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Spatiotemporal Analysis Framework for Identifying Emerging Hot Spots and Energy Potential from Livestock Manure in Turkey

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by

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I, **Büşra Yüksel Ruhbaş** declare that this thesis titled **Spatiotemporal Analysis Framework for Identifying Emerging Hot Spots and Energy Potential from Livestock Manure in Turkey** and the work presented in it are my own. I confirm that:

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Spatiotemporal Analysis Framework for Identifying Emerging Hot Spots and Energy Potential from Livestock Manure in Turkey

Abstract

Biogas technology offers both an environmentally sustainable solution for livestock manure and generates renewable energy. Renewable energy production from livestock manure highly depends on the feedstock availability; therefore, the spatial and temporal variability of livestock manure is critical for sustainable management of livestock manure via biogas plants. In this regard, this study aims to develop a replicable geographic information system-based spatiotemporal method to determine emerging hot spots and power capacities for new biogas plants and capacity expansion for the existing plants. The method was conducted to analyze energy production from livestock manure at the district level in Turkey between 2013 and 2019.

The spatial dimension consists of 970 districts, which makes this study the spatially most detailed investigation of energy potential from livestock manure in Turkey, while the temporal dimension consists of 13-time steps. 66 districts were determined as emerging hot spots in which 43 have no biogas plants. These hot spots were specified as districts with high priority for the installation of new biogas plants with power capacities ranging between 6.30 MWe and 22.54 MWe. The total theoretical power capacity was calculated as 640 MWe. Capacity expansions were calculated between 0.52 to 13.87 MWe for the existing 63 biogas plants. The unit cost of electricity generation from livestock manure via biogas plants was calculated as greater than the feed-in tariff paid by the government. This is the major reason for the small number of biogas plants considering that Turkey has one of the highest livestock animal and poultry populations in Europe. The method aids in the decision-making process of environmentally and economically sustainable livestock manure management planning and biogas investors to direct their investments into profitable locations.

Keywords: Biogas; manure; GIS; renewable energy; spatial analysis; Turkey

Türkiye'deki Hayvan Gübresinin Yoğun Olarak Bulunduğu Bölgelerin ve Bu Bölgelerin Enerji Potansiyellerinin Mekansal ve Zamansal Analizler ile Belirlenmesi

Öz

Biyogaz teknolojisi, hem hayvan gübresi için çevresel açıdan sürdürülebilir bir çözüm sunar hem de yenilenebilir enerji üretir. Hayvan gübresinden yenilenebilir enerji üretimi, büyük ölçüde hammadde mevcudiyetine bağlıdır; bu nedenle, canı hayvan gübresinin mekânsal ve zamansal değişkenliği, biyogaz tesisleri aracılığıyla hayvan gübresinin sürdürebilir yönetimi için kritik öneme sahiptir. Bu bağlamda, bu çalışma, yeni biyogaz tesisleri için ortaya çıkan sıcak noktaları, güç kapasitelerini ve mevcut tesisler için kapasite genişletme potansiyellerini belirlemek için tekrarlanabilir bir coğrafi bilgi sistemi tabanlı zaman-uzamsal bir yöntem geliştirmeyi amaçlamaktadır. Bu yöntem, 2013-2019 yılları arasında Türkiye'de ilçe düzeyinde, hayvan gübresinden enerji üretimini analiz etmek için geliştirilmiştir.

Çalışmanın mekânsal boyutu 970 ilçeden oluşmaktadır, bu da bu çalışmayı Türkiye'deki canlı hayvan gübresinden elde edilen enerji potansiyelinin mekânsal olarak en detaylı incelemesi haline getirirken, zamansal boyut 13 zaman adımından oluşmaktadır. 43'ünde biyogaz tesisi bulunmayan 66 ilçe, yükselen sıcak noktalar olarak belirlendi. Bu sıcak noktalar, güç kapasiteleri 6,3 MWe ve 22,54 MWe arasında değişen yeni biyogaz santrallerinin kurulumu için yüksek önceliğe sahip ilçeler olarak belirlendi. Toplam teorik güç kapasitesi 640 MWe olarak hesaplanmıştır. Mevcut 63 biyogaz tesisi için kapasite artışları 0,52 ile 13,87 MWe arasında hesaplanmıştır. Biyogaz tesisleri aracılığıyla canlı hayvan gübresinden elektrik üretimin birim maliyeti, devlet tarafından ödenen tarife garantisinden daha fazla olduğu hesaplanmıştır. Türkiye'nin Avrupa'daki en yüksek besi ve kümes hayvanı popülasyonlarından birine sahip olduğu düşünüldüğünde, biyogaz tesislerinin az sayıda olmasının başlıca nedeni budur. Geliştirilen bu yöntem, çevresel ve ekonomik olarak sürdürülebilir hayvan gübresi yönetimi planlanmasına ve biyogaz yatırımcılarına yatırımlarını karlı yerlere yönlendirmek için karar verme sürecine yardımcı olur.

Anahtar Kelimeler: Biyogaz; hayyvan gübresi; GIS, yenilenebilir enerji; mekansal analiz; Türkiye

This thesis is dedicated to my beloved family.

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List of Abbreviations

GIS	Geographic information system
O&M	Operation and maintenance
OFMSW	Organic fraction of municipal solid waste
UTM	Universal Traverse Mercator
WGS	World Geodetic System
TUIK	Turkish Statistical Institute
EJ	Exajoule
MJ	Megajoule
AD	Anaerobic digestion
Ppm	Parts per million

List of Symbols

a	Annuitization coefficient
CH_4	Methane
Cl	Chlorine
CO_2	Carbon dioxide
D	Average manure density (kg/m3)
H	Livestock manure (ton/y)
H_2	Hydrogen
H_2S	Hydrogen sulfide
I	Investment cost ($)
i	Discount rate
i j	Index notation
IT	Internal consumption rate
KF	Capacity factor
M_{LM}	Methane generation for livestock manure (m^3 CH_4/ton)
N_2	Nitrogen
NH_3	Ammonia
η	Energy conversion efficiency
n, m	Total number of elements in an index
O_2	Oxygen
P_e	Plant energy production (kWh/y)
Q	Organic waste generation rate (ton/y)
Q_M	Lower heating value for methane (MJ/m^3)

S_{TS}	Total solids content (kg TS/kg manure)
T	Plant lifetime (yr)
T_C	Total annual cost ($/y)
T_R	Annual revenue collected due to electricity sale ($/y)
U_e	Unit electric sale price ($/kWh)
x_e	Energy generation rate (MWh)
x_p	Installation size (kW)
α	Collectable part of livestock manure

Chapter 1

Introduction

The unregulated disposal of livestock manure and direct use as fertilizer in farmlands are the two major problems in livestock manure management in Turkey. A new regulation was legislated to control livestock manure management [1]. To be valid from the second half of 2021, this new regulation restricts the direct application of livestock manure onto the soil. In addition, livestock farms have been made responsible for the proper storage of livestock manure and the development of manure management plans. This regulation also encourages the use of livestock manure for biogas production as a management strategy.

Biogas is produced by the breakdown of organic materials such as manure, agricultural waste, sewage sludge, and food waste in the absence of oxygen. It mainly consists of methane and carbon dioxide that can be converted into heat and electric energy. Biogas is also known as a renewable energy resource. It is widely used throughout Europe since it has matured technology. There were 17,783 biogas plants in operation in Europe by the end of 2017 and most of them utilize agricultural waste, including livestock manure, as feedstock. Germany alone has 10,971 biogas plants using manure and other biowastes for biogas production [2]. There are only 72 biogas plants (excluding the plants utilizing landfill gas) in Turkey, 63 uses livestock manure as feedstock [3]. Considering the number of livestock (evaluated under the study area section) and the need for a livestock manure management strategy, the number and capacity of existing biogas plants are insufficient in Turkey. Biogas energy is also considered a renewable energy source. Therefore, the purchase of electric energy generated from biogas is guaranteed for the first ten years by a higher feed-in tariff by the government. Installation of new biogas plants or capacity expansion may still require special attention to spatiotemporal variability of feedstock availability for economically sustainable investment. Knowing where the resources are located, and their spatiotemporal trends are important aspects of planning biogas investments.

According to the previously mentioned statements, this study consists of four main steps to evaluate biogas potential from livestock manure in Turkey. This study started with a data collection step. In this step, the administrative boundaries (districts, provinces, and country), existing biogas plants locations, and livestock data between 2013 and 2019 were collected. The second step included geocoding of existing biogas plants and livestock data for geodatabase design and generation to be used in spatiotemporal analyses. Spatiotemporal pattern mining of biogas potential from livestock manure was the third step of this study. This step was divided into two sections: Creating a space-time cube with 2013-2019 livestock data and the density analysis with the 2019 livestock data. Trend analyses and the emerging hot spot analyses were performed in creating a space-time cube section. In the fourth and the final step, the emerging biogas plant locations were determined. According to the overall results, an economic analysis was performed for the sustainable planning of biogas energy generation.

This thesis consists of 5 chapters. In the first chapter, an introduction is made for a better understanding of biogas energy potential from livestock manure and the upcoming chapters. The second and the third chapters include a literature review and materials and methods used in the scope of the thesis along with the procedure of the spatiotemporal analysis, respectively. The results and discussion part were included in the fourth chapter. The fifth chapter consists of general conclusions and a few recommendations for possible future studies.

Chapter 2

Literature Review

In this chapter, renewable biogas energy was discussed in detail. The literature review was divided into the following topics to give the reader an in-depth explanation of biogas energy and its potential as a renewable energy source: The renewable energy needs in Turkey and the world, biogas as an inseparable part of renewable energy, literature.

2.1 The Renewable Energy Needs in Turkey and the World

Energy can be defined as the ability to do work. From the past today, people have used energy in various forms by changing it from one form to another such as heat, electrical, chemical act. The main sources of this energy production have been obtained from nature and utilized directly in the energy generation process. These main sources can be listed as coal, oil, nuclear energy, natural gas, and these are called fossil fuels [4]. Besides providing a high amount of energy, fossil fuels cause various environmental problems which are simultaneously related to the continuity of humanity from global warming to acid precipitation, air pollution, greenhouse gas emissions, etc. On contrary to these sources, there are renewable energy sources that can be utilized more sustainably for the good future of nature like wind, hand, wave energy, biomass, geothermal, solar, hydraulic [5]. The categorization of energy sources as renewable and non-renewable is demonstrated in Figure 2.1 [6]. As an important asset, renewable energy usage comes to the fore with reducing the energy-related environmental problems with the ability of self-perpetuation and reduction greenhouse gas emission.

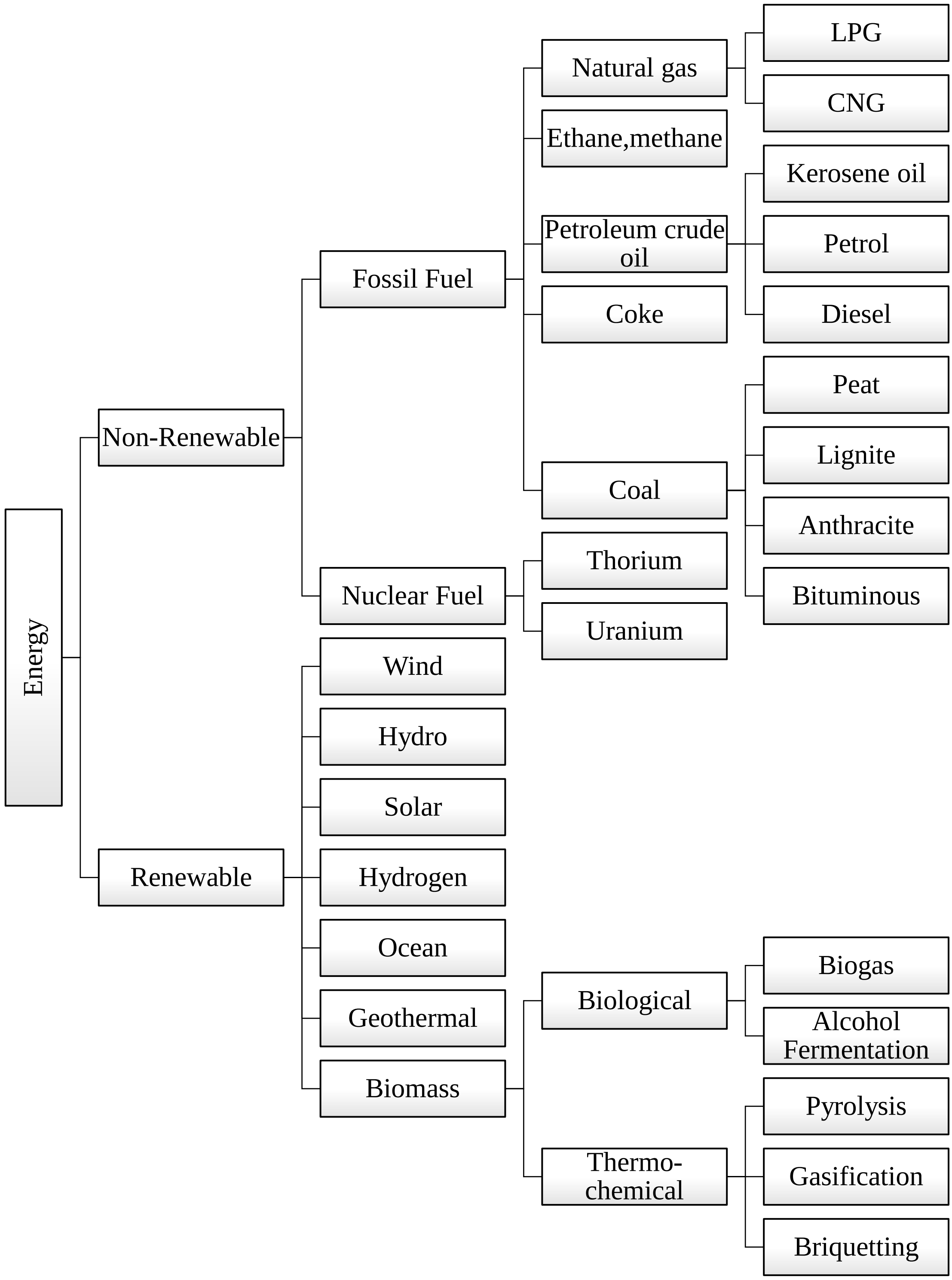


Figure 2.1: The categorization of energy sources as renewable and non-renewable [6].

The world has a population of a consistently increasing number and it will continue to increase. Parallel to this fact, the energy demand of the world is predicted to increase by 1000 EJ (EJ=1018J) or even more [7]. Another result shows that while global energy demand was 254 EJ in 1973, it reached 606 EJ in 2019 [8]. The world's total energy supply sources and their percentages in total consumption are demonstrated in Figure 2.2.

Like the rest of the world, Turkey’s energy consumption has grown in years. For instance, while the energy consumption of Turkey was calculated as 3,1 EJ in 2000, it increased to 6,5 EJ in 2019 [9]. The energy consumption of Turkey between 2000 and 2019 is demonstrated in Figure 2.2. All these results show that fossil fuels can not meet this increasing energy demand alone when sustainability and the amount of energy are considered. The leading cause of environmental problems like air pollution and global warming is an increase in the amount of fossil fuels usage to meet the world’s energy needs. Besides environmental problems, this amounts of fossil fuels utilization increase the external dependence of Turkey and affect the country’s economy [10].

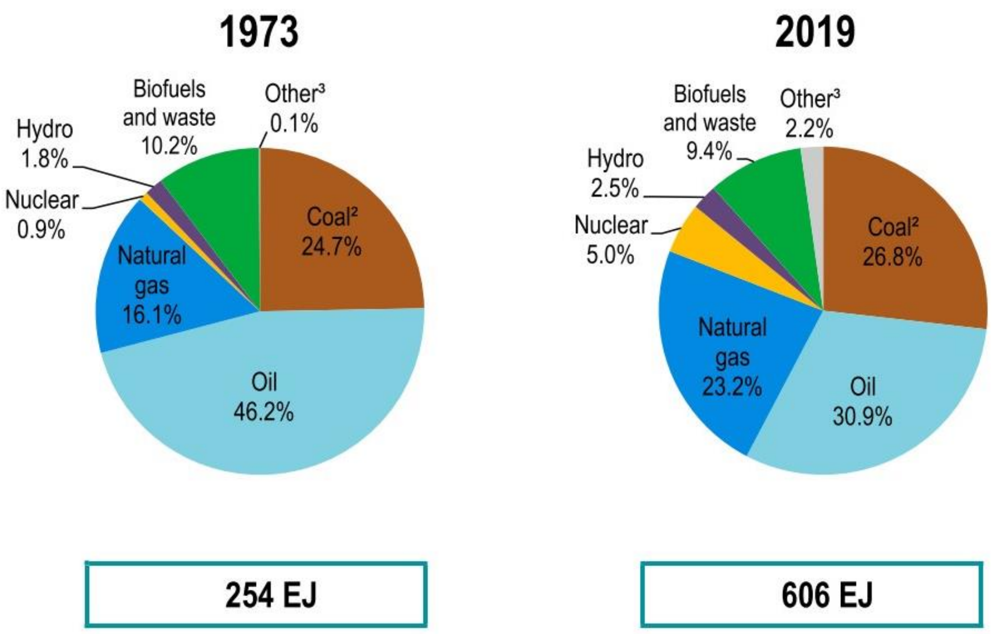


Figure 2.2: The world's total energy supply sources and their percentages in total consumption (in exajoules) [8].

Fossil fuel reserves are limited, can require outsourcing because of the absence, and they may run out in the future. These emergencies obligate the countries to take precautions to decrease the negative environmental and economic effects of fossil fuel usage. Renewable energy sources can decrease this fossil fuels rate in the total energy generation. Their utilization also has much fewer negative consequences both on the environment and economies.

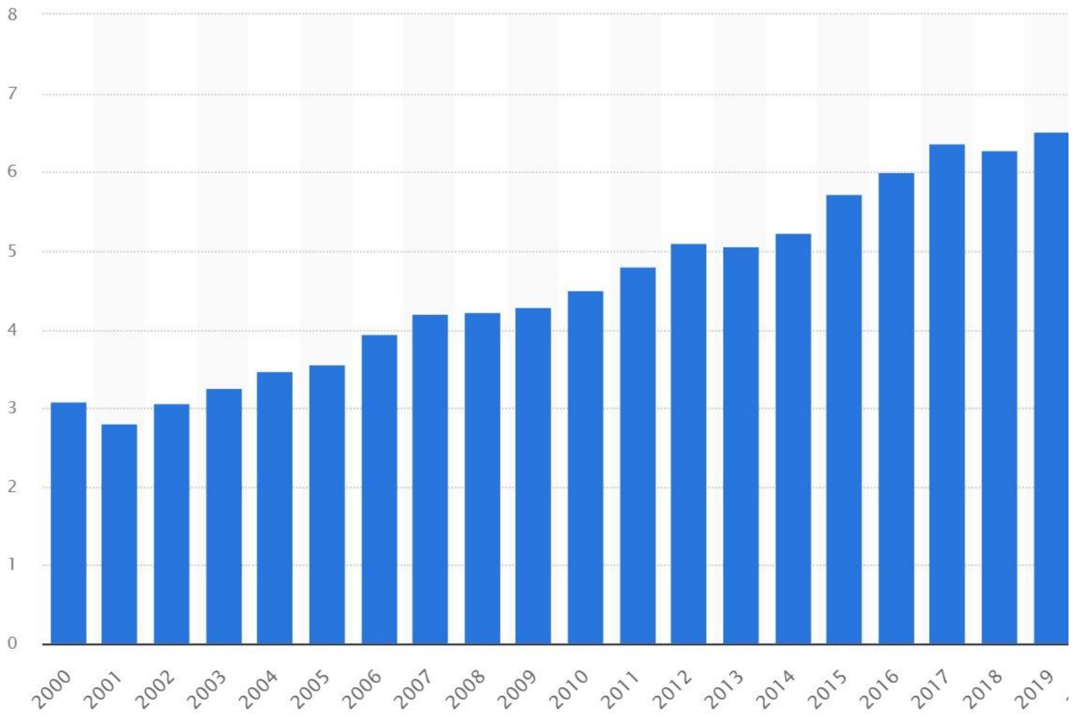


Figure 2.3: The energy consumption of Turkey between 2000 and 2019 (in exajoules) [9].

2.2 Biogas as an Inseparable Part of Renewable Energy

In recent years, the search for new and renewable energy source technologies has significantly increased in the world and our country because of its decreasing effect on climate change while contributing to economic growth by creating new working opportunities. Several sources are used as renewable energy sources such as biomass, hydroelectric, geothermal, wind, and solar [11,12]. These sources generate a more secure and diverse energy supply to the world.

The production of biogas from organic wastes is considered an effective and alternative way of producing energy [11]. When biogas energy potential is considered, it is seen that there are lots of agricultural biomass in the world [13]. The same situation is situated for Turkey too. Agricultural biomass and livestock manure are important and suitable sources for biogas production with a big market share of agricultural activities in the national economy. Besides these benefits, livestock manure utilization for biogas production is an effective way of livestock manure management. In this way, the water, soil, and air contamination from unregulated biomass applications are prevented [14].

While renewable energy needs increases day by day, biogas energy technology can meet some parts of energy needs efficiently. For example, it is calculated by Polpraser [15] that 1 m^3 of biogas combustion is enough to:

- work an engine with a 0,73 KW for two hours,
- generate 1,25 kWh electricity
- generate heat for cooking 3 times a day for five persons
- generate light equivalent for 6 hours with 60 W lamp
- operate a cooler with a capacity of 1 m^3 for one hour
- operate an incubator with a capacity of 1 m^3 for half-hour.

All these reasons clearly state that the technologies for the energy generation from organic wastes like livestock manure or agricultural biomass have significant importance and biogas production is an inseparable part of this energy generation process.

2.2.1 The Definition and Components of Biogas

Biogas is essentially a combustive mixture of gasses. This mixture is obtained by the degradation of organic materials such as livestock manure, crops, wastes, etc. under anaerobic conditions as a result of biochemical fermentation and microbiological activity and it is %20 lighter than air. The calorific value of biogas is 21 MJ/m^3 [16,17].

There is a diversity in biogas components. For instance, the biogas which is obtained by sewage digester generally consists of %35-45 carbon dioxide (CO_2), %55-60 methane (CH_4), lesser than %1 nitrogen (N). On the other hand, the biogas from organic waste mainly consists of %30-40 carbon dioxide, %60-70 methane, lesser than %1 nitrogen (N_2). The landfills biogas usually consists of %30-40 carbon dioxide, %45-55 methane, %5-15 nitrogen. With these components, there are also aromatic compounds, hydrogen sulfide, siloxane, and halogenated compounds [18]. The components and the average percentages of biogas components are given in Table 2.1 [19]. The last two components can observe more commonly in landfill biogas than biogas from the anaerobic digestion of livestock manure [18]. The CO_2 and CH_4 percentages of biogas from organic waste are demonstrated in Figure 2.4.

Table 2.1: Ranges of Components of Biogas [18].

	Chemical Symbol	Anaerobic Digester Biogas	Landfill Biogas
Density (kg/m^3)	-	1.1	1.3
Relative density (air =1.0)	-	0.9	1.1
Methane (%)	CH_4	60-70	35-65
Heavy hydrocarbons	-	0	0
Hydrogen (%)	H_2	0	0-3
Carbon dioxide (%)	CO_2	30-40	15-40
Nitrogen (%)	N_2	-	5-40
Oxygen (%)	O_2	-	0-5
Hydrogen sulfide (Ppm)	H_2S	0-400	0-100
Ammonia (Ppm)	NH_3	100	5
Total chlorine (Ppm)	Cl	0-5	20-200

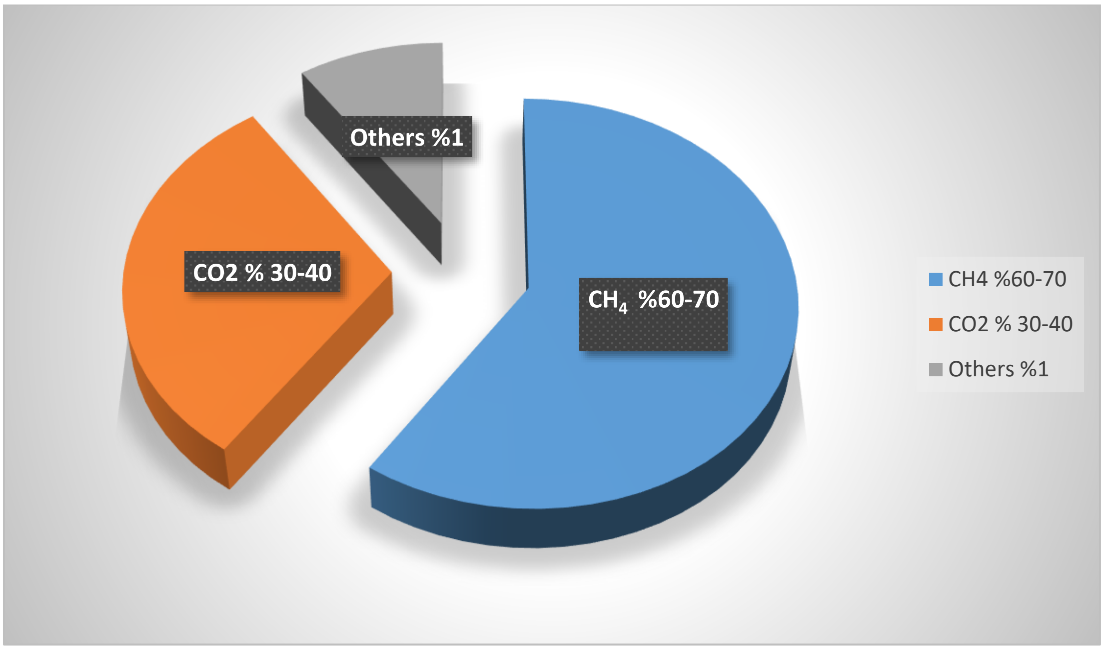


Figure 2.4: The CH_4 and CO_2 percentages of biogas from organic waste

2.2.2 The Technical Properties of Biogas

Biogas has lesser energy contents than other energy sources which are gas formed except hydrogen. Since it is lighter than air, it does not precipitate to the bottom. With this property, it can easily mix with the air, and this reduces the risk of an explosion. The combustion velocity of biogas is low with 0,25 m/s in the air because of the low CO_2 value. It needs to be at least %5 percent in the air to combustion. But %30 percent is preferred to ensure the ideal combustion [20].

The combustion of biogas produces water vapor, carbon dioxide, sulfur dioxide, carbon monoxide, nitrogen oxides, and carbon black. The energy equations of 1 m^3 of biogas are given in Table 2.2 [21].

Biogas is colorless and odorless. While biogas is like other gases in terms of combustion and calorific values because of the methane it contains, it is different in physical properties from propane and butane gases. For the same amounts, the energy generation of biogas is 2/3 of natural gas. The comparison of biogas with natural gas is given in Table 2.3 [22].

Table 2.2: The energy equations of 1 m^3 of biogas [21].

1 m^3 biogas =	0.66 lt diesel fuel	0.75 lt gasoline
	0.25 m^3 propane	0,2 m^3 butane
	0,85 kg coal	0.62 lt gas oil
	1.46 kg wood charcoal	3.47 wood
	4.70 kWh electricity energy	12.3 kg cowpat

Table 2.3: The comparison of biogas with natural gas [22].

Properties	Biogas	Natural Gas
Composition volume percentage (%)	55-65	95-98
Molecular weight (kg/mol.kg)	26.18	16.04
Density (k/m^3)	0.82	1.21
Calorific value (MJ/m^3)	21.48	36.14
Max combustion speed (m/s)	0,25	0,39

The amount of methane gas in the biogas is high if the waiting period is long in the process. Besides this, the methane amount of biogas depends on carbohydrates, fats, and proteins of feedstock as shown in Table 2.4 [19]. Shorts period for generating biogas brings methane gas less than %50 and this causes short combustion time. On the other hand, the liquefaction of biogas is not feasible economically. While propane, butane, etc. gases liquefaction occurs in the terms of room temperature and low pressure, biogas needs high temperature and pressure values for liquefaction. As a result of these non-feasibility conditions of liquefaction, biogas utilization needs to be in the same place where it is generated, or it needs to carry with pipes [20].

Table 2.4: The methane amount of different feedstocks [19].

Feedstock Type	Methane (%)	Biogas (m^3/t fresh feedstock)
Liquid pig manure	68	28
Liquid cattle manure	60	25
Distillers' grains with soluble	61	40
Pig manure	60	60
Cattle manure	60	45
Poultry manure	60	80
Organic waste	61	100
Beet	53	88
Forage beet	51	111
Sweet sorghum	54	108
Corn silage	52	202
Grass silage	54	172

2.2.3 Production of Biogas

Unlike the other combustible gases like natural gas, biogas is produced only from organic materials. The main materials as a feedstock used in the production of biogas such as livestock manure, agricultural biomass, industrial organic waste, municipal organic waste, harvest residues are shown in Figure 2.5 [23].

The usage of organic wastes in the biogas production process is an effective way of waste management in the terms of waste disposal and at the same time obtaining energy from waste. With this effective waste management, it is ensured that the fertilizer gain into the soil mature earlier within the fermentation period and this is increases productivity in agricultural areas [24].

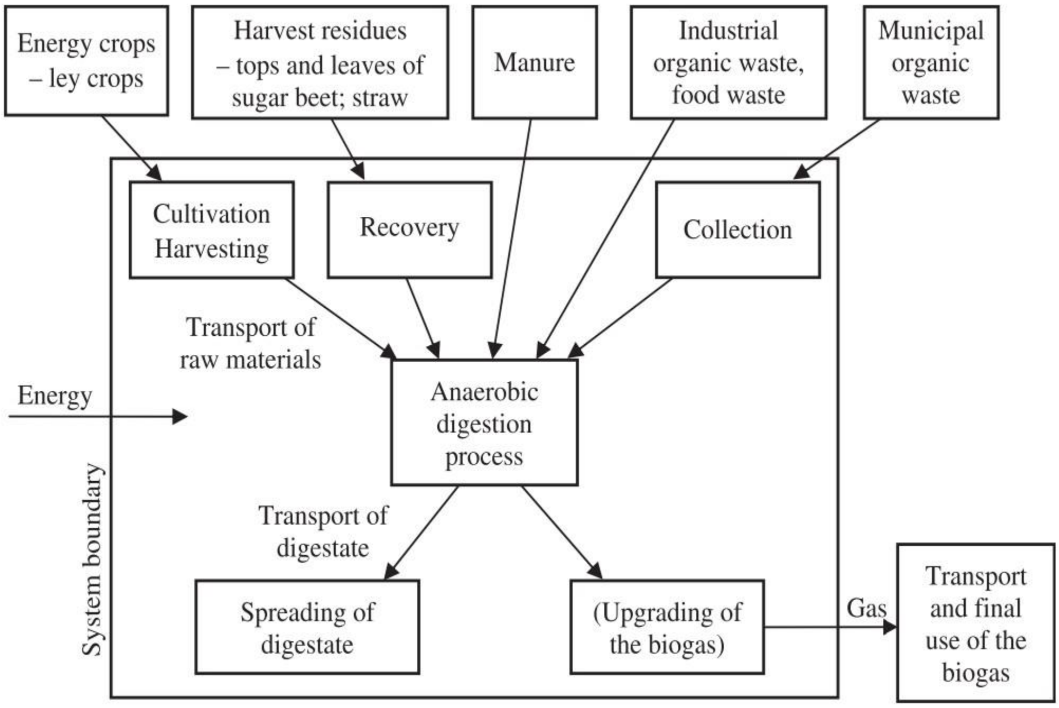


Figure 2.5: General view of the biogas system [23].

Biogas production depends on the existence of four main compounds. These components are organic material, microorganisms, anaerobic environment, and heat [25]. Organic material is the substance of the microorganisms for methane production. The most important resources for these organic materials are husbandry and agricultural activities.

The transaction for the biogas production that occurs as a result of all several steps is called anaerobic digestion. Degradation of organic wastes happens with anaerobic digestion under anaerobic conditions by microorganisms. This biogas production has an integrated system in which four consecutive steps. As can be shown in Figure 2.6., the biological stages of anaerobic digestion are named hydrolysis, acidogenesis, acetogenesis, and methanogenesis [26]. As seen with these steps, there are important main factors in biogas production. These can be defined as:

- Time of retention,
- Composition of sublayer,
- Digester temperature,
- Working pressure of the digester,
- Volatile fatty acids,
- pH of the fermentation [27].

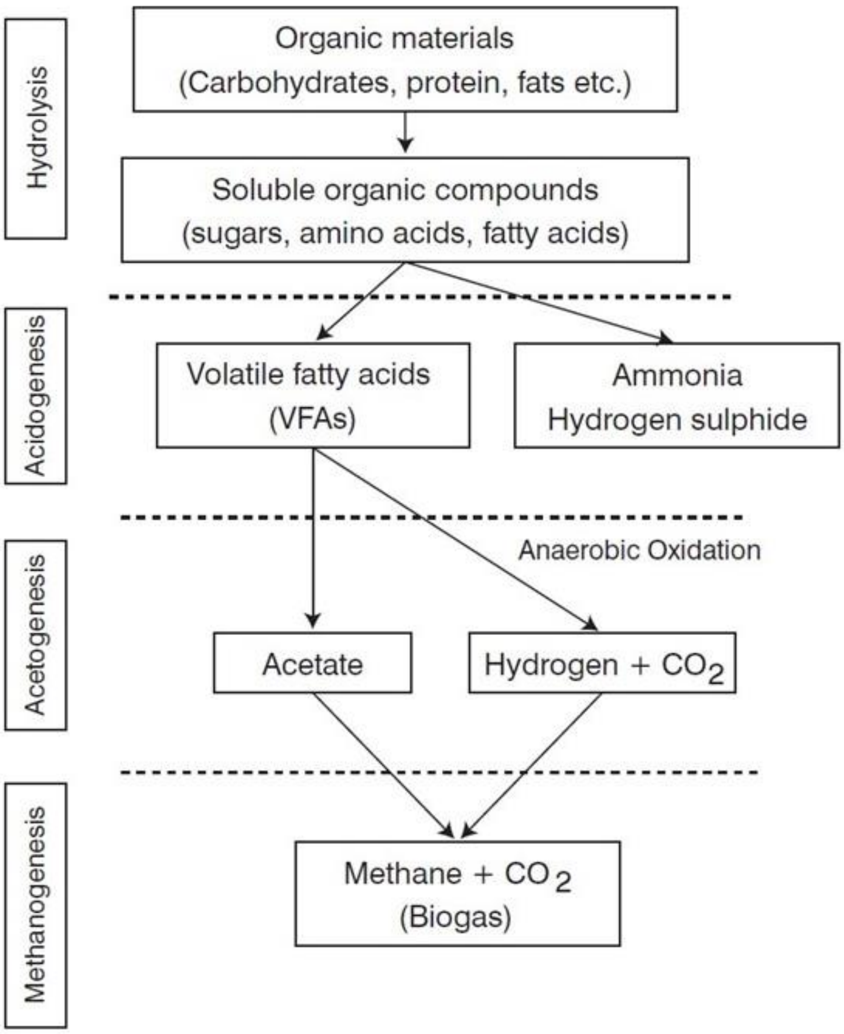


Figure 2.6: The biogas production process [26].

2.2.3.1 Hydrolysis

Hydrolysis is the first step of the anaerobic digestion process. Generally, biomass is the total of the complex organic polymers. In this step, the decomposition of organic polymers to the soluble, simple monomers is occurred by hydrolytic microorganisms such as amylase, lipase, protease, and cellulase throughout extracellular enzymes [28]. This decomposition creates evaporative more simple organic materials. At this stage, carbohydrates such as cellulose, hemicellulose, lignin are converted to the smaller monomer glucose, pentose, and hexose. On the other hand, proteins turn into a polypeptide, amino acids, and fats also are broken down into alcohol, fatty acids, and hydrogen. While the processing time about hydrolysis of carbohydrates can take an average of 5 hours, the hydrolysis of lipids and proteins can occur within a few days. Decomposition of lignin and lignocellulose is very slow, and it cannot occur completely [29]. The important factors affecting the rate of hydrolysis are pH, temperature [30].

2.2.3.2 Acidogenesis

After decomposition of polymers such as fat, carbohydrate, and protein into smaller monomers by anaerobic microorganisms occurs in hydrolysis, in the acidogenesis step these monomers are degraded to short-chain organic acids, alcohols, C1-C5 molecules, carbon dioxide, and hydrogen [29].

2.2.3.3 Acetogenesis

The result products of the acidogenic step are used as the substrate for the microorganisms of the third acetogenesis step. In the acetogenic step, endergonic reactions occur [29]. Acetogenic microorganisms convert fatty acids into acetate, hydrogen, and carbon dioxide [28]. These microorganisms necessarily produce H_2. They can only get the energy they need to live and grow at very low hydrogen concentrations. When there is a low hydrogen partial pressure; hydrogen, carbon dioxide, and acetate are formed by acetogenic bacteria. At high hydrogen partial pressure, ethanol is formed mainly with butyric, Capron, propionic, and valeric acids. From these products, methanogenic microorganisms can only use acetate, hydrogen, and carbon dioxide [29].

2.2.3.4 Methanogenesis

The methanogenesis step is the final step of the anaerobic digestion process. In this step, methane gases occur under very high anaerobic conditions. The resulting step is categorized as an exergonic reaction [29]. Firstly, acetic acids, hydrogen, and carbon dioxide are converted to methane by absolute anaerobic methanogenic bacteria. As can be seen in equation 2.1., hydrogen-utilizing methanogens produce methane from hydrogen and carbon dioxide, while acetolactic methane formers decompose acetic acid into methane. While %30 of the methane comes from the conversion of carbon dioxide and hydrogen, the main part of methane as %70 is generated from acetate [19].

$$Acetic\ acid \xrightarrow{\text{Methanogenic bacteria}} methane + carbon\ dioxide$$

$$Hydrogen + carbon\ dixoide \xrightarrow{\text{Methanogenic bacteria}} methane + water \qquad (2.1)$$

The most critical step is the methanogenesis in the anaerobic digestion process with the reason of the being slowest reaction of the process. Operation conditions influence this step. Overloading of the digester, a large amount of oxygen entering, or sudden temperature changes can cause the termination of methane production [19].

2.2.4 The Utilization of Biogas Energy

Biogas has great usage potential as an energy source within local demand. It can be used in the generation of electricity through micro turbines or fuel cells. On the other hand, with the direct combustion of biogas, it can be used for heating, CHP generation, or can be used as fuel for vehicles. A general overview of biogas utilization is shown in Figure 2.7. [19].

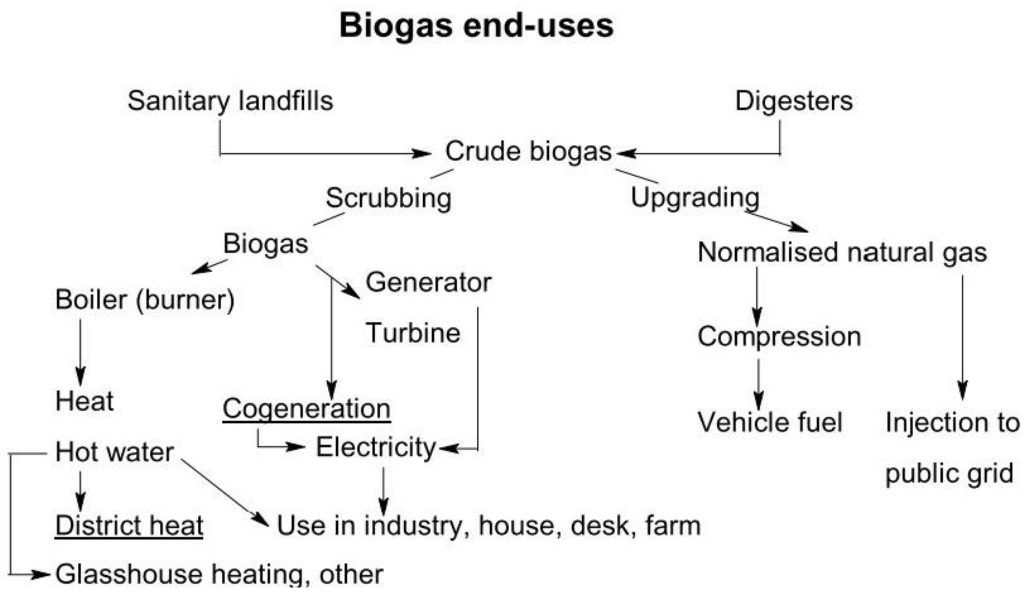


Figure 2.7: General overview of biogas utilization [19].

2.3 Literature

Biogas potential depends on feedstock availability, which is geographically dispersed. Therefore, most of the previous studies involve spatial analysis. Studies considering spatial and temporal aspects together are rare in the literature. Yalcinkaya [31], for example, investigated the siting, sizing, and economic feasibility of management of livestock manure and organic fraction of municipal solid waste (OFMSW) through biogas plants in Izmir, Turkey. In this study, a stepwise methodology was performed. First, a land suitability analysis was conducted to determine the potential biogas plant sites. Then, a location-allocation analysis was conducted to determine the relationship between the number of biogas plants, and plant location, capacity, and transportation distances. Finally, an economic assessment was performed to determine the optimum solution out of the potentials. The most recent annual average feedstock availability and collection of all livestock manure and OFMSW were considered in this study.

Sharma et al. [32] developed a geographic information system (GIS) based spatial model for identifying suitable sites and capacities for bioethanol plants throughout the US. Energy crops, switchgrass, miscanthus, and corn stover, were considered as feedstock. Feedstock availability was calculated using a crop growth and production model.

A 64 km radius buffer zone was used in the determination of available feedstocks. Valenti et al. [33]) also conducted a GIS-based spatial analysis for siting and sizing of potential regional biogas plants in Sicily, Italy. Agricultural residues, including livestock manure, and food wastes were used as feedstock. A 45 km radius buffer zone was defined as the biogas plant service area. Spatial analysis results were used in the economic assessment of the proposed biogas plant investments.

A GIS-based land suitability model was developed by Zareei [34] for determining the suitable locations of potential biogas plants in Iran. Rural household waste and livestock manure were used as feedstock in this study. The spatial density of theoretical biogas potential was determined at province scale (31 provinces) and utilized as a preference factor in the model.

Sliz-Szkliniarz and Vogt [35] conducted a GIS-based spatial analysis for the assessment of biogas potential from selected crops and livestock manure at Kujawsko-Pomorskie Voivodeship in Poland. Poland set ambitious goals for increasing biogas power starting in 2010. The study was aimed to provide insights into the economic feasibility of biogas plant installation, to evaluate the incentives to encourage biogas development and to determine the amount of biogas feedstock within reasonable collection distances that make the system economically sustainable.

Rios and Kaltschmitt [36] performed statistical and GIS-based spatial analyses for the calculation of electricity generation potential from biogas in Mexico. Municipal solid waste, industrial and municipal wastewater, and livestock manure were utilized as feedstock. The study was also aimed to identify the most promising municipalities (2,454 municipalities) for electricity generation from biogas.

Venier and Yabar [37] applied consecutive GIS-based land suitability and spatial cluster analyses for the determination of biogas energy potential from cattle manure in the Buenos Aires Province of Argentina. Siting and sizing of potential biogas plants were identified considering the economically feasible transportation distances.

Díaz-Vázquez et al. [38] targeted a similar goal to this thesis which is developing a replicable GIS-based approach to identify priority sites for biogas plants to provide an environmentally sustainable livestock manure management. Similar to Venier and Yabar [37], Díaz-Vázquez et al. [38] were also applied consecutive GIS-based land suitability and spatial cluster analyses. Priority sites were identified based on clusters of nitrogen and phosphorous recovery and energy generation from livestock manure were identified in the Jalisco State of Mexico.

Investigation of energy potentials from livestock manure in Turkey gained attention after the increase of feed-in tariff for renewable energy in 2011. Ekinci et al. [39] and Avcioğlu and Türker [40] conducted one of the first studies on this subject. They estimated province-scale biogas potentials from 2009 livestock manure data.

Karaca [41], and Ersoy and Ugurlu [42] investigated spatial distribution and magnitude of energy potentials from poultry and dairy cattle manure, and all livestock manure, respectively. Both studies conducted GIS-based analyses using 2015 livestock data at province (81 provinces) scale in Turkey.

Melikoglu and Menekse [43] on the other hand, forecasted Turkey's energy generation potential from sheep and cattle manure regardless of spatial distribution from 2018 to 2026. They utilized the historical data on per capita milk production and meat consumption for the estimation of the livestock population.

Chapter 3

Materials and Methods

The methodology of this study consists of four consecutive steps: data collection for the calculation of biogas production from livestock manure (1), geodatabase design and generation for spatiotemporal analyses (2), spatiotemporal pattern mining of biogas potential from livestock manure (3), and economic assessment of potential biogas plants (4). The step-by-step methodology is demonstrated in Fig 3.1.

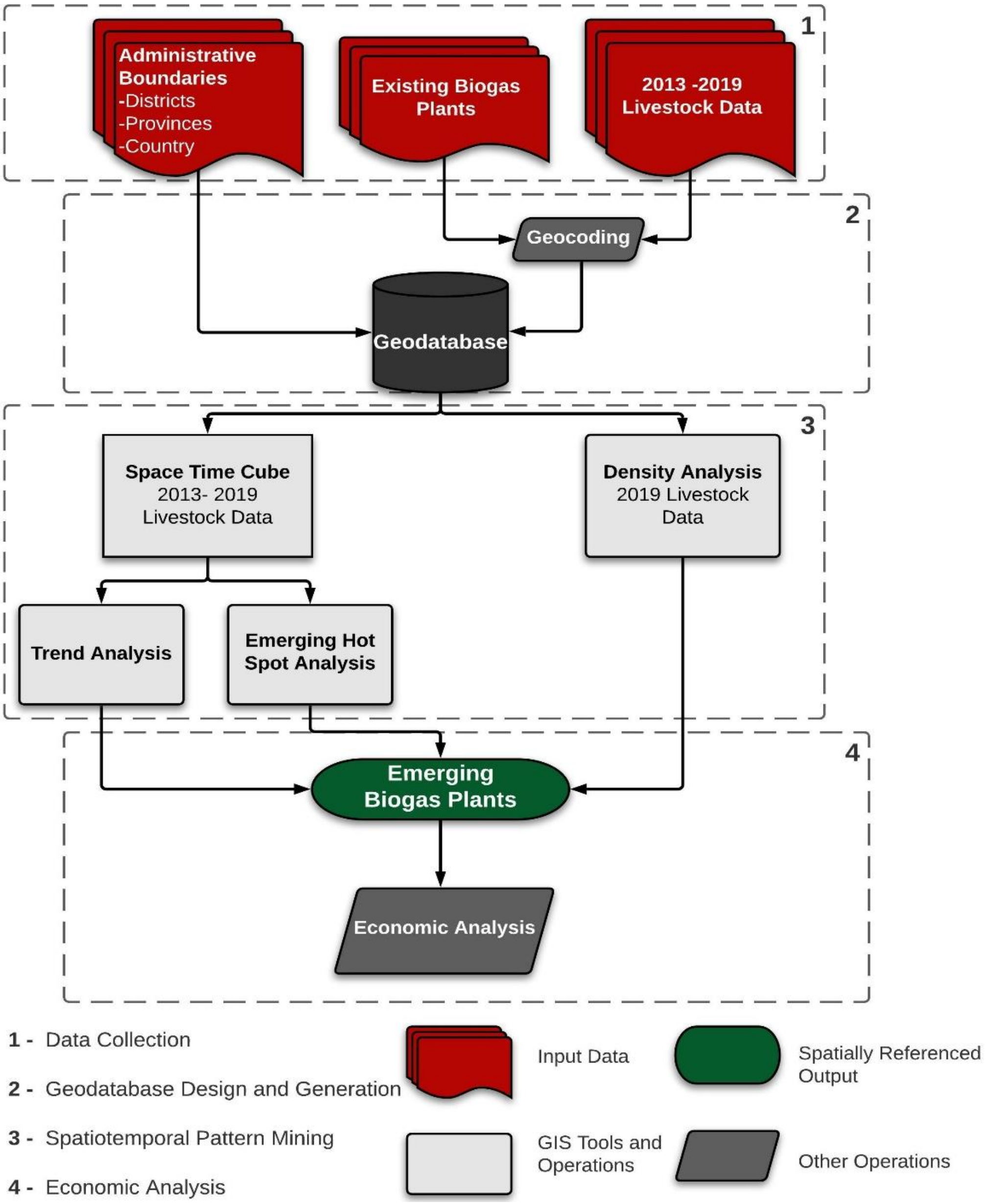


Figure 3.1: Demonstration of the step-by-step methodology.

3.1 Study Area

Turkey is located between Asia and Europe as shown in Figure 3.2. continents with a 780,043 km^2 surface area. There are 81 provinces and 970 districts in Turkey [44]. The area of districts ranges between 4,036 km^2 and 7 km^2, while the average district area is approximately 802 km^2 [45].

Figure 3.2: The study area located in the world.

According to the 2020 population census, Turkey's population is approximately 83.6 million. The population is significantly high in the northwest of the country, which causes high urbanization, while the northeast region is the least populated [46]. Turkey has the highest livestock population in Europe with 17.221 million bovine animals, 33.678 million sheep, and 10.635 million goats, and it comes second in the poultry population [47]. Bovine animal, sheep and goat, and poultry population increased by 23%, 26%, and 29% between the spatiotemporal analysis time range of the present study, 2013 and 2019, respectively [48]. However, Turkey, with only 72 active biogas plants (63 utilize livestock manure as feedstock), is listed towards the end of the list of the number of biogas plants in Europe [2,3]. The plant power capacities range between 0.24 and 15.25 MWe, while the average capacity is 3.71 MWe. The study area and the existing biogas plants utilizing livestock manure are shown in Figure 3.3.

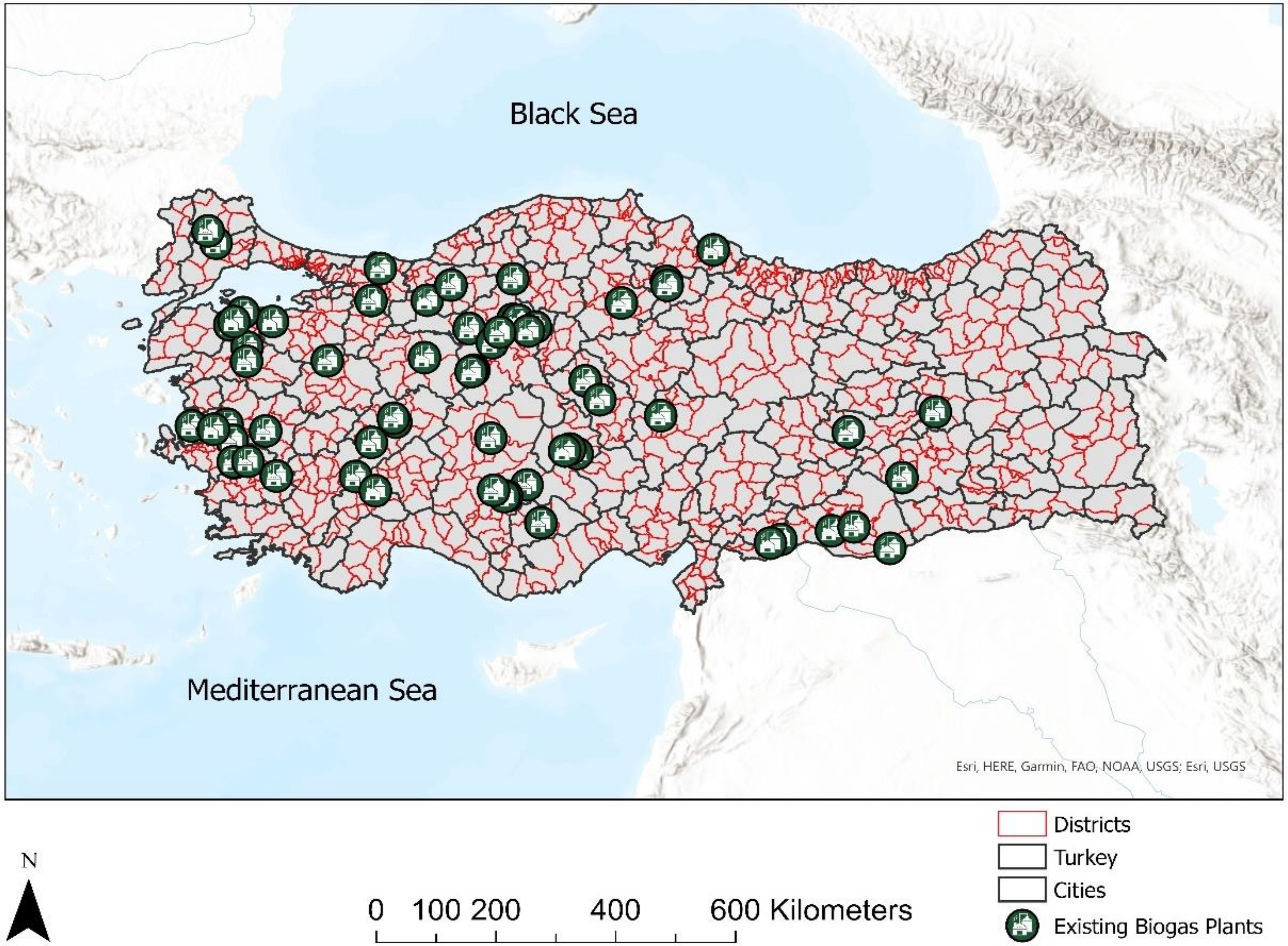


Figure 3.3.: Demonstration of the study area and the existing biogas plants.

3.2 Data Collection and Geodatabase Design and Generation

The first step of the methodology is data collection and geodatabase design and generation. District level livestock and poultry population data were obtained from the Turkish Statistical Institute for 7 years, between 2013 and 2019 [46].

The data was obtained in 63 different categories based on type, age, and gender of animals in tabular format. Livestock categories and their weekly manure production rates are presented in Table 3.1. [49].

Table 3.1: Weekly slurry production rates.

Livestock	Slurry (m^3/week)
Dairy Cattle (6.000 L/year milk production)	0.33
Dairy Cattle (3.000 L/year milk production)	0.29
Cattle>2 years	0.26
Cattle (18-24 months)	0.26
Cattle (12-18 months)	0.15
Cattle (6-12 months)	0.15
Cattle (0-6 months)	0.08
Goat	0.02
Sheep	0.03
Lamb (baby sheep)	0.01
Poultry - 1000	0.81

Livestock manure represents manure from bovine animals, sheep and goat, and poultry in this study. Livestock manure production, biogas production, energy generation, and power capacities were calculated from livestock population data, as explained in the following section. Administrative boundaries at nation, province, and district levels were obtained from the General Directorate of Mapping in vector format [50]. Tabular livestock data was converted into georeferenced data by associating each district with its livestock population, manure production, biogas production, energy generation, and power capacities. 13-time steps were established for each district (2 periods for each year). Existing biogas plants and their locations were gathered from the Energy Market Regulatory Authority [51]. The ArcGIS Pro software version 2.7 was used to create the geodatabase, process data, create a space-time cube, and perform trend analysis, emerging hot spot analysis, and density analysis. All data were transformed to World Geodetic System 1984 (WGS 1984) Universal Traverse Mercator (UTM) Zone 35 projected coordinate system to preserve the integrity of the spatiotemporal analyses. Data types and sources used in this study are presented in Table 3.2.

Table 3.2: Data types and sources

Data Type	Source
Administrative boundaries	General Directorate of Mapping [50]
Livestock data	Turkish Statistical Institute [48]
Existing biogas plants data	Energy Market Regulatory Authority [51]

3.3 Spatiotemporal Pattern Mining of Energy Potential from Livestock Manure

3.3.1 Energy Potential from livestock manure

Equations and parameters to estimate energy potentials were adopted from Yalcinkaya [31]. Energy potential from livestock manure was calculated using Equation (3.1), as follows:

$$Energy\ Potential_{LM} = \sum_{i=1}^{n} \sum_{j=1}^{m} H_{ij} \times S_{TS_J} \times M_{LM_j} \times \alpha_j \times D \times Q_M \times \eta \times \frac{1}{7} \frac{week}{day} \tag{3.1}$$

where H (ton/year) represents the amount of the livestock manure; i and j are indexed for district and livestock type, respectively; n is the total number of districts; m is the total number of livestock type; S_{TS} is the total solid content (kg TS/kg manure); M_{LM} indicates the methane generation per unit of total solids (m^3 CH_4/kg TS); D is the average manure density (kg/m^3); α is the collectible livestock manure, Q_M is lower heating value for methane (MJ/m^3), and η is the electrical energy conversion efficiency [31]. S_{TS} and M_{LM} values vary depending on the type of livestock, therefore indexed by j. D values were reported between 1009 and 1041 kg/m^3 for bovine animals, sheep and goat, and poultry by Lorimor et al. [52]. D was taken as 1000 kg/m^3 for all livestock manure in this study. Q_M was taken as 37.2 MJ/m^3 [53]. η for electrical energy generation from biogas by internal combustion engines was reported between 38 % and 46% by the manufacturer (General Electric, 2018). η was taken as 0.4 (40%) in this study. H_{ij} was calculated by multiplying the amount of each livestock type and the weekly manure production rate reported in Table 3.1 [49].

Yalcinkaya [31] conducted field studies in Izmir, Turkey, and determined that collectible livestock manure (α) values vary depending on the scale of facilities. In large industrial farms where animals are kept in closed areas the manure collection rate is close to the theoretical level (where α=0.99), while most of the livestock manure cannot be collected due to the insufficient infrastructure in small enterprises. In this case, the α value is approximately 0.5 for cattle, sheep, and goats. High rates were observed (α = 0.99) at poultry facilities which are generally well-equipped large facilities. Because the new regulation will be in charge by the end of 2021, theoretical energy potentials with high collection rates (α = 0.99) were also considered in the following spatiotemporal analyses. Finally, energy potentials for each district were converted into installed power capacities in MWe units. M_{LM}, S_{TS}, and α values for different livestock animals are given in Table 3.3.

Table 3.3: Methane generation per unit of total solids (M_{LM}), total solids content (S_{TS}), and collectible part of the total livestock manure (α) for different livestock types a ([53]), b ([54]), c ([31]).

Livestock	M_{LM} [a] (m^3 CH_4/kg TS)	S_{TS} [a] (kg TS/kg manure)	α
Dairy Cattle > 24 months	0.14	0.11	0.5 [c]
Cattle > 24 months	0.14	0.11	0.5 [c]
Cattle 12-14 months	0.14	0.15	0.5 [c]
Cattle < 12 months	0.14	0.15	0.5 [c]
Sheep	0.11	0.23	0.5 [b]
Goat	0.07	0.32	0.5 [b]
Poultry	0.19	0.16	0.99 [c]

District level density analyses were conducted using the most recent livestock data in 2019. The spatial distribution and magnitude of livestock manure were investigated. Density analyses were performed for both theoretical and collectible livestock manure.

3.3.2 Spatiotemporal Pattern Mining

The first step of spatiotemporal analyses is to create a space-time cube. A space-time cube consists of bins over constant locations. Each bin contains temporal data for those defined locations and may accumulate on top of each other for a designed time. By creating a space-time cube spatiotemporal data is stored into a netCDF data structure which allows to visualize and analyze spatiotemporal data in GIS software. In our case, there are 970 spatial variables (districts) that do not change over time and 13 temporal variables (livestock data 2 periods per year for 7 years). The number of data and statistics (sum, mean, median, minimum, maximum, and standard deviation) are calculated for every bin of the defined location cube.

Mann-Kendall trend test was used in trend analysis to determine the temporal trend of bin values at each defined location. In the Mann-Kendall trend test, bin values and their time sequence are analyzed with rank correlation. The first bin value of a defined location is compared to the second bin value. The result becomes +1 if the second bin value is larger than the first bin value. The result becomes -1 if the second bin value is smaller than the first bin value. The result becomes 0 if the first and second bin values are equal. Every bin value is compared to its successive bin value and the results are summed. If the sum is zero, which is the expected result, it means that there is no temporal trend in the variable for the defined location. To determine the statistical significance of the difference, the calculated sum and the expected sum are compared. Z-scores (standard deviation) and p-values (probability) are used to determine the statistical significance of the bin time series' trends. The trend with a small p-value is statistically significant. If the trend is increasing, it has a positive z-score, and if it is decreasing it has a negative z-score [55].

Besides trend analysis for temporal trends and density analysis for the magnitude of the variable, emerging hot spot analysis was conducted to determine the locations that require the highest attention or priority in a decision-making process. Emerging hot spot analysis classifies each defined location into new, consecutive, intensifying, persistent, diminishing, sporadic, oscillating, and historical hot and cold spots based on patterns detected over time and space. It might also detect no pattern. The space-time cube in the netCDF data structure is used as input for the emerging hot spot analysis. First, Getis-Ord Gi* statistic is calculated for each bin to determine the intensity of clusters for high and low values. Every bin is compared with its neighboring space-time bins to assess whether its value contributes to a statistically significant hot or cold spot or not. A high bin value may not be a statistically significant hot spot unless it is surrounded by space-time bins, which also have high values. Two parameters, namely, neighborhood time step and neighborhood distance are inputted to describe the neighborhood of each bin [56]. A fixed neighborhood distance of 10 km and 70 km, and a time step of 1 (the current and preceding time periods) were set in this study. The impacts of selected neighborhood distances were evaluated in the results and discussion section. Following the Getis-Ord Gi* statistic calculations, the Mann-Kendall trend test is performed to determine whether these hot and cold spots are new, consecutive, intensifying, persistent, diminishing, sporadic, oscillating, or historical over time [57].

3.4 Economic Assessment

An economic assessment was conducted to evaluate the economic feasibility of biogas plants installation at the emerging hot spots. The economic assessment was conducted based on costs and revenues. District-level central biogas plants were considered in the economic assessment. Costs include investment costs (I), and operation and maintenance (O&M) costs, while electricity generation from biogas was considered as the revenue.

The unit costs were taken from the International Renewable Energy Agency reports [58]. The investment cost of biogas plants was reported between 2,574 and 6,104 $/kW. The average reported value of 4,339 $/kW was used in Equation 2. The investment cost includes feedstock handling and preparation machinery, construction, engineering, equipment, and planning costs. Operation and maintenance costs were classified into variable and fixed costs. Fixed O&M consists of scheduled maintenance, labor, insurance, and routine component/equipment replacement. 2.1 to 7% of investment cost was reported as the annual fixed O&M costs. Variable O&M costs are estimated based on the energy generation rate of the plant and were reported as 4.2 $ per MWh energy generation. Variable O&M costs include incremental servicing, unplanned maintenance, and equipment replacement costs. The installed capacity (x_p) and energy generation (x_e) were calculated using the most recent livestock data (2019) for each district in the density analysis. The cost equations (3.2-3.3) are given below:

$$Investment\ cost, I\ (\$)\ = 4339x_p(x_p, kW\ ) \tag{3.2}$$

$$O\&M\ cost\left(\frac{\$}{y}\right) = 0.045\ I + 4.2\ x_e(x_e, MWh\ ) \tag{3.3}$$

The annual cost (T_c) of a biogas plant was estimated using the equation (3.4):

$$T_c = Ia + O\&M$$

$$a\ = \frac{i\ (1+i\ )^{T}}{((1+i\ )^{T}-1\ )} \tag{3.4}$$

where T_C indicates the annual total cost (\$/y); α indicates the annuitization co-efficient; I represent the investment cost (\$); O&M represents operation and maintenance costs (\$/y); i stands for the discount rate; T indicates the lifetime of a biogas plant. A 20-year lifetime is generally considered for biogas plants [35,53,58] and 10% discount rate was taken [31,58].

The annual revenue from the electric energy generation at a biogas plant was estimated using the following equation (3.5):

$$T_R = KF\ \times\ IT\ \times\ P_e\ \times U_e \tag{3.5}$$

where T_R is the annual revenue collected due to electricity sale (\$/y); KF indicates the capacity factor for the power plant; IT indicates the rate of internal energy consumption; P_e is the annual electricity generation of a plant (kWh/y); U_e is the unit electric sale price \$/kWh. The capacity factor (KF) and rate of internal consumption (IT) were taken as 91.3% and 5%, respectively [59]. Annual electricity generation (Pe) was calculated using the most recent livestock data (2019) for each district in the density analysis. The net unit revenue from electricity generation (\$/kWh) was calculated by subtracting the costs from the revenue and diving the result by the total energy generation.

Chapter 4

Result and Discussion

Results of the spatiotemporal trend analyses, density analyses, opportunity analysis, impact analysis, and conclusion are given in this chapter respectively.

4.1 Spatiotemporal Trend Analyses

The spatiotemporal analyses of energy potential from livestock manure were conducted for 970 districts with 13-time steps (time steps of 6 months). Temporal trend analysis for energy potential at each district was measured using the Mann-Kendall trend test. An increasing trend was observed over the study area in general, which complies with the increase in livestock and poultry population between 2013 and 2019 as stated in the study area section. 532 districts were classified with a p-value of less than 0.1 while 529 of those are classified with a p-value less than 0.01. Low p-values indicate that rather than a random pattern, energy potentials across time exhibit a statistically significant increase for those 532 districts. Increasing trends were observed especially in the central and southeast regions of Turkey. Despite this positive trend, few active biogas plants are located in the central and the southeast regions. By increasing the number of active biogas plants, a sustainable method in the management of livestock manure will also be achieved in these regions. On the other hand, 113 districts exhibited decreasing trends. In addition, no particular trend of increase or decrease was observed in 328 districts. The results of temporal trend analysis are presented in Figure 4.1.

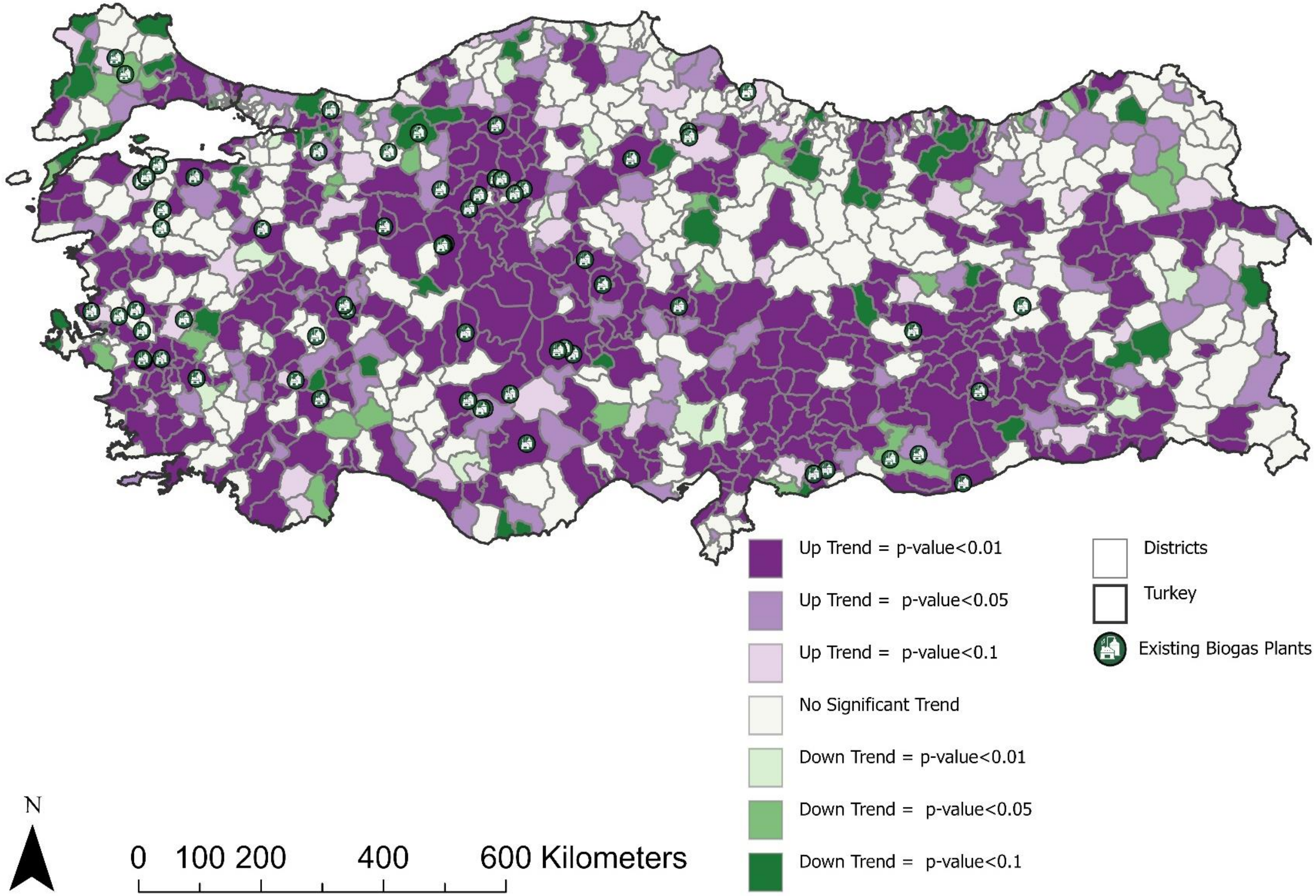


Figure 4.1: Temporal trend map of energy potential from livestock manure between 2013 and 2019 with the Mann-Kendall trend test.

Emerging hot spot analysis considers spatial distribution, magnitude, and temporal trends together; therefore, it provides better insights into the prioritization of districts for livestock manure management through biogas plants. Emerging hot spot analysis was conducted within fixed distances of 10 km and 70 km considering the transportation of livestock manure. Time step interval was defined as 1 which encompasses the analysis time step and one preceding time step. The resulting emerging hot spots map indicates the districts that require priority when planning to construct new biogas plants or expand the capacity of existing biogas plants. Since the maximum district radius is approximately 35 km (if districts are assumed to have circular shapes), emerging hot spot analysis was performed with 70 km neighborhood distance at first to allow every district has at least 1 neighbor (bin). It was observed that even if a district has high energy potential, it may not be pointed as a hot spot due to the surrounding districts within 70 km distance from its center. When the emerging hot spot analysis was conducted within the 10 km distance, all districts with high energy potentials were correctly specified as hot spots. Because most of the districts were evaluated within themselves when the neighborhood distance was less than 10 km. Transportation distance between feedstock sources and potential plant sites is one of the most important factors for the economically sustainable management of livestock manure through biogas plants. It was reported that if the transportation distance between livestock manure source and biogas plant is more than 20 km, it results in a negative energy inflow/outflow ratio [60]. Even with a 5 km distance, the ratio is over 60%. This indicates that biogas plants must be located close to feedstock sources if livestock manure is the feedstock. Therefore, further analyses were conducted within a 10 km distance band.

Emerging hot spot analysis with a 10 km distance band resulted in 66 emerging hot spots as shown in Table 4.1.

Table 4.1.: Districts defined as emerging hot spots.

Districts (Emerging Hot Spots)	City	Power Capacity Rank	Theoretical Installed Power Capacity, Mwe	Services Area Radius, km	Existing Biogas Plant Installed Power Capacity, Mwe	Capacity Expansion for the Existing Biogas Plants, Mwe	Number of Existing Plants
Central District	Aksaray	1	22.54	45.6	8.67	13.87	3
Siverek	Sanlıurfa	2	17.71	44.8			
Ödemis	Izmir	3	17.04	22.9	4.87	12.17	1
Tarsus	Mersin	4	16.38	31.9			
Eregli	Konya	5	16.01	33.6			
Central District	Igdır	6	14.19	26.2			
Tire	Izmir	7	13.32	19.2	9.07	4.25	2
Central District	Elazıg	8	12.64	34.2	0.24	12.40	1
Viransehir	Sanlıurfa	9	12.12	34.0			
Central District	Nigde	10	11.99	33.8			
Central District	Afyonkarahisar	11	11.82	25.7	12.42	-0.60	2
Meram	Konya	12	11.59	30.2	6.00	5.58	1

Table 4.1.: Districts defined as emerging hot spots (continued)

Districts (Emerging Hot Spots)	City	Power Capacity Rank	Theoretical Installed Power Capacity, Mwe	Services Area Radius, km	Existing Biogas Plant Installed Power Capacity, Mwe	Capacity Expansion for the Existing Biogas Plants, Mwe	Number of Existing Plants
Karapınar	Konya	13	11.54	36.6			
Central District	Kars	14	11.09	33.6			
Central District	Mus	15	11.05	38.0			
Dogubayazıt	Agrı	16	10.97	34.7			
Altıeylül	Balıkesir	17	10.77	22.6	3.20	7.56	1
Central District	Ardahan	18	10.75	26.6			
Bulanık	Mus	19	10.65	32.1			
Ergani	Diyarbakır	20	10.49	27.9			
Milas	Mugla	21	10.29	32.2			
Central District	Kırsehir	22	10.24	30.2	3.00	7.24	1
Karatay	Konya	23	10.18	38.1	3.00	7.18	1
Cumra	Konya	24	9.94	32.8	7.51	2.43	2

Table 4.1.: Districts defined as emerging hot spots (continued)

Districts (Emerging Hot Spots)	City	Power Capacity Rank	Theoretical Installed Power Capacity, Mwe	Services Area Radius, km	Existing Biogas Plant Installed Power Capacity, Mwe	Capacity Expansion for the Existing Biogas Plants, Mwe	Number of Existing Plants
Central District	Karaman	25	9.92	45.0	1.41	8.51	1
Polatlı	Ankara	26	9.89	43.5	9.97	-0.08	3
Derik	Mardin	27	9.75	26.4			
Salihli	Manisa	28	9.74	26.4	0.27	9.47	1
Central District	Agrı	29	9.67	30.3			
Cınar	Diyarbakır	30	9.49	31.0			
Biga	Canakkale	31	9.37	26.9			
Central District	Sivas	32	9.04	43.4			
Bayındır	Izmir	33	9.03	16.8			
Kiraz	Izmir	34	8.8	17.2			
Esme	Usak	35	8.77	24.5			
Gürpınar	Van	36	8.64	45.6			

Table 4.1.: Districts defined as emerging hot spots (continued)

Districts (Emerging Hot Spots)	City	Power Capacity Rank	Theoretical Installed Power Capacity, Mwe	Services Area Radius, km	Existing Biogas Plant Installed Power Capacity, Mwe	Capacity Expansion for the Existing Biogas Plants, Mwe	Number of Existing Plants
Karacabey	Bursa	37	8.49	25.3	6.40	2.08	1
Baglar	Diyarbakır	38	8.28	15.4			
Bigadic	Balıkesir	39	8.21	24.3			
Cine	Aydın	40	8.14	20.4			
Central District	Corum	41	8.07	36.6	6.02	2.05	1
Bergama	Izmir	42	8.05	28.6			
Kagızman	Kars	43	7.93	32.0			
Göle	Ardahan	44	7.89	26.8			
Sarıkamıs	Kars	45	7.77	33.4			
Karesi	Balıkesir	46	7.73	19.4	1.50	6.23	1
Idil	Sırnak	47	7.67	24.0			
Kocasinan	Kayseri	48	7.66	28.2	1.50	6.16	1

Table 4.1.: Districts defined as emerging hot spots (continued)

Districts (Emerging Hot Spots)	City	Power Capacity Rank	Theoretical Installed Power Capacity, Mwe	Services Area Radius, km	Existing Biogas Plant Installed Power Capacity, Mwe	Capacity Expansion for the Existing Biogas Plants, Mwe	Number of Existing Plants
Central District	Burdur	49	7.61	28.2	3.01	4.60	1
Selim	Kars	50	7.53	23.3			
Karayazı	Erzurum	51	7.3	32.4			
Cermik	Diyarbakır	52	7.28	22.1			
Civril	Denizli	53	7.26	28.5			
Mudurnu	Bolu	54	7.23	26.9	1.20	6.03	1
Silvan	Diyarbakır	55	7.18	25.4			
Acıpayam	Denizli	56	7.08	29.9			
Kemalpasa	Izmir	57	7.05	18.8	3.00	4.05	1
Central District	Bolu	58	6.99	29.9	2.30	4.69	1
Tekman	Erzurum	59	6.95	33.6			
Sehitkamil	Gaziantep	61	6.83	26.4			

Table 4.1.: Districts defined as emerging hot spots (continued)

Districts (Emerging Hot Spots)	City	Power Capacity Rank	Theoretical Installed Power Capacity, Mwe	Services Area Radius, km	Existing Biogas Plant Installed Power Capacity, Mwe	Capacity Expansion for the Existing Biogas Plants, Mwe	Number of Existing Plants
Bandırma	Balıkesir	63	6.71	25.5	2.13	4.58	1
Eskil	Aksaray	64	6.71	28.5			
Erciş	Van	65	6.66	20.4			
Cubuk	Ankara	68	6.54	29.7	6.02	0.52	2
Yüksekova	Hakkari	69	6.44	33.6			
Central District	Siirt	72	6.37	24.8			

The only district identified as the new hot spot is located in central Turkey. This district was never classified as a hot spot except for the last time step. 24 districts were classified as intensifying hot spots. High energy potentials through ninety percent of all time steps were calculated for these districts and the intensity of energy increased in each time step. Although the biogas potential is high, the most important region that does not have a biogas plant is again the eastern region. There are active biogas plants in most of the other regions. However, this number of biogas plants in these districts is insufficient when compared to the biogas potential of the regions. Consecutive hot spots are the most abundant hots spots with 25 districts. These districts have continuously high energy potentials over time. 8 districts were classified as persistent hot spots. They have high energy potentials over time but neither increasing nor decreasing temporal trends was observed. 7 districts were classified as sporadic hotspots. These districts have high energy potentials through less than 90 percent of all-time steps but never were a cold spot. The only diminishing hot spot is in the northwest. This district has significant energy potential in each time step, but the intensity of the energy potential has been decreasing. Cold spots were observed in the metropolitan areas of the northwest region (in Istanbul) as a result of urbanization. The emerging hot spots are presented in Figure 4.2.

Emerging hot spots analysis showed that Turkey has a significant biogas potential. This potential needs to be used in the management of livestock manure and energy production. Per this purpose, it should be developed depending on the characteristics of regions. At this point, the components of the biogas production process such as transportation and cost, which vary from region to region should be evaluated sustainably. As a result of these differences, a single planning system to be applied to all regions will not be effective on livestock manure management. The regulation on the livestock manure management and the energy needs are the major subjects as the priority of this planning of livestock manure.

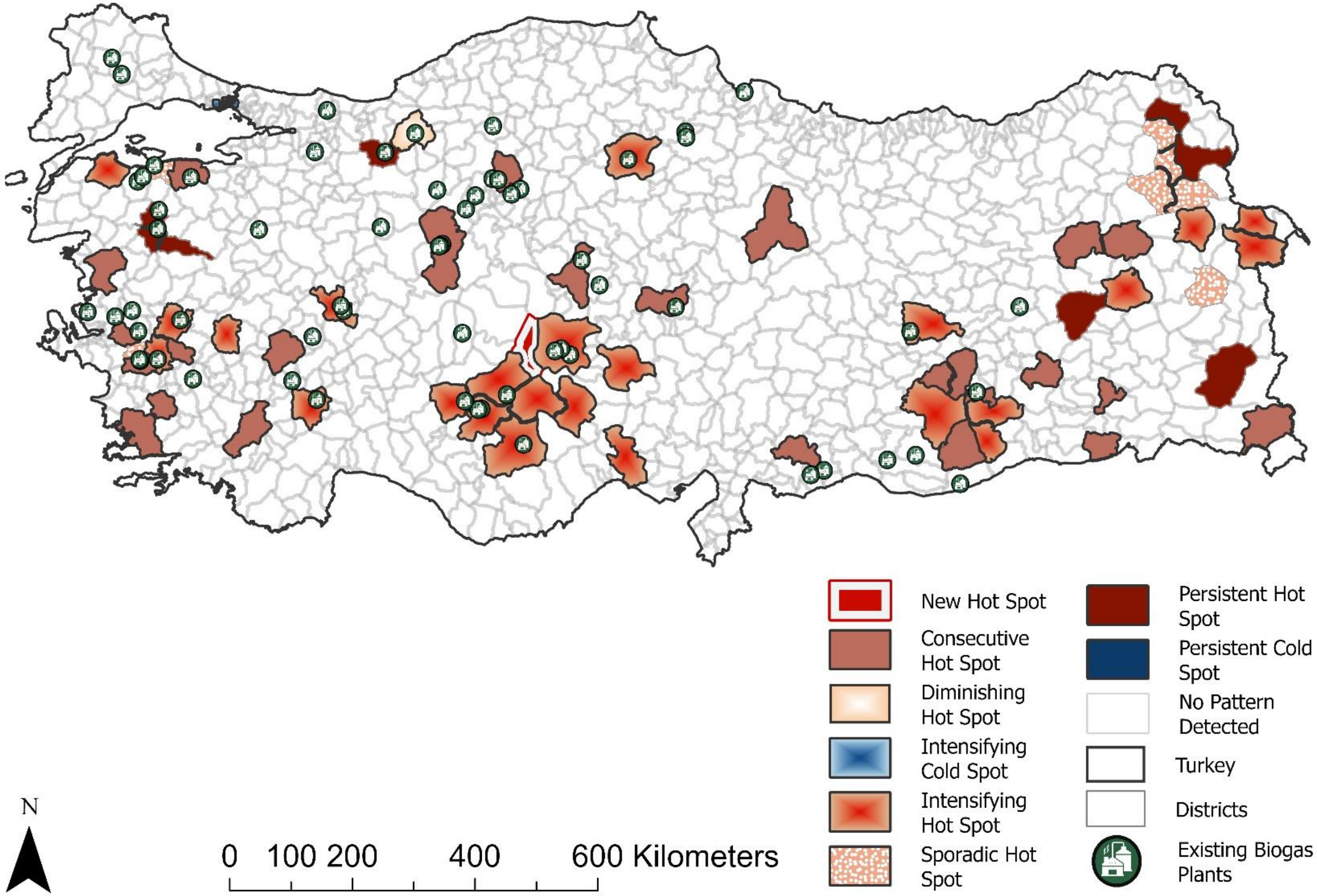
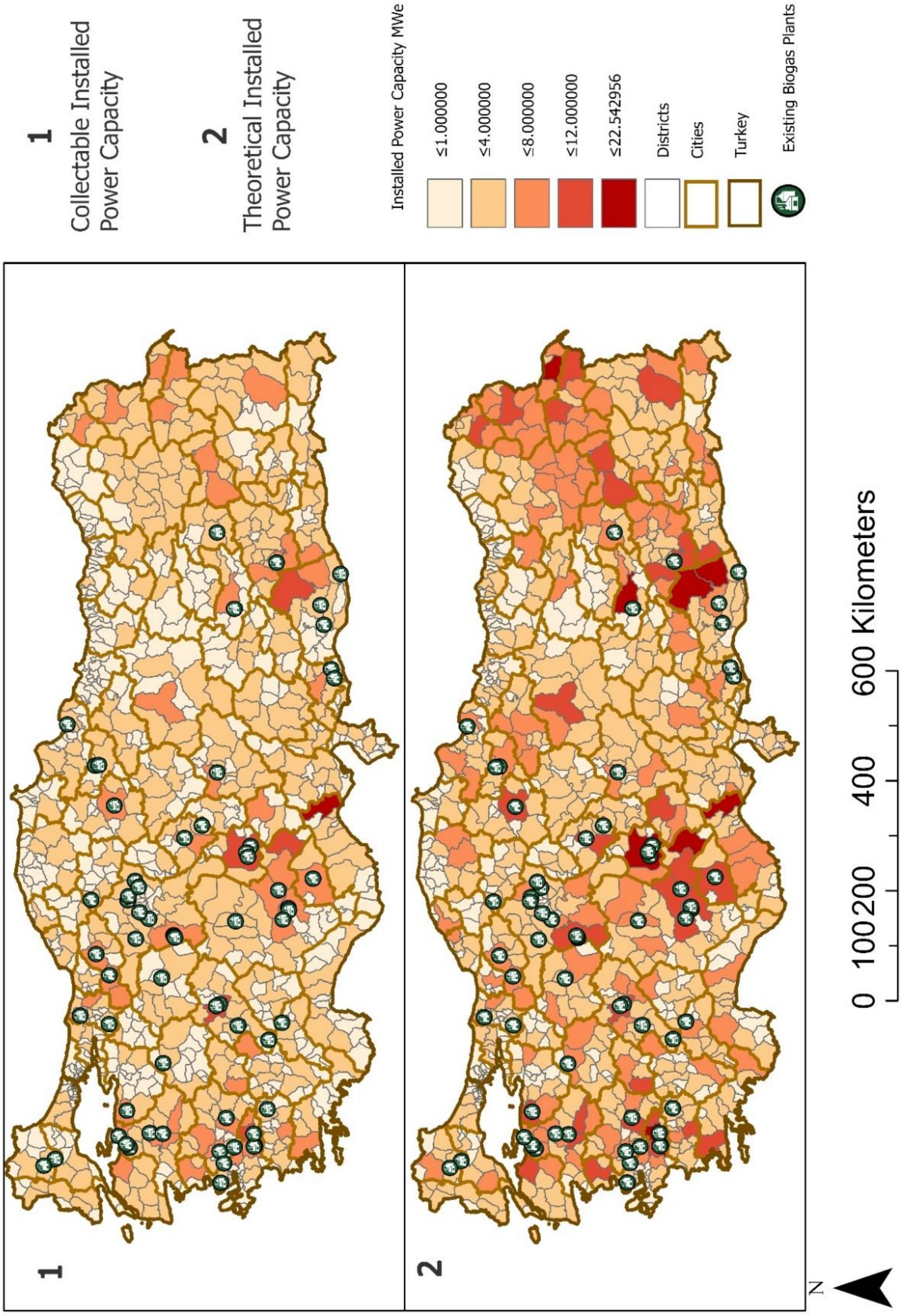


Figure 4.2: Emerging hot spots for energy generation from livestock manure with 10 km distance band and 1 time step.

4.2 Density Analyses

District level density analyses were conducted to analyze spatial distribution and magnitude of theoretical and collectable installed power capacity (MWe) from livestock manure using 2019 data. Energy Potential Equation 3.1. was used to obtain the following results. The total theoretical and collectable power capacity were calculated as 2,269.61 MWe and 1,238.57 MWe, respectively. There is an important difference between the theoretical and collectable installed power capacities due to the poor manure management. This gap is expected to be significantly reduced by the application of the new regulation. The highest power capacities were observed in the eastern, central, and some western districts, where livestock and poultry populations are higher than in the other regions. The highest theoretical power capacity of 22.5 MWe was calculated for the central district of the city of Aksaray, located in the central region (Table 4.1). There are 3 existing biogas plants in this district with a total installed capacity of 8.67 MWe. Despite the high-power capacity of the eastern region, there is not any biogas plant in this region. Another important region is the southeast of Turkey, where power capacities range between 4 MWe and 22 MWe. There are only a few biogas plants in this region. Similarly, a great part of the south and central regions shows high rates of power capacities. The third highest power capacity of 17 MWe was calculated for one of the western districts, Odemis (city of Izmir, Table 4.1). An important number of the existing plants are located in the western region. The results of density analyses are presented in Figure 4.3.


1
Collectable Installed Power Capacity
2
Theoretical Installed Power Capacity
Installed Power Capacity MWe
≤1.000000
≤4.000000
≤8.000000
≤12.000000
≤22.542956
Districts
Cities
Turkey
Existing Biogas Plants
1
2
N
0 100200 400 600 Kilometers

4.3 Opportunity Analysis

Districts defined as emerging hot spots along with their cities, power capacity rankings, installed power capacities, services area radiuses, existing biogas plant capacities, capacity expansions for the existing plants, and the number of existing plants are listed in Table 4.1. These districts emerge as priority locations in terms of livestock manure management investments via biogas plants considering their energy potential. These results do not mean that districts not defined as hot spots do not have enough feedstock for constructing new biogas plants. It means that the resulting hot spot districts are prominent among others considering the magnitude and temporal variation in energy potentials. The results may be used to determine the 1st phase of biogas plant installation sites. The same analyses may be performed consecutively by excluding the previous hot spots to determine the next phases.

Energy Potential Equation 3.1. was used to obtain the following results. 66 districts were defined as emerging hot spots which are listed among the 72 highest power capacity districts. Theoretical power capacities of these 66 districts range between 6.4 to 22.54 Mwe. The total theoretical and calculated power capacities of these districts are 640 and 357.62 MWe, corresponding to 28% and 29% of the total power capacities, respectively. 16% (102.71 MWe) of the theoretical power capacity of the emerging hot spots is already in use by the 31 existing biogas plants. Capacity expansion can range between 0.52 to 13.87 MWe, while 2 districts have more installed power capacity than the theoretical power capacity. 43 out of 66 districts have no biogas plant, which indicates the importance of this study. Service area radiuses were calculated assuming that the districts have circular shapes. The service area radius ranges between 45.6 and 15.4 km, while the average is 29.5 km.

Another important finding is that 63 existing biogas plants are located in 52 districts and 12 of those districts have biogas plants with installed power capacities more than the district's theoretical power capacity as presented in Table 4.2. 4 of those are defined as districts with overcapacity since their existing plants only utilize livestock manure. Biogas plants in the remaining 8 districts utilize other feedstock besides livestock manure. Therefore, they can compensate for the negative capacity difference by other feedstock sources.

Table 4.2.: Existing biogas plants at district level and their features.

Districts	City	Number of Existing Plants	Services Area Radius, km	Existing Biogas Plants Installed Power Capacity, MWe	Theoretical Installed Power Capacity, Mwe	Difference, MWe	Feedstock Type
Central District	Aksaray	3	45.6	8.67	22.54	13.9	Livestock manure, Agricultural residue
Odemis	Izmir	1	22.9	4.87	17.04	12.2	Livestock manure, Agricultural residue, Other waste
Tire	Izmir	2	19.2	9.07	13.32	4.25	Livestock manure, Agricultural residue
Central District	Elaziğ	1	34.2	0.24	12.64	12.4	Livestock manure
Central District	Afyonkarahisar	2	25.7	12.42	11.82	-0.6	Livestock manure, Agricultural residue
Meram	Konya	1	30.2	6	11.59	5.58	Agricultural residue, Livestock manure
Altieylul	Balikesir	1	22.6	3.2	10.77	7.56	Livestock manure
Central District	Kirsehir	1	30.2	3	10.24	7.24	Livestock manure, Agricultural residue

Table 4.2.: Existing biogas plants at district level and their features (continued).

Districts	City	Number of Existing Plants	Services Area Radius, km	Existing Biogas Plants Installed Power Capacity, MWe	Theoretical Installed Power Capacity, Mwe	Difference, MWe	Feedstock Type
Karatay	Konya	1	38.1	3	10.18	7.18	Agricultural residue, Livestock manure, Agricultural residue
Çumra	Konya	2	32.8	7.51	9.94	2.43	Livestock manure, Agricultural residue
Central District	Karaman	1	45	1.41	9.92	8.51	Livestock manure
Polatli	**Ankara**	**3**	**43.5**	**9.97**	**9.89**	**-0.08**	**Livestock manure**
Salihli	Manisa	1	26.4	0.27	9.74	9.47	Agricultural residue, Livestock manure
Karacabey	Bursa	1	25.3	6.4	8.49	2.08	Livestock manure, Agricultural residue, Other waste
Central District	Çorum	1	36.6	6.02	8.07	2.05	Livestock manure, Agricultural residue
Karesi	Balikesir	1	19.4	1.5	7.73	6.23	Livestock manure

Table 4.2.: Existing biogas plants at district level and their features (continued).

Districts	City	Number of Existing Plants	Services Area Radius, km	Existing Biogas Plants Installed Power Capacity, MWe	Theoretical Installed Power Capacity, Mwe	Difference, MWe	Feedstock Type
Kocasinan	Kayseri	1	28.2	1.5	7.66	6.16	Livestock manure
Central District	Burdur	1	28.2	3.01	7.61	4.6	Livestock manure
Mudurnu	Bolu	1	26.9	1.2	7.23	6.03	Livestock manure
Kemalpasa	Izmir	1	18.8	3	7.05	4.05	Livestock manure, Agricultural residue
Central District	Bolu	1	29.9	2.3	6.99	4.69	Livestock manure
Bandirma	Balikesir	1	20.4	2.13	6.71	4.58	Livestock manure
Çubuk	Ankara	2	25.6	6.02	6.54	0.52	Livestock manure
Oğuzeli	Gaziantep	1	18.5	1	6.02	5.02	Livestock manure, Agricultural residue

Table 4.2.: Existing biogas plants at district level and their features (continued).

Districts	City	Number of Existing Plants	Services Area Radius, km	Existing Biogas Plants Installed Power Capacity, MWe	Theoretical Installed Power Capacity, Mwe	Difference, MWe	Feedstock Type
Central District	Bingol	1	31	2.13	5.9	3.76	Livestock manure, Agricultural residue, Industrial waste, Agricultural residue
Gonen	Balikesir	2	25.2	9.86	5.56	-4.3	Livestock manure, Agricultural residue, Other waste
Saruhanli	Manisa	1	20.1	2.3	5.5	3.2	Livestock manure
Kaynarca	Sakarya	1	13.9	15.25	5.36	-9.89	Livestock manure, Agricultural residue, Forest biomass
Sincan	Ankara	1	22.6	3.2	5.04	1.84	Livestock manure
Suluova	Amasya	2	15.9	3.5	4.92	1.42	Livestock manure
Haliliye	Sanliurfa	1	31.1	5.2	4.8	-0.4	Livestock manure, Agricultural residue
Tavsanli	Kutahya	1	31.8	1.5	4.53	3.03	Livestock manure

Table 4.2.: Existing biogas plants at district level and their features (continued).

Districts	City	Number of Existing Plants	Services Area Radius, km	Existing Biogas Plants Installed Power Capacity, MWe	Theoretical Installed Power Capacity, Mwe	Difference, MWe	Feedstock Type
Sarayonu	Konya	1	29	0.25	4.35	4.1	Livestock manure, Agricultural residue
Basmakçi	Afyonkarahisar	1	13.6	4	4.18	0.18	Livestock manure, Agricultural residue
Kayapinar	Diyarbakir	1	15.9	3.54	3.95	0.41	Livestock manure, Agricultural residue
Luleburgaz	**Kirklareli**	**1**	**24**	**4.8**	**3.9**	**-0.9**	**Livestock manure**
Ceylanpinar	Sanliurfa	1	28.2	1.26	3.76	2.5	Livestock manure, Agricultural residue
Beypazari	Ankara	1	30.4	0.79	3.71	2.92	Livestock manure
Sandikli	Afyonkarahisar	1	25.4	1.4	3.68	2.28	Livestock manure
Çerkes	Çankiri	1	23	1.5	3.53	2.03	Livestock manure

Table 4.2.: Existing biogas plants at district level and their features (continued).

Districts	City	Number of Existing Plants	Services Area Radius, km	Existing Biogas Plants Installed Power Capacity, MWe	Theoretical Installed Power Capacity, Mwe	Difference, MWe	Feedstock Type
Eyyubiye	Sanliurfa	1	28.5	1.56	3.45	1.89	Livestock manure, Agricultural residue, Agricultural residue
Nizip	Gaziantep	1	21.7	1.5	3.42	1.91	Livestock manure
Kuyucak	Aydin	1	16.7	1.07	3.21	2.15	Livestock manure
Foça	**Izmir**	**1**	**11.4**	**3.2**	**3.13**	**-0.07**	**Livestock manure**
Babaeski	Kirklareli	1	19.5	4.27	2.67	-1.6	Livestock manure, Agricultural residue
Yunusemre	Manisa	1	20.8	1.5	2.4	0.9	Agricultural residue, Livestock manure, Industrial waste
Mucur	Kirsehir	1	22.9	4.5	2.3	-2.2	Livestock manure, Agricultural residue
Akyurt	**Ankara**	**2**	**14.2**	**6.12**	**2.29**	**-3.84**	**Livestock manure**

Table 4.2.: Existing biogas plants at district level and their features (continued).

Districts	City	Number of Existing Plants	Services Area Radius, km	Existing Biogas Plants Installed Power Capacity, MWe	Theoretical Installed Power Capacity, Mwe	Difference, MWe	Feedstock Type
Kahramankazan	Ankara	1	17.4	0.48	2.14	1.66	Livestock manure, Agricultural residue, Forest biomass, Other waste
Tekkekoy	Samsun	1	13.6	1.5	2	0.5	Livestock manure
Beylikova	Eskisehir	1	19.6	1.56	1.41	-0.15	Agricultural residue, Livestock manure, Agricultural residue
Pamukova	Sakarya	1	12.6	1.49	1	-0.49	Agricultural residue, Livestock manure

4.4 Impact Analysis

Turkey's electricity energy generation was 303,898 GWh in 2019. According to electricity generation statistics of the Turkish Electricity Transmission Corporation, 43.88% of the electricity was generated from renewable energy sources (including reservoir hydropower, 21.69%) and the remaining %56.1 was from fossil fuels [61].). As a result of the high energy demands, a significant part of the energy is imported from external suppliers. Turkey's current energy policy aims to decrease this dependency and increase the amount of renewable energy generation. The government guarantees the purchase of electricity generated from renewable sources for 10 years with constant feed-in tariffs (8.6 cents/kWh for biomass) [62]. Annual theoretical and collectable energy generation from livestock manure at the emerging hot spots were calculated as 4,849.78 GWh (Eqn. 3.1) and 2,714.1 GWh (Eqn. 3.1) in this study, respectively. The theoretical and collectable energy from livestock manure at the hot spots corresponds to 1.5% and 0.89% of the total energy generation in Turkey, respectively. Management of livestock manure through biogas plants can help reduce the energy dependence of Turkey and use of fossil fuels, while providing environmentally sustainable livestock manure management.

The economic feasibility of the installation of biogas plants at the emerging hotspots was evaluated through the comparison of the unit cost of electricity generation and revenues. The transportation of livestock manure from livestock facilities to biogas was assumed to be conducted by the producer at their own expense. Equations 3.2, 3.3, 3.4, and 3.5 were used to obtain the following results. The total cost of 4,849.78 GWh electricity generation from livestock manure was calculated as 450,440,152 $/year which equals 0.093 $/kWh unit cost of electricity generation. Total revenue, on the other hand, was calculated as 359,052,224 $/year and corresponds to 0.07 $/kWh unit revenue. The annual deficit is calculated as 91 million $ with the existing feed-in tariff. Turkish Association of Electricity Producers suggested a minimum feed-in tariff of 12.2 cents/kWh for biogas plants utilizing agricultural waste including livestock manure and extension of the existing 10-year purchase guarantee [59]. On the contrary, the previous 13.3 cents/kWh feed-in tariff was reduced to 8.6 cents/kWh in 2021, and the 10-year purchase guarantee did not change. It can be concluded that the existing feed-in tariff for biomass-based renewable energy fails to satisfy the investors. The economic downsides along with the lack of regulation in livestock manure management may have made energy generation from livestock manure unfavorable.

Chapter 5

Conclusions

In this study, a replicable GIS-based spatiotemporal method was developed to determine emerging hot spots and power capacities for new biogas plants and capacity expansion for the existing plants. The method was conducted to analyze energy production from livestock manure at the district level in Turkey between 2013 and 2019. This study calculated the energy potential from livestock manure in Turkey at the smallest spatial scale ever. 66 districts were determined as emerging hot spots that had high power capacities. 43 out of 66 districts have no biogas plants. The total theoretical power capacity was calculated as 640 MWe. These hot spots were specified as districts with high priority for the installation of new biogas plants with power capacities ranging between 6.30 MWe and 22.54 MWe. Capacity expansion was also investigated for the existing 63 biogas plants in Turkey. Capacity expansions were calculated between 0.52 to 13.87 MWe. 4 districts were determined to have existing biogas plants with more installed power capacity than the district's theoretical installed power capacity. The results indicate the need for a systematic method in planning biogas plant installations. Our method aids in the decision-making process of environmentally and economically sustainable livestock manure management planning and biogas investors to direct their investments into profitable locations.

Livestock manure amounts and the biogas potential of livestock manure has significant importance for energy demand, prevention of environmental pollution and sustainability. Biogas potential and planning require the access to the number of animals in small scales. This numbers can not be determined in very specifically and the study is performed with more limited animal data. Access to all data for the calculation of biogas potential of Turkey needs to be more detailed for the future studies. With this way, not just even for district, it can be considered for the neighborhood scale.

Energy demand emerges as a need that constantly exist all over the world. Parallel to this fact, environmental problems have become one of the most important problems. To prevent these problems, measures are taken to reduce the usage of fossil fuels with interstate agreements such as the Paris Agreement, which is also signed by Turkey. High biogas energy potential of Turkey which emerged because of this study can be an important solution in clean energy production.

The unit cost of electricity generation from livestock manure via biogas plants was calculated as greater than the feed-in tariff paid by the government. Increasing the existing feed-in tariff and 10-year purchase guarantee to 20 years may increase biogas investments. In addition, the new regulation, which will be in practice towards the second half of 2021, may force livestock facilities to perform more environmentally sustainable manure management practices including biogas. In this case, this study can guide biogas investors and environmental agencies to prioritize the districts and make economically more sustainable choices.

References

[1] Ministry of Environment and Urban Planning. Atıkların Düzenli Depolanmasına Dair Yönetmelik [İnternet] Ankara 2017 [accessed April 25, 2021]. https://www.resmigazete.gov.tr/eskiler/2010/03/20100326-13.htm

[2] European Biogas Association. EBA Statistical Report 2018. Brussels: 2019.

[3] YEKDEM. Enerji Piyasası Düzenleme Kurumu. Repub Turkey Energy Mark Regul Auth [İnternet] 2020 [accessed January 5, 2021]. http://epdk.gov.tr/Detay/Icerik/3-0-0-122/yenilenebilir-enerji-kaynaklari-destekleme-mekanizmasi-yekdem

[4] Erdin C, Ozkaya G. Turkey's 2023 energy strategies and investment opportunities for renewable energy sources: Site selection based on ELECTRE. Sustain 2019;11. doi.org/10.3390/su11072136.

[5] Şengül Ü, Eren M, Eslamian Shiraz S, Gezder V, Sengül AB. Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey. Renew Energy 2015;75:617–25. doi.org/10.1016/j.renene.2014.10.045.

[6] Gupta N, Kumar S, Khojyangbam RS. Biogas Technology Towards Sustainable Development 2011.

[7] Moriarty P, Honnery D. What is the global potential for renewable energy? Renew Sustain Energy Rev 2012;16:244–52. doi.org/10.1016/j.rser.2011.07.151.

[8] International Energy Agency. Key World Energy Statistics 2021 2021:1–82.

[9] Statista. • Europe: bioenergy capacity by country 2020 2020 [İnternet]. [accessed July 21, 2021]. https://www.statista.com/statistics/1122093/europe-bioenergy-capacity-by-country/.

[10] Hansen C, Skinner R. Oxford Energy Comment July 2005 Nuclear Power and

Renewables: Strange Bedfellows? n.d.

[11] Mao C, Feng Y, Wang X, Ren G. Review on research achievements of biogas from anaerobic digestion. Renew Sustain Energy Rev 2015;45:540–55. doi.org/10.1016/j.rser.2015.02.032.

[12] Toklu E. Overview of potential and utilization of renewable energy sources in Turkey. Renew Energy 2013;50:456–63. doi.org/10.1016/j.renene.2012.06.035.

[13] Entürk E, Lmezsoy KYETİ, Öztürk M. Design of Fixed-Dome Chinese Type Biogas Reactor in Treatment of Manure Wastes : a Typical Application 2006:119–27.

[14] Ošlaj M, Muršec B. Biogas as a renewable energy source. Teh Vjesn 2010;17:109–14.

[15] Polprasert C. Organic Waste Recycling. vol. 6. 2015. doi.org/10.2166/9781780402024.

[16] The Pembina Institute. Biogas Generator Biogas Generator. Engineering 2002:1–5.

[17] June P. A system approach to biogas technology Components of a biogas system. Soc Dev 1997.

[18] Speight JG. Biogas Production and Properties 2019.

[19] Seadi T Al, Rutz D, Prassl H, Köttner M, Finsterwalder T, Volk S, et al. Biogas: Training Handbook. 2008.

[20] Bugutekin A. Atıklardan Biyogaz Üretiminin İncelenmesi 2007;6:325–59.

[21] Akova İ. Enerji ve Alternatif Enerji Kaynakları 2003.

[22] Aktaş A. Yukari Akişli Havasiz Çamur Yatakli Reaktörlerde Çamur Granüllerinin Oluşmasina Etki Eden Faktörlerin Belirlenmesi 2008.

[23] Berglund M, Börjesson P. Assessment of energy performance in the life-cycle

of biogas production. Biomass and Bioenergy 2006;30:254–66. doi.org/10.1016/j.biombioe.2005.11.011.

[24] Ko N, Ko N, Enstit Fb, Kelimeler A, Art B, Mikt B. Türkiye ’ De Hayvancilik Potansiyeli Ve Biyogaz Castle-Dealing Potential Of Turkey And Biogas Production 2006.

[25] İlkılıç C, Deviren H. Biyogaz ın Oluşumu ve Biyogazı Saflaştirma Yöntemleri 2011:16–8.

[26] Nicholas E. Korres, Padraig O’Kiely JAHB and JSW. Bioenergy Production by Anaerobic Digestion. 2013. doi.org/10.4324/9780203137697.

[27] Dobre, P., Nicolae F. MF. Main factors affecting biogas production - an overview:Letters, Romanian Biotechnological. Rom Biotechnol Lett 2014;19:9283–96.

[28] Debruyn J, Hilborn D. Anaerobic Digestion Basics. Small 2007;2007:1–6.

[29] Deublein D, Steinhauser A. Biogas from Waste and Renewable Resources. 2008.

[30] Deviren H, İlkiliç C, Aydin S. Biyogaz Üretiminde Kullanılabilen Materyaller ve Biyogazın Kullanım Alanları. Batman Univ J Life Sci Batman Üniversitesi Yaşam Bilim Derg 2017;7.

[31] Yalcinkaya S. A spatial modeling approach for siting, sizing and economic assessment of centralized biogas plants in organic waste management. J Clean Prod 2020;255:120040. doi.org/10.1016/j.jclepro.2020.120040.

[32] Sharma B, Birrell S, Miguez FE. Spatial modeling framework for bioethanol plant siting and biofuel production potential in the U.S. Appl Energy 2017;191:75–86. doi.org/10.1016/J.APENERGY.2017.01.015.

[33] Valenti F, Porto SMC, Dale BE, Liao W. Spatial analysis of feedstock supply and logistics to establish regional biogas power generation: A case study in the region of Sicily. Renew Sustain Energy Rev 2018;97:50–63. doi.org/10.1016/j.rser.2018.08.022.

[34] Zareei S. Evaluation of biogas potential from livestock manures and rural wastes using GIS in Iran. Renew Energy 2018;118:351–6. doi.org/10.1016/j.renene.2017.11.026.

[35] Sliz-Szkliniarz B, Vogt J. A GIS-based approach for evaluating the potential of biogas production from livestock manure and crops at a regional scale: A case study for the Kujawsko-Pomorskie Voivodeship. Renew Sustain Energy Rev 2012;16:752–63. doi.org/10.1016/j.rser.2011.09.001.

[36] Rios M, Kaltschmitt M. Electricity generation potential from biogas produced from organic waste in Mexico. Renew Sustain Energy Rev 2016;54:384–95. doi.org/10.1016/j.rser.2015.10.033.

[37] Venier F, Yabar H. Renewable energy recovery potential towards sustainable cattle manure management in Buenos Aires Province: Site selection based on GIS spatial analysis and statistics. J Clean Prod 2017;162:1317–33. doi.org/10.1016/j.jclepro.2017.06.098.

[38] Díaz-Vázquez D, Alvarado-Cummings SC, Meza-Rodríguez D, Senés-Guerrero C, de Anda J, Gradilla-Hernández MS. Evaluation of biogas potential from livestock manures and multicriteria site selection for centralized anaerobic digester systems: The case of Jalisco, Mexico. Sustain 2020;12. doi.org/10.3390/SU12093527.

[39] Ekinci K, Kulcu R, Kaya D, Yaldiz O, Ertekin C, Ozturk H. The prospective of potential biogas plants that can utilize animal manure in Turkey. Energy Explor Exploit 2010;28:187–206. doi.org/10.1260/0144-5987.28.3.187.

[40] Avcioğlu AO, Türker U. Status and potential of biogas energy from animal wastes in Turkey. Renew Sustain Energy Rev 2012;16:1557–61. doi.org/10.1016/j.rser.2011.11.006.

[41] Karaca C. Determination of biogas production potential from animal manure and GHG emission abatement in Turkey. Int J Agric Biol Eng 2018;11:205–10. doi.org/10.25165/j.ijabe.20181103.3445.

[42] Ersoy E, Ugurlu A. The potential of Turkey’s province-based livestock sector

to mitigate GHG emissions through biogas production. J Environ Manage 2020;255. doi.org/10.1016/j.jenvman.2019.109858.

[43] Melikoglu M, Menekse ZK. Forecasting Turkey's cattle and sheep manure based biomethane potentials till 2026 [İnternet]. Biomass and Bioenergy 2020;132. [accessed April 3, 2021]. doi.org/10.1016/j.biombioe.2019.105440.

[44] Turkey Ministry of Interior. Türkiye Mülki İdare Bölümleri Envanteri 2020. https://www.e-icisleri.gov.tr/Anasayfa/MulkiIdariBolumleri.aspx

[45] General Directorate of Mapping. İl ve Yüz Ölçümleri 2014 [İnternet] [accessed January 5, 2021]. https://www.harita.gov.tr/urun/il-ve-ilce-yuzolcumleri/176

[46] TUIK. Temel İstatistikler. Turkish Stat Inst [İnternet] 2020 [accessed January 5, 2021]. https://data.tuik.gov.tr/Bulten/Index?p=The-Results-of-Address-Based-Population-Registration-System-2020-37210&dil=2.

[47] Eurostat. European Statistical System [İnternet] 2020 [accessed July 31, 2021]. https://ec.europa.eu/eurostat/web/main/data/database.

[48] TUIK. Hayvancılık İstatistikleri. Turkish Stat Inst [İnternet] 2020 [accessed January 25, 2021]. https://biruni.tuik.gov.tr/medas/

[49] Ministry of Food Agriculture and Livestock. Sularda Tarımsal Faaliyetlerden Kaynaklanan Nitrat Kirliliğinin Önlenmesine Yönelik İyi Tarım Uygulamaları Kodu Tebliği-Ekler n.d.

[50] General Directorate of Mapping. Türkiye Mülki İdare Sınırları. Polit Map Turkey [İnternet] 2020 [accessed February 4, 2021]. https://www.harita.gov.tr/urun/turkiye-mulki-idare-sinirlari/232.

[51] Energy Market Regulatory Authority. EPDK | Enerji Piyasası Düzenleme Kurumu [İnternet] 2021 [accessed August 5, 2021]. http://epdk.gov.tr/Detay/Icerik/3-0-0-122/yenilenebilir-enerji-kaynaklari-destekleme- mekanizmasi-yekdem.

[52] Lorimor J, Powers W, Sutton A. Manure Characteristics. 2004.

[53] Gómez A, Zubizarreta J, Rodrigues M, Dopazo C, Fueyo N. Potential and cost of electricity generation from human and animal waste in Spain. Renew Energy 2010;35:498–505. doi.org/10.1016/j.renene.2009.07.027.

[54] DBFZ. Türkiye'de Biyogaz Yatırımları İçin Geçerli Koşulların ve Potansiyelin Değerlendirilmesi. Dtsch Biomasse Forschungs Zent Gemeinnützige GmbH Torgauer Straße [İnternet] 2011 [accessed April 4, 2021]. http://www.biyogaz.web.tr/files/docs/dbfz_turkiye_biyogaz_potansiyel_raporu.pdf.

[55] ESRI. How Create Space Time Cube works. ArcGIS Pro [İnternet] 2021. [accessed April 3, 2021]. https://pro.arcgis.com/en/pro-app/latest/tool-reference/space-time-pattern mining/learnmorecreatecube.htm#ESRI_SECTION2_4518F0A12E194690AA986118D508E9F7.

[56] ESRI. How Emerging Hot Spot Analysis works. ArcGIS Pro [İnternet] 2021 [accessed April 3, 2021]. https://pro.arcgis.com/en/pro-app/latest/tool-reference/space-time-pattern-mining/learnmoreemerging.htm.

[57] ArcGIS Pro. Emerging Hot Spot Analysis (Space Time Pattern Mining)—ArcGIS Pro | Documentation. ESRI [İnternet] 2016 [accessed April 11, 2021] https://pro.arcgis.com/en/pro-app/latest/tool-reference/space-time-pattern-mining/emerginghotspots.htm.

[58] IRENA. Renewable Energy Cost Analysis - Biomass for Power Generation. Int Renew Energy Cost Agency 2012.

[59] Association Of Electricity Producers. Hizmete Özel Elektrik Üreticileri Derneği 2020 Sonrasi Yenilenebilir Enerji Kaynaklari Destek İhtiyaçlari Ve Mekanizma Önerileri Çalişma Grubu Raporu 2018.

[60] Pöschl M, Ward S, Owende P. Evaluation of energy efficiency of various biogas production and utilization pathways. Appl Energy 2010;87:3305–21. doi.org/10.1016/j.apenergy.2010.05.011.

[61] Turkish Electricity Transmission Corporation. TÜRKİYE ELEKTRİK

ÜRETİM-İLETİM İSTATİSTİKLERİ [İnternet] 2020 [accessed April 25, 2021] https://www.teias.gov.tr/tr-TR/turkiye- elektrik-uretim-iletim-istatistikleri).

[62] Energy Market Regulatory Authority. EPDK | Enerji Piyasası Düzenleme Kurumu [İnternet] 2021 [accessed April 13, 2021]. http://epdk.gov.tr/Detay/Icerik/3-0-0-122/yenilenebilir-enerji-kaynaklari-destekleme- mekanizmasi-yekdem.

Appendices

Appendix A

Publications from the Thesis

Conference Papers

1. Yalcinkaya S, Ruhbaş BY. Determination of Turkey's Biogas Generation Potential From Livestock Manure Via Spatiotemporal Analysis. Proceedings of the 6th International Congress On Innovative Scientific Approaches; 2021 Dec 19-20; Samsun.

Republic of Turkey
İzmir Kâtip Çelebi University
Graduate School of Natural and Applied Sciences

Spatiotemporal Analysis Framework for Identifying Emerging Hot Spots and Energy Potential from Livestock Manure in Turkey

Department of Urban Regeneration

Master's Thesis

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February, 2022

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Spatiotemporal A. Framework for Identifying E.H. S.
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MASTER’S THESIS

2022

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Publications:

1. Yalcinkaya S, Ruhbaş BY. Determination of Turkey's Biogas Generation Potential From Livestock Manure Via Spatiotemporal Analysis. Proceedings of the 6th International Congress On Innovative Scientific Approaches; 2021 Dec 19-20; Samsun.