1/3	1	3	1/5	1/5	1	1/5	1	3	1	1	1/5
14	1	1/3	1/3	1/3	1/3	1/3	1	1/3	5	3	1/3	3	3	1	1/3	7	7	3	1/3	3	1/5	3	1	3	1/3
15	1/3	1	1/5	1/5	1/5	1/5	1/3	1/5	3	1	1/5	1	1	1/3	1	3	1/5	1/5	1	1/5	1	3	1	1	1/5
16	5	3	5	3	5	3	3	5	3	3	3	1	3	1/3	1	1	1	5	5	5	5	5	5	5	5
17	1	1/3	1	1/3	1	1/3	1/3	1	1/3	1/3	1/3	1/5	1/3	1/7	1/5	1	1	1	1	1	1/3	1	1/3	1/3	1/3
18	1/3	1	1/5	1/5	1/5	1/5	1/3	1/5	3	1	1/5	1	1	1/3	1	3	1/5	1	1	1/5	1	3	1	1	1/5
19	1	1/3	1	1/3	1	1/3	1/3	1	1/3	1/3	1/3	1/5	1/3	1/7	1/5	1	1/5	1	1	1	1/3	1	1/3	1/3	1/3
20	1/3	1	1/5	1/5	1/5	1/5	1/3	1/5	3	1	1/5	1	1	1/3	1	3	1/5	1/5	1	1	1	3	1	1	1/5
21	3	1	3	1	3	1	1	3	1	1	1	1/3	1	1/5	1/3	3	1/3	3	3	3	1	3	3	3	3
22	1/3	1	1/5	1/5	1/5	1/5	1/3	1/5	3	1	1/5	1	1	1/3	1	3	1/5	1/5	1	1/5	1	1	1	1	1/5
23	1	1/3	1/3	1/3	1/3	1/3	1	1/3	5	3	1/3	3	3	1	1/3	7	7	3	1/3	1/3	3	1/5	3	1	1/3
24	1/3	1	1/5	1/5	1/5	1/5	1/3	1/5	3	1	1/5	1	1	1/3	1	3	1/5	1/5	1	1/5	1	3	1	1	1/5
25	3	1	1	1	1	1	3	1	7	5	1	5	5	3	1	9	9	5	1	5	1/7	5	3	5	1

Appendix 6. The importance assessment matrix of the candidate facility locations in northern part of İzmir according to criterion of main roads

Facility ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1	1	1	3	1/3	5	1	1	5	5	1	7	3	3	1/3	1	1/3	1/3	1/3	1/3	1/3	5	1	3	1
2	1	1	1	3	1/3	5	1	1	5	5	1	7	3	3	1/3	1	1/3	1/3	1/3	1/3	1/3	5	1	3	1
3	1	1	1	3	1/3	5	1	1	5	5	1	7	3	3	1/3	1	1/3	1/3	1/3	1/3	1/3	5	1	3	1
4	1/3	1/3	1/3	1	1/5	3	1/3	1/3	3	3	1/3	5	1	1	1/5	1/3	1/5	1/5	1/5	1/5	1/5	3	1/3	1	1/3
5	3	3	3	5	1	7	3	3	7	7	3	9	5	5	1	3	1	1	1	1	1	7	3	5	3
6	1/5	1/5	1/5	1/3	1/7	1	1/5	1/5	1	1	1/5	3	1/3	1/3	1/7	1/5	1/7	1/7	1/7	1/7	1/7	1	1/5	1/3	1/5
7	1	1	1	3	1/3	5	1	1	5	5	1	7	3	3	1/3	1	1/3	1/3	1/3	1/3	1/3	5	1	3	1
8	1	1	1	3	1/3	5	1	1	5	5	1	7	3	3	1/3	1	1/3	1/3	1/3	1/3	1/3	5	1	3	1
9	1/5	1/5	1/5	1/3	1/7	1	1/5	1/5	1	1	1/5	3	1/3	1/3	1/7	1/5	1/7	1/7	1/7	1/7	1/7	1	1/5	1/3	1/5
10	1/5	1/5	1/5	1/3	1/7	1	1/5	1/5	1	1	1/5	3	1/3	1/3	1/7	1/5	1/7	1/7	1/7	1/7	1/7	1	1/5	1/3	1/5
11	1	1	1	3	1/3	5	1	1	5	5	1	7	3	3	1/3	1	1/3	1/3	1/3	1/3	1/3	5	1	3	1
12	1/7	1/7	1/7	1/5	1/9	1/3	1/7	1/7	1/3	1/3	1/7	1	1/5	1/5	1/9	1/7	1/9	1/9	1/9	1/9	1/9	1/3	1/7	1/5	1/7
13	1/3	1/3	1/3	1	1/5	3	1/3	1/3	3	3	1/3	5	1	1	1/5	1/3	1/5	1/5	1/5	1/5	1/5	3	1/3	1	1/3
14	1/3	1/3	1/3	1	1/5	3	1/3	1/3	3	3	1/3	5	1	1	1/5	1/3	1/5	1/5	1/5	1/5	1/5	3	1/3	1	1/3
15	3	3	3	5	1	7	3	3	7	7	3	9	5	5	1	3	1	1	1	1	1	7	3	5	3
16	1	1	1	3	1/3	5	1	1	5	5	1	7	3	3	1/3	1	1/3	1/3	1/3	1/3	1/3	5	1	3	1
17	3	3	3	5	1	7	3	3	7	7	3	9	5	5	1	3	1	1	1	1	1	7	3	5	3
18	3	3	3	5	1	7	3	3	7	7	3	9	5	5	1	3	1	1	1	1	1	7	3	5	3
19	3	3	3	5	1	7	3	3	7	7	3	9	5	5	1	3	1	1	1	1	1	7	3	5	3
20	3	3	3	5	1	7	3	3	7	7	3	9	5	5	1	3	1	1	1	1	1	7	3	5	3
21	1/5	1/5	1/5	1/3	1/7	1	1/5	1/5	1	1	1/5	3	1/3	1/3	1/7	1/5	1/7	1/7	1/7	1/7	1/7	1	1/5	1/3	1/5
22	1/3	1/3	1/3	1	1/5	3	1/3	1/3	3	3	1/3	5	1	1	1/5	1/3	1/5	1/5	1/5	1/5	1/5	1	1/3	1	1/3
23	1	1	1	3	1/3	5	1	1	5	5	1	7	3	3	1/3	1	1/3	1/3	1/3	1/3	1/3	5	1	3	1
24	1/3	1/3	1/3	1	1/5	3	1/3	1/3	3	3	1/3	5	1	1	1/5	1/3	1/5	1/5	1/5	1/5	1/5	3	1/3	1	1/3
25	1	1	1	3	1/3	5	1	1	5	5	1	7	3	3	1/3	1	1/3	1/3	1/3	1/3	1/3	5	1	3	1