

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**TECHNICAL-ECONOMIC-ENVIRONMENTAL FEASIBILITY
ANALYSIS OF FARM BASED MANURE AND BIOGAS PRODUCTION
IN TURKEY BASED ON DIFFERENT LIVESTOCK AND RED
MEAT/MILK DEMAND SCENARIOS**

ZEYNEP KÜBRA MENEKŞE
A THESIS SUBMITTED FOR THE DEGREE OF
MASTER OF SCIENCE
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T.C.
GEBZE TEKNİK ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

TÜRKİYE’DE ÇEŞİTLİ KIRMIZI ET/SÜT
TÜKETİMİ SENARYOLARI BAZLI HAYVAN
ÇİFTLİĞİ MENŞELİ GÜBRE VE BİYOGAZ
ÜRETİMİNİN TEKNİK-EKONOMİK-
ÇEVRESEL FİZİBİLİTE ANALİZİ

ZEYNEP KÜBRA MENEKŞE
YÜKSEK LİSANS TEZİ
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DANIŞMANI
DOÇ. DR. MEHMET MELİKOĞLU

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SUMMARY

In this thesis study, first, a global guide providing average values for fresh manure yield per animal per day (kg/day), total solids in different types of animal manure (%), availability factors (%) of different types of animal manure, methane content (%) in biogas generated from different types of animal manure, and methane yield from different types of animal manure (m^3/tonne fresh matter) is prepared for cattle (large ruminants), chicken, pig, and sheep (small ruminants) manure after a detailed literature review. Turkey's cattle and sheep manure based biomethane potentials are forecasted till 2026. Novel to this thesis study, semi-empirical models based on per capita meat consumption and milk production are used to forecast Turkey's cattle and sheep population. It is estimated that Turkey's cattle and sheep population in 2026 could reach up to 18.7 and 39.2 million, respectively (from meat consumption based modelling). At these population levels, Turkey's cattle and sheep manure based biomethane generation could reach up to 1.99 billion m^3 and 0.15 billion m^3 , respectively. This is equal to a total of nearly 2.14 billion m^3 of biomethane in 2026. This amount of biomethane could provide nearly 6,600 GWh of electricity or supply nearly 2.9% of Turkey's natural gas demand in 2026. Therefore, careful planning must be made before any small, mid and large scale biogas related investments. Finally, it is suggested that farm based biogas generation (from animal manure) should be supported by incentives, and funds if nationwide distribution of small, mid, and large scale systems are wanted.

Key Words: Biogas, Cattle, Electricity, Sheep, Turkey.

ÖZET

Bu tez çalışmasında, öncelikle, hayvan başına düşen günlük gübre verimi (kg/gün), farklı türdeki hayvan gübresindeki toplam katılar (TS) (%), farklı türdeki hayvan dışkılarının kullanılabilirlik faktörleri (%), farklı türdeki hayvan gübrelerinden elde edilen biyogazın metan içeriği (%) ve farklı türdeki hayvan gübrelerinin metan verimi (m^3/ton taze gübre), inek (büyükbaş hayvan), tavuk, domuz ve koyun (küçükbaş hayvan) gübreleri cinsinden veriler için detaylı literatür incelemesi yapılmış ve bu verileri gösteren ortalama değerler sağlayan küresel bir rehber (tablo) hazırlanmıştır. Bu tez çalışmasında, Türkiye'nin inek ve koyun gübresi bazlı biyometan potansiyeli 2026 yılına kadar tahmin edilmektedir. Türkiye'nin inek ve koyun popülasyonunu tahmin etmek için kişi başına düşen et tüketimine ve süt üretimine dayanan yarı-ampirik modeller kullanılmıştır. Türkiye'nin 2026 yılında inek ve koyun popülasyonunun sırasıyla 18,7 ve 39,2 milyona ulaşabileceği tahmin edilmektedir (et tüketimi bazlı modellemeye göre). Bu popülasyon seviyelerinde, Türkiye'nin inek ve koyun gübresi bazlı biyometan jenerasyonu sırasıyla 1,99 milyar m^3 ve 0,15 milyar m^3 'e ulaşmaktadır. Bu, 2026 yılında toplamda yaklaşık 2,14 milyar m^3 biyometana eşittir. Bu üretilen biyometan, yaklaşık 6.600 GWh elektriğe dönüşebilecek ya da Türkiye'nin 2026 yılındaki doğal gaz talebinin yaklaşık %2,9'unu karşılayabilecektir. Bu nedenle, küçük, orta ve büyük ölçekli biyogaz yatırımlardan önce dikkatli planlama yapılmalıdır. Son olarak, ülke çapındaki küçük, orta ve büyük ölçekli çiftlik temelli biyogaz üretimi (hayvan gübresinden) sistemlerinin dağıtımı isteniyorsa, bu projelerin teşvikler ve fonlar tarafından desteklenmesi gerektiği önerilmektedir.

Anahtar Kelimeler: Biyogaz, İnek, Elektrik, Koyun, Türkiye.

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LIST of ABBREVIATIONS and ACRONYMS

<u>Abbreviations</u>	<u>Explanations</u>
<u>and Acronyms</u>	
ε_t	: Random error term
η	: Overall efficiency of biogas conversion to electricity
A_{manure}	: Availability factor of fresh animal manure
CC_{meat}	: Correlation coefficient between per capita meat consumption
CC_{milk}	: Correlation coefficient between per capita milk production
CH_4	: Methane
CO_2	: Carbon dioxide
E_{biogas}	: Amount of electricity generated from biogas
EC_{biogas}	: Energy content of biogas
G_{manure}	: Manure generation
G_{methane}	: Methane generation
$G_{\text{methane, total}}$	: Total methane generation
H_2S	: Hydrogen sulfide
NH_3	: Ammonia
Nm^3	: Normal cubic meter
O_2	: Oxygen
P_{animal}	: Animal population
PCA	: Per capita animal population
PCA_{pcmc}	: Per capita animal based on per capita meat consumption
PCA_{pcmp}	: Per capita animal based on per capita milk production
PCMC	: Per capita meat consumption
PCMP	: Per capita milk production
P_{human}	: Human population
R_{methane}	: Methane content in biogas
Y_{methane}	: Methane yield
AcoD	: Anaerobic co-digestion
AD	: Anaerobic digestion
BAU	: Business as usual

CD	: Cow dung
CM	: Chicken manure
DM	: Dry matter
EU	: European Union
FM	: Fresh manure
GDP	: Gross Domestic Product
GHG	: Greenhouse gas
GWh	: Giga Watt hour
NL	: Normal litre
odw	: Organic dry weight
OECD	: Organisation for Economic Co-operation and Development
SM	: Sheep manure
SOC	: Soil organic carbon
TPES	: Total Primary Energy Supply
TS	: Total solids
TurkStat	: Turkish Statistical Institute
US\$	: United States dollars
VS	: Volatile solids

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1. INTRODUCTION

Turkey is a recently developed country with a population over 80 million [Web 1, 2018]. According to the Turkish Statistical Institute (TurkStat), more than 15% of Turkey's population is classified as young (ages between 15 and 24) [TurkStat, 2017b]. Turkey's gross domestic product (GDP) has been increasing almost continuously in the last two decades [Web 2, 2018]. The only decreases were after the 2001 Turkish economic crisis and the 2008 global economic crisis [Web 3, 2018]. Yet, the Turkish economy easily overcame these economic problems due to its resilience. As a result, in 2017, Turkey's GDP exceeded 10,000 US\$ [Web 4, 2018]. In 2018, Turkey faced another economic downturn and today it's trying to overcome this obstacle [Web 5, 2018].

Agriculture is an important part of Turkey's economy and social life. Turkey is known with its cuisine. As a result, agricultural output directly affects Turkish lifestyle. For decades, Turkey was an agriculturally self-sustaining country, which exported different agricultural commodities around the globe. However, recently Turkey started to import some of the key agricultural products that it used to export; including some of the main crops, fruits and vegetables. As a result of this shift, food consumption and food waste become an important topic for Turkey.

Turkey's climate and vast arable lands are suitable for large scale sustainable agricultural processes. Historically, this has been the case and the country is known as major cereal/crop repository, direct translation of the Turkish words "tahıl ambarı". When the land is available for agriculture then livestock farming also grows concurrently. The livestock sector has been a major driver of the Turkish economy since the foundation of the Republic. In 1950s, the country's economy was depended on agriculture, 75% of the population lived in villages and only 25% lived in towns [Melikoglu, 2013a]. Turkey's organic farming processes changed to conventional farming (western) after 1970s. As a result, Turkey's agriculture and livestock farming became more and more machine and petrochemical (fertilizer) driven. Animal husbandry or livestock farming generates significant economic activity, especially in the rural areas because Turkey has a big livestock population. According to the TurkStat, in 2017, Turkey's cattle, sheep and goat populations were nearly 15.9 million, 33.7 million and 10.6 million, respectively [TurkStat, 2017a].

Thus, totaling to nearly 60.3 million animals; this also means nearly 75 animals per 100 people.

Energy is an important item for developing economies [Kadam and Panwar, 2017]. Countries that have bountiful indigenous reserves are not affected from the global energy price shifts. However, for countries like Turkey, which do not have enough energy reserves, when energy prices fluctuate economies are seriously affected. This means that countries like Turkey must safely supply their energy demand from local resources (energy security). If energy security cannot be attained then local and international political problems might rise over time due to supply and demand related problems [Achinas et al., 2017].

Fossil fuels such as coal, natural gas, and petroleum play an important role in the countries total primary energy supply (TPES). Around the world, increasing energy demands increase the consumption of fossil fuels [Kadam and Panwar, 2017]. It is known that renewable energy sources will play an important role in the future of energy systems (national and global). Biomass is the only renewable energy source that can be combusted. Solar, wind, and hydro do not have combustible (chemical/biological fuel) properties. This means that any renewable energy conversion process that requires a combustible fuel will eventually consume biomass or biomass driven fuels. Different types of biomass are still used in many parts of the World for energy supply. Biomass has three forms: solid, liquid and gas. Most well-known types of biomass are wood, animal dung (manure), crops etc. These solid biomass can be converted into liquid and gaseous forms via man-made processes or naturally. Naturally conversion is when animal dung or any type of biomass is left to disintegrate and eventually converted into biogas via anaerobic digestion (AD). The composition of biogas will be explained later in this thesis study. Also, crops and cereals can be converted into bioethanol and biodiesel by man-made applications. Since the topic of biomass-based energy generation is too wide, in this thesis study the focus will be given to biogas generation from animal wastes (manure).

Biogas as a form of energy only supplies a small portion of our global energy consumption [Achinas et al., 2017]. Biogas is produced via AD from organic matter (biomass) such as food waste, crop waste, animal waste and other types of biomass. Controlled biogas production from waste portion of any biomass helps national waste management policies and renewable energy generation (both in action and policy development) [Kadam and Panwar, 2017], [Achinas et al., 2017]. As a result, biogas

can be an important energy resource for both emerging and developed economies that also aim to reduce their food and animal waste related greenhouse gas (GHG) emissions. Fossil fuels are limited resources. This means that in the future their reserves will finish and they cease to exist for energy generation; and hence, research on new energy sources should be encouraged [Omer and Fadalla, 2003]. This is a very important topic for future generations' energy security. As a rule of thumb, nations must have sustainable energy sources in order to secure their future energy demands. Many futurists believe that after 2050s our global economy would be renewable and nuclear energy driven. In that scenarios biogas and other biomass based fuels would be the only combustible renewable resources (as stated above).

Livestock farming produces massive amounts of animal manure all around the world. Livestock manures are generally left on field or seldom used as fertilizers if animals are free-range. For sheep, goat, free-range chicken and certain types of cattle this is common. However, most of livestock farming (cattle and poultry) in the modern world is barn based. As a result, livestock manure generation especially from cattle and poultry can be collected in certain locations (barns, animal husbandries, etc.). This means that animal farmers must sustainably get rid of these animal manures.

Livestock manure if collected and treated properly is an excellent source for biogas generation. However, if left untreated it can pollute the environment via uncontrolled GHG emissions, might cause diseases and result in soil-water pollution. With the modern biogas technology, the risk of diseases caused by animal wastes is significantly reduced, resulting in more healthy environmental conditions for both humans and animals [Afazeli et al., 2014]. For this reason, biogas technology must be developed and implemented for the benefit of societies in order to eliminate the aforementioned problems and generate renewable energy [Sefeedpari et al., 2012].

Biogas generation begins with the AD of animal manure. The main output of this is methane (CH_4) and carbon dioxide (CO_2); also, there are other products such as hydrogen sulfide (H_2S), ammonia (NH_3) and siloxanes in smaller volumes [Kadam and Panwar, 2017], [Zeng et al., 2018], [Zaidi et al., 2018], [Hung et al., 2017]. In general, the composition of the biogas can be defined as: 40%-75% methane, 25%-55% carbon dioxide, about 1% hydrogen sulfide, about 3% nitrogen and the remaining of water [Morero et al., 2017], [Abdeshahian et al., 2016], [Sun et al., 2015], [Rasi et al., 2007], [Teymoori Hamzehkolaei and Amjady, 2018]. AD of

animal manure consists of four main biochemical processes (steps): (i) hydrolysis, (ii) acidogenesis, (iii) acetogenesis, and (iv) methanogenesis. The leftover solid from the biomass is called the digestate. The steps of biogas and digestate generation from animal manure by AD is shown in Figure 1.1 [Abdelsalam et al., 2018], [Achinas et al., 2018], [Ganzoury and Allam, 2015], [Holm-Nielsen et al., 2009], [Kadam and Panwar, 2017], [Li et al., 2011], [Mao et al., 2015], [Zaidi et al., 2018]. (Note: The figure is drawn based on the descriptions of these references).

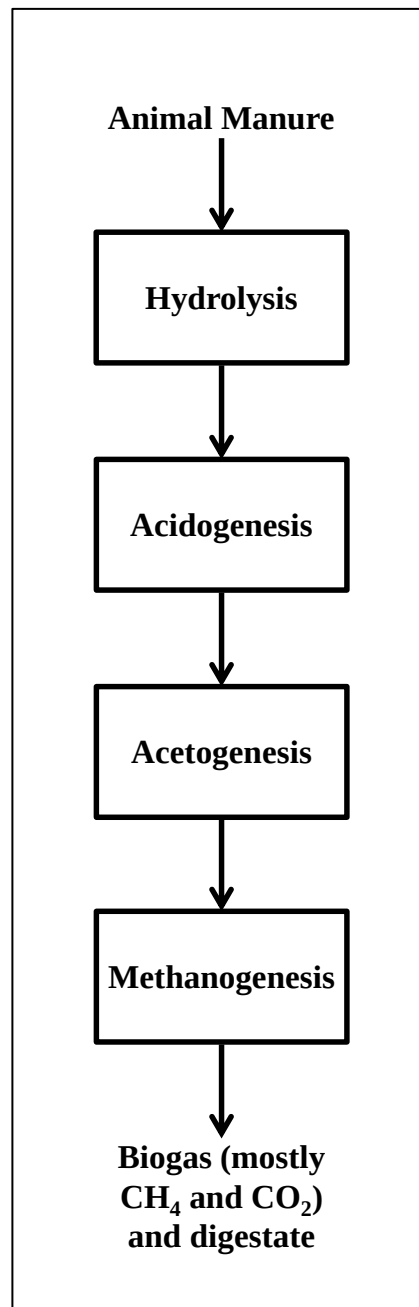


Figure 1.1: Anaerobic Digestion Processes.

As stated in the previous paragraph, when biogas is generated from animal manure some unwanted products are also formed. H_2S in the biogas should be removed before utilization of biogas as a fuel because it is a serious air pollutant and its spread to the atmosphere is unwanted [Zeng et al., 2018]. Therefore, various methods are developed for cleaning biogas from these unwanted pollutants [Kadam and Panwar, 2017]. Details of these can be found from the literature. Not all the outputs are unwanted. Besides CH_4 , which is a valuable fuel, the digestate can be used as a valuable fertilizer. Digestate is rich in organic compounds and it lost most of its contaminants during AD. As a result, digestate can be used as an organic fertilizer (or it may be called as bio-fertilizer). Digestate consumption as a fertilizer can also reduce greenhouse gas emissions during vegetable/crop farming if it replaces petrochemical based fertilizers. Digestate also does not contain chemical components, pesticides or fossil wastes [Deng et al., 2017]. This is a good way to move forward in sustainable farming and a major benefit of biogas generation from animal wastes/manure.

Controlled biogas generation decreases or even eliminates uncontrolled CH_4 and CO_2 emissions into the atmosphere. Overall, (i) renewable energy production, (ii) collection of CO_2 , H_2S and other gases [Sahota et al., 2018] and (iii) digestate generation makes controlled biogas production from animal manure a win-win process.

Turkey is a part of the Europe and an associate member of the European Union (EU). As a result, biogas generation in Turkey will eventually follow the EU regulations and standards. In Europe, Germany is one of the pioneer countries in biogas production from agricultural wastes [Achinas et al., 2017] and Turkish investors in biogas generation can contact to their German colleagues for technology transfer and/or import. However, this can only be a preliminary solution. As an energy policy suggestion biogas generation and related technology should be developed in Turkey via the help of the universities and local companies. This can only be achieved with the implementation of local subsidies and government incentives. As a result, biogas generation in Turkey should be fostered by the government and private sector. Also, universities should foster related research. Thus, this thesis is aimed provide this knowledge gap in the literature and produce novel outcomes.

Electricity generation from biogas is the final goal of energy related investments. Therefore, this will be scrutinized in this thesis study. Many European countries have set their own standards for the electricity generation from biogas production using biomass and/or bio-waste (animal manure) [Achinas et al., 2017]. Therefore, this thesis study would provide a preliminary analysis for electricity generation potential estimations from different types of animal manure in Turkey. The amount of biogas generated and consequently CH₄ production depends on animal manure type. Biogas generation potential estimation (both economic and environmental) depends on substrate selection and the digestate management [Lijó et al., 2017]. Cattle (or other large ruminants), sheep (or other small ruminants), chicken (or poultry) and pigs (or swine) manure are suitable substrates (organic) for biogas generation. Therefore, related analysis must be carried out as a detailed investigation (scrutiny) of biogas generation from these different sources (animal manure). In this thesis study, the focus will be given on manure generation from cattle, sheep, goat and poultry. The issue related with pig manure is explained in the next section.

It is envisaged that animal manure based biomethane generation will have an important role in Turkey's renewable energy future [Melikoglu, 2013b], [Melikoglu, 2016], [Melikoglu, 2017]. However, information about this topic is scarce in the published literature. Therefore, this thesis is intended to provide this valuable information for the use of academics, animal farmers, researchers and policy planners.

Consequently, this thesis is structured as follows: In section 2, as a part of the literature review process a global guide is prepared for animal manure based energy and biomass related calculations. Then, in section 3 (Theory, Calculations, Results and Discussion) Turkey's cattle and sheep population till 2026 are forecasted based on per capita meat consumption and milk production projections. This is because cattle and sheep population are strongly affected by per capita meat consumption and milk production. Then, in the same section, Turkey's animal manure and methane generation data are forecasted using these animal population projections and the global guide prepared in section 2. Also, using these estimated methane production data potential electricity generation and potential supply rate of Turkey's natural gas demand till 2026 are evaluated and the future of animal manure based biogas generation in Turkey is scrutinized in section 3. Then, recommendations for the

future work on biogas and biomethane harnessing from animal manure are given in section 4. Finally, the conclusions drawn from this study are given in section 5.

2. LITERATURE REVIEW

2.1. Data for Animal Manure Based Energy and Biomass Calculations

Animal manure is an unavoidable end-product of livestock farming [Burg et al., 2018]. It has been reported that controlled biogas generation from animal manure has great benefits with respect to greenhouse gas emissions and global warming [Hamelin et al., 2014]. In order to calculate potential biogas and methane yields from different types of animal manure the following data must be found from the literature: (i) daily manure generation per animal (ii) total solids (TS) content of different manure types (iii) availability factors of different manure types (iv) methane content in biogas generated from different types of manure, and lastly (v) biogas and methane yield from different types of animal manure. Also, when these data are found it would be beneficial to collect them together in a single table/guide for further studies. After a detailed analysis, this valuable information is found from the literature and summarized in the following subsections of this thesis. Each roman numeral given in the list above is used as a subsection heading for ease of understanding.

2.1.1. Average Amounts of Manure Generation per Animal per Day

Biogas is an end-product of AD. Therefore, from chemical engineering perspective, it is evident that the amount of biogas generated from animal manure is directly proportional to the amount of bioprocessed raw material, which is animal manure. Therefore, as a starting point, these values (manure generation per animal per day) must be found from the literature. Detailed analysis of the literature clearly showed that the amount of manure generated per animal per day depends on average weight, age and some other breed related parameters (such as gender, dairy cattle, beef cattle or etc.). As a result, in this thesis study, average values are given. Daily fresh manure (FM) generation (kg/day per animal) from different animals are pored over from the literature and the results are given in Table 2.1 [Abdeshahian et al., 2016], [Afazeli et al., 2014], [Makara and Kowalski, 2018], [Ngwabie, et al., 2018], [QLD, 2018], [USDA, 2018].

Table 2.1: Estimation of daily FM production from different animals (kg/day).

			Calculated in this study	Calculated in this study
Source:	[USDA, 2018]			
	Raw Data			
Livestock type	Total manure (lbs/day/1000-lb animal unit) ^c		Animal	Fresh animal manure (kg/day)
Beef cattle ^a	59.1		Cattle (average)	38.8
Dairy cattle _b	80.0			
Source:	[QLD, 2018]			
	Manure production (kg/day) ^d		Animal	Fresh animal manure (kg/day)
Feedlot cattle	27.0		Cattle (average)	27.0
Source:	[Abdeshahian et al., 2016]			
Animal type	Manure (kg/day)		Animal	Fresh animal manure (kg/day)
Large ruminants ^e	22.5		Large ruminants (average)	22.5
Small ruminants ^e	1.6		Small ruminants (average)	1.6
Poultry ^e	0.045		Poultry (average)	0.045
Source:	[Afazeli et al., 2014]			
Animal type	Manure/Excreta (kg/day)		Animal	Fresh animal manure (kg/day)
Cow	23		Cattle (average)	23.0
Sheep	1.3		Sheep (average)	1.3
Poultry	0.01		Poultry (average)	0.01

Table 2.1: (continued).

Source:	[Ngwabie et al., 2018]			
	Manure (kg/day)		Animal	Fresh animal manure (kg/day)
Pig ^f	3.06 ± 2.0		Pig (average)	3.06
Source:	[Makara and Kowalski, 2018]			
	Manure (kg/day)		Animal	Fresh animal manure (kg/day)
Pig	100 pigs produce nearly 2,850 kg of pig manure per day		Pig (average)	2.85
		Average Values	Animal	Fresh animal manure (kg/day)
			Cattle (average)	27.8
			Sheep (average)	1.45
			Poultry (average)	0.0275
			Pig (average)	2.955
Notes: ^a High forage diets ^b Lactating cow ^c Manure production is expressed in terms of 1,000 pound animal units. It is assumed that a single dairy cow weighs about 1,400 pounds, or 1.4 animal units; a typical steer weighs about 1,000 pounds or 1 animal unit. ^d From a 450 kg beast (volatile solids generation: 2.7 kg/day) ^e Average animal body weights large ruminants: 250 kg, small ruminants: 40 kg, poultry: 1.5 kg ^f Pigs weight between 26 kg and 75 kg				

As can be seen from Table 2.1, it can be assumed that daily on average 27.8 kg, 1.45 kg, 0.0275 kg, and 2.955 kg of fresh animal manure can be generated from for cattle, sheep, poultry, and pig, respectively. These data will later be used in the related calculations.

2.1.2. Total Solids in Different Types of Animal Manure

Biogas is generated from solid portion of manure during AD. Therefore, total solids content of biomass directly affects biogas and concurrently methane generation. As a result, total solids in different types of animal manure (%) are pored over from the literature and the results are given in Table 2.2 [Abouelenien et al., 2009], [Achinas et al., 2018], [Angelidaki and Ellegaard, 2003], [Astals et al., 2011], [Bujoczek et al., 2000], [Kanwar and Kalia, 1993], [Kaparaju and Rintala, 2005], [Li et al., 2013], [Murto, et al., 2004], [QLD, 2018], [Xie et al., 2011].

Table 2.2: Total solids %, in different types of animal manure.

				Calculated in this study	Calculated in this study
Source:	[Kanwar and Kalia, 1993]				
Animal manure type	Total solids			Animal manure type	TS, %
Cattle dung	20%			Cattle (average)	20%
Sheep droppings	49%			Sheep (average)	49%
Source:	[Achinas et al., 2018]				
Animal manure type	TS (g/kg)			Animal manure type	TS, %
Cow dung (CD)	121.3			Cattle (average)	12.1%
Sheep manure (SM)	252.8			Sheep	25.3%
Source:	[QLD, 2018]				
	Manure production (kg/day) ^d	Total solids (kg/day) ^d		Animal manure type	TS, %
Feedlot cattle	27.0	3.1		Cattle (average)	11.5%

Table 2.2: (continued).

Source:	[Bujoczek et al., 2000]				
	Total solids, %			Animal manure type	TS, %
Poultry manure	20%-25%			Poultry (average)	22.5%
Source:	[Abouelenien et al., 2009]				
	Total solids, %			Animal manure type	TS, %
Chicken manure (CM)	25%			Chicken (average)	25%
Source:	[Li et al., 2013]				
	Total solids, %			Animal manure type	TS, %
Chicken manure (CM)	24.9% $\pm$ 2.3%			Chicken (average)	24.9%
Source:	[Murto et al., 2004]				
	Total solids, %			Animal manure type	TS, %
Pig manure	9%			Pig (average)	9%
Source:	[Kaparaju and Rintala, 2005]				
	Total solids, %			Animal manure type	TS, %
Pig manure	6.0%-7.8%			Pig (average)	6.9%
Source:	[Astals et al., 2011]				
	g TS $\cdot$ kg ⁻¹			Animal manure type	TS, %

Table 2.2: (continued).

Pig manure	50.4			Pig (average)	5.0%
Source:	[Angelidaki and Ellegaard, 2003]				
	Total Solids, %			Animal manure type	TS, %
Pig manure	5%-7%			Pig (average)	6.0%
Source:	[Xie et al., 2011]				
	TS (% fresh weight)			Animal manure type	TS, %
Pig manure	12.6%			Pig (average)	12.6%
			Average Values	Animal manure type	TS, %
				Cattle (average)	14.5%
				Sheep (average)	37.2%
				Chicken (average)	24.1%
				Pig (average)	7.9%
Abbreviations: TS: total solids					
Notes:					
^d From a 450 kg beast					

As can be seen from Table 2.2, average TS content (%) of cattle, sheep, chicken, and pig manure can be assumed as 14.5%, 37.2%, 24.1%, and 7.9%, respectively. These data will later be used in the related calculations.

2.1.3. Availability Factors for Different Types of Animal Manure

The availability factor shows what percentile (%) of the fresh animal manure can be recovered for biogas generation. As a result, availability factors for different

types of animal manure (%) are pored over from the literature and the results are given in Table 2.3 [Avcioğlu and Türker, 2012], [Meyer et al., 2018], [Moreda, 2016], [Zareei, 2018].

Table 2.3: Availability factors (%) for different types of animal manure.

			Calculated in this study	Calculated in this study
Source:	[Avcioğlu and Türker, 2012]			
Animal manure type	Availability of waste, %		Animal manure type	Availability factor, % ^a
Cattle	50%		Cattle (average)	50%
Small ruminants	13%		Small ruminants (average)	13%
Poultry	99%		Poultry (average)	99%
Source:	[Meyer et al., 2018]			
Animal manure type	Availability, % Low availability; moderate availability; high availability		Animal manure type	Availability factor, % ^a
Cattle	50%; 60%; 70%		Cattle (average)	60%
Pig	70%; 80%; 90%		Pig (average)	80%
Poultry	70%; 80%; 90%		Poultry (average)	80%
Source:	[Zareei, 2018]			
Animal manure type	Availability coefficient		Animal manure type	Availability factor, % ^a
Cow (average)	0.14		Cattle (average)	14%
Light livestock	0.10		Small ruminant (average)	10%

Table 2.3: (continued).

Source:	[Moreda, 2016]			
Animal manure type	Availability (%)		Animal manure type	Availability factor, % ^a
Ruminal content, manure, other solids (average)	50%-80%		Cattle (average)	65%
		Average Values	Animal manure type	Availability factor, % ^a
			Cattle (average)	47.3%
			Sheep (average)	11.5%
			Pig (average)	80.0%
			Poultry (average)	89.5%
Notes: ^a The availability factor shows what percentile of the fresh animal manure can be recovered for biogas generation				

As can be seen from Table 2.3, average availability factors (%) of cattle, sheep, poultry, and pig manure can be assumed as 47.3%, 11.5%, 89.5%, and 80.0%, respectively. These data will later be used in the related calculations.

2.1.4. Methane Content in Biogas Generated from Different Types of Animal Manure

Estimation of CH₄ content in biogas generated from different types of animal manure, %, is a key parameter for energy related calculations from biogas. Therefore, CH₄ content in biogas generated from different types of animal manure are pored over from the literature and the results are given in Table 2.4 [Achinas et al., 2018], [Ferrer et al., 2009], [Huang and Shih, 2018], [Kafle and Kim, 2013], [Kanwar and Kalia, 1993], [Niu et al., 2014], [Nuchdang and Phalakornkule, 2012], [Qiao et al., 2011], [Rasi et al., 2007], [Teymoori Hamzehkolaei and Amjady, 2018].

Table 2.4: Estimation of methane content in biogas generated from different types of animal manure, %.

			Calculated in this study	Calculated in this study
Source:	[Kanwar and Kalia, 1993]			
Animal manure type	Methane content in biogas, %		Animal manure type	Methane content in biogas, %
Cattle dung	56%-60%		Cattle (average)	58.0%
Sheep droppings	70%-72%		Sheep (average)	71.0%
Source:	[Achinas et al., 2018]			
Animal manure type	Methane content in biogas, %		Animal manure type	Methane content in biogas, %
Cow dung (CD)	64%		Cattle (average)	64.0%
Sheep manure (SM)	54%		Sheep (average)	54.0%
Source:	[Teymoori Hamzehkolaei and Amjady, 2018]			
	Methane content in biogas, %		Animal manure type	Methane content in biogas, %
Animal manure ^a	45%-60%		Animal manure (average)	52.5%
Source:	[Rasi et al., 2007]			
	Methane content in biogas, %		Animal manure type	Methane content in biogas, %
Animal manure, farm biogas plant ^a	55%-58%		Animal manure (average)	56.5%
Source:	[Ferrer et al., 2009]			

Table 2.4: (continued).

	Methane content in biogas, %		Animal manure type	Methane content in biogas, %
Pig manure ^b	60%-70%		Pig manure (average)	65.0%
Source:	[Nuchdang and Phalakornkule, 2012]			
	Methane content in biogas, %		Animal manure type	Methane content in biogas, %
Pig manure ^c	62%		Pig manure (average)	62.0%
Source:	[Qiao et al., 2011]			
	Methane content (%)		Animal manure type	Methane content in biogas, %
Pig manure	65.9		Pig manure (average)	65.9%
Source:	[Kafle and Kim, 2013]			
	Methane content (%)		Animal manure type	Methane content in biogas, %
Swine manure	79%		Pig manure (average)	79.0%
Source:	[Huang and Shih, 2018]			
	Methane content (%)		Animal manure type	Methane content in biogas, %
Manure of laying hens	70%		Chicken manure (average)	70.0%
Source:	[Niu et al., 2014]			
	CH ₄ (%)		Animal manure type	Methane content in biogas, %

Table 2.4: (continued).

Pre-treated chicken manure	61.75%		Chicken manure (average)	56.4%
Raw chicken manure	51.01%			
		Average Values	Animal manure type	Methane content in biogas, %
			Cattle (average)	57.8%
			Sheep (average)	58.5%
			Chicken (average)	63.2%
			Pig (average)	68.0%
Notes: ^a Average animal manure methane content in biogas values are used for estimating cattle and sheep because distinction is not made in the source publications ^b Average of various studies from the literature for pig manure ^c co-digestion of acid-treated glycerol with pig manure				

As can be seen from Table 2.4, average methane content (%) in cattle, sheep, chicken, and pig manure can be assumed as 57.8%, 58.5%, 63.2%, and 68.0%, respectively. These data will later be used in the related calculations.

2.1.5. Biogas and Methane Yield from Different Types of Animal Manure

Biogas and CH₄ yield are key parameters for energy related calculations from biogas. Therefore, biogas and methane yield from different types of animal manure are pored over from the literature and the results are given in Table 2.5 [Angelidaki and Ellegaard, 2003], [Burg et al., 2018], [Meyer et al., 2018], [Scarlat et al., 2018], [Selvaggi et al., 2018], [Surendra et al., 2014], [Tišma et al., 2018].

Table 2.5: Biogas and methane yield from different types of animal manure.

				Calculated in this study	Calculated in this study
Source:	[Selvaggi et al., 2018]				
Animal manure type	Biomethane specific yield (Nm ³ /tonne VS)	Biomethane specific yield (Nm ³ /tonne FM)		Animal manure type	Methane yield from fresh animal manure (m ³ /tonne FM)
Cattle manure, liquid	240	14.1		Cattle (average)	26.2
Cattle manure	212	38.3		Pig (average)	9.7
Pig manure, liquid	300	9.7		Poultry (average)	128.3
Poultry manure	320	106.6			
Laying hens manure	300	150.0			
Source:	[Scarlat, et al., 2018]				
Animal manure type	Methane yield (m ³ /tonne VS)	Methane yield (m ³ /tonne FM)		Animal manure type	Methane yield from fresh animal manure (m ³ /tonne FM)
Cattle manure	200	13.6		Cattle (average)	14.6
Dairy cows' manure	230	15.6		Sheep or goat (average)	48.0
Sheep/goats manure	200	48.0		Pig (average)	14.4
Pigs	300	14.4		Poultry (average)	51.2
Poultry	320	51.2			

Table 2.5: (continued).

Source:	[Meyer et al., 2018]				
Animal manure type	Biogas yield based on TS (m ³ /tonne)			Animal manure type	Methane yield from fresh animal manure (m ³ /tonne FM) ^{a, b, c}
Cattle manure	240			Cattle (average)	20.1
Pig manure	370			Pig (average)	19.9
Poultry manure	400			Poultry (average)	60.9
Source:	[Burg et al., 2018]				
Animal manure type	Methane yield (NL/kg odw) – lab scale measurement (fresh from the stable)	Methane yield (NL/kg odw) – literature values		Animal manure type	Methane yield from fresh animal manure (m ³ /tonne FM) ^{a, b, c} calculated from lab + literature data
Dairy cow, liquid manure	364 (±14)	150		Cattle (average)	39.9
Dairy cow, solid manure	359 (±14)	250		Pig (average)	26.1
Fattening cattle, liquid manure	326 (±2)	150		Poultry (average)	66.2
Fattening cattle, solid manure	355 (±3)	250			
Pig, liquid	411 (±3)	250			
Hen	259 (±9)	290			

Table 2.5: (continued).

Source:	[Tišma et al., 2018]				
Animal manure type	Biogas potential (Nm ³ /kg _{TS})			Animal manure type	Methane yield from fresh animal manure (m ³ /tonne FM) ^{a, b, c}
Cow manure	0.211			Cattle (average)	17.7
Source:	[Surendra et al., 2014]				
Animal manure type	Specific biogas production (Nm ³ /kg _{DM}) ^d			Animal manure type	Methane yield from fresh animal manure (m ³ /tonne FM) ^{a, b, c}
Cattle manure	0.20-0.30			Cattle (average)	21.0
Chicken manure	0.31			Poultry (average)	47.2
Pigs manure	0.25-0.50			Pig (average)	20.1
Sheep manure	0.30-0.40			Sheep (average)	76.2
Source:	[Surendra et al., 2014]				
Animal manure type	Specific biogas production (Nm ³ /kg _{DM}) ^d	Maximum methane production potential for developing countries (Nm ³ /kg VS)		Animal manure type	Methane yield from fresh animal manure (m ³ /tonne FM) ^{a, b, c}
Buffaloes	0.25	0.10		Cattle (average)	21.0
Cattle	0.25	0.11		Poultry (average)	47.2
Chickens	0.31	0.24		Pig (average)	20.1

Table 2.5: (continued).

Pigs	0.37	0.29		Sheep (average)	76.2
Sheep	0.35	0.13			
Source:	[Angelidaki and Ellegaard, 2003]				
Animal manure type	Methane yield (CH ₄ /tonne of manure treated)			Animal manure type	Methane yield from fresh animal manure (m ³ /tonne FM)
Cattle (average)	0.10-0.20			Cattle (average)	15.0
			Average Values	Animal manure type	Methane yield from fresh animal manure (m ³ /tonne FM) ^{a, b, c}
				Cattle (average)	22.1
				Sheep (average)	62.1
				Poultry (average)	70.8
				Pig (average)	18.0
Abbreviations: VS: volatile solids; FM: fresh matter; NL: normal litre; odw: organic dry weight; Nm ³ : normal cubic metre; DM: dry matter; TS: total solids					
Notes: ^a Total solids/fresh animal manure (%) is assumed as 14.5% for cattle manure and 37.2% for sheep manure, 24.1% for poultry manure, and 7.9% for pig manure (average values are taken from Table 2) ^b Methane % in biogas generated from cattle, sheep, chicken and pig manure are assumed as 57.8, 58.5%, 63.2%, and 68.0% respectively (average values are taken from Table 4) ^c It is assumed that odw=DM=TS ^d Reference [Surendra et al., 2014] is used once for calculating average methane yield values					

As can be seen from Table 2.5, methane yield from fresh manure (m³/tonne FM) of cattle, sheep, poultry, and pig manure can be assumed as 22.1 m³/tonne FM,

62.1 m³/tonne FM, 70.8 m³/tonne FM, and 18.0 m³/tonne FM, respectively. These data will later be used in the related calculations.

2.2. Guide Preparation

Using the valuable information given in Tables 2.1-2.5, a global guide providing average values for fresh manure yield per animal per day (kg/day), total solids in different types of animal manure (%), availability factors (%) of different types of animal manure, methane content (%) in biogas generated from different types of animal manure, and methane yield from different types of animal manure (m³/tonne fresh matter) are prepared and summarized in Table 2.6 [Abdeshahian et al., 2016], [Abouelenien et al., 2009], [Achinas et al., 2018], [Afazeli et al., 2014], [Angelidaki and Ellegaard, 2003], [Astals et al., 2011], [Avcioğlu and Türker, 2012], [Bujoczek et al., 2000], [Burg et al., 2018], [Ferrer et al., 2009], [Huang and Shih, 2018], [Kafle and Kim, 2013], [Kanwar and Kalia, 1993], [Kaparaju and Rintala, 2005], [Li et al., 2013], [Makara and Kowalski, 2018], [Meyer et al., 2018], [Moreda, 2016], [Murto et al., 2004], [Ngwabie et al., 2018], [Niu et al., 2014], [Nuchdang and Phalakornkule, 2012], [Qiao et al., 2011], [QLD, 2018], [Rasi et al., 2007], [Scarlat et al., 2018], [Selvaggi et al., 2018], [Surendra et al., 2014], [Teymoori Hamzehkolaei and Amjady, 2018], [Tišma et al., 2018], [USDA, 2018], [Xie et al., 2011], [Zareei, 2018].

Table 2.6: A global guide: Average values for FM yield per animal per day (kg/day), TS in different types of animal manure (%), availability factors (%) of different types of animal manure, CH₄ content (%) in biogas generated from different types of animal manure, and CH₄ yield from different types of animal manure (m³/tonne FM) are prepared.

		References
Animal	Fresh animal manure (kg/day)	[Abdeshahian et al., 2016; Afazeli et al., 2014; Makara and Kowalski, 2018; Ngwabie et al., 2018; QLD, 2018; USDA, 2018]
Cattle (average)	27.8	
Sheep (average)	1.45	
Poultry (average)	0.0275	
Pig (average)	2.955	

Table 2.6: (continued).

Animal manure type	TS, %	[Abouelenien et al., 2009; Achinas et al., 2018; Angelidaki and Ellegaard, 2003; Astals et al., 2011; Bujoczek et al., 2000; Kanwar and Kalia, 1993; Kaparaju and Rintala, 2005; Li et al., 2013; Murto et al., 2004; QLD, 2018; Xie et al., 2011]
Cattle (average)	14.5%	
Sheep (average)	37.2%	
Chicken (average)	24.1%	
Pig (average)	7.9%	
Animal manure type	Availability factor, %	[Avcioglu and Türker, 2012; Meyer et al., 2018; Moreda, 2016; Zareei, 2018]
Cattle (average)	47.3%	
Sheep (average)	11.5%	
Pig (average)	80.0%	
Poultry (average)	89.5%	
Animal manure type	Methane content in biogas, %	[Achinas et al., 2018; Ferrer et al., 2009; Huang and Shih, 2018; Kafle and Kim, 2013; Kanwar and Kalia, 1993; Niu et al., 2014; Nuchdang and Phalakornkule, 2012; Qiao et al., 2011; Rasi et al., 2007; Teymoori Hamzehkolaei and Amjady, 2018]
Cattle (average)	57.8%	
Sheep (average)	58.5%	
Chicken (average)	63.2%	
Pig (average)	68.0%	
Animal manure type	Methane yield from fresh animal manure (m ³ /tonne FM)	[Angelidaki and Ellegaard, 2003; Burg et al., 2018; Meyer et al., 2018; Scarlat, et al., 2018; Selvaggi et al., 2018; Surendra et al., 2014; Tišma et al., 2018]
Cattle (average)	22.1	
Sheep (average)	62.1	
Poultry (average)	70.8	
Pig (average)	18.0	
Abbreviations: FM: fresh matter; TS: total solids		

It is believed that the valuable information given in Table 2.6 can be used by other researchers for energy and biomass related calculation from different types of

animal manure. To sum up, in this section the literature is scrutinized, and a global guide is prepared.

3. THEORY, CALCULATIONS, RESULTS and DISCUSSIONS

3.1. Forecasting Turkey's Biomethane and Electricity Generation Potentials from Cattle and Sheep Manure till 2026

There are various techniques used for animal manure management including aquatic forage, composting and field application of untreated manure [Wang et al., 2018]. Out of many, biogas harnessing is the most promising in terms of economic and environmental benefits [Chen and Liu, 2017]. It is expected that biogas will have an important role in the global renewable energy market [Ferella et al., 2019]. From global to local, in this thesis study, Turkey's biomethane and electricity generation potentials from cattle and sheep manure is forecasted till 2026. As a clarification, in Turkey, consumption of pork is very limited. Therefore, biogas generation from pig manure is not feasible at large scale. Also, biogas generation from poultry manure is not assessed in this thesis study because a sound forecasting model for poultry population cannot be found from the literature. In addition, in this section, methane generation potentials will be calculated rather than biogas generation potentials (which can also be calculated using the average methane content in biogas conversion factors given in Table 2.4) because methane in biogas is a renewable energy source, which can be used for heat and power generation.

3.1.1. Forecasting Cattle and Sheep Populations in Turkey till 2026

It is known that cattle and sheep population strongly depend on per capita meat consumption and milk production. Novel to this thesis study, Turkey's sheep and cattle populations are estimated based on these two parameters. As a remark, it is known that Turkey is not a closed economy so increased milk and meat consumption may not be met internally but rather through increased imports. Animal population estimations in this thesis study consider this factor. The semi-empirical models generated in this study are used to estimate animal populations based on meat and milk demands. Turkey is not considered as a closed system but accepted as an open one with import/export (livestock, meat and milk) options. Therefore, it must be

stated that the animal populations given in here are potential maxima because if red meat and milk is imported to supply the internal demand instead of live animals then it is evident that the animal populations won't rise to the forecasted levels.

Turkey's cattle and sheep populations based on per capita meat consumption data are estimated using Equation (3.1).

$$P_{animal}(t) = P_{human}(t) \times PCA_{pcmc}(t) + \varepsilon_t \quad (3.1)$$

In Equation (3.1), $P_{animal}(t)$ is animal population (cattle or sheep) in year t ; $P_{human}(t)$ is human population in year t ; $PCA_{pcmc}(t)$ is per capita animal based on per capita meat consumption (beef or sheep meat) in year t ; and ε_t is a "random" error term.

$P_{human}(t)$ projections for 2018-2026 are found from the TurkStat [TurkStat, 2018c] and shown in Figure 3.1(a). $PCA_{pcmc}(t)$ is estimated using Equation (3.2).

$$PCA_{pcmc}(t) = PCA(t_{ref}) \times \frac{PCMC(t)}{PCMC(t_{ref})} \times CC_{meat}(t) + \varepsilon_t \quad (3.2)$$

In Equation (3.2), $PCA_{pcmc}(t)$ is explained in Equation (3.1); t_{ref} is taken as 2017, $PCA(t_{ref})$ is per capita animal population (cattle or sheep) in year t_{ref} ; $PCMC(t)$ is per capita meat (beef or sheep meat) consumption in year t ; $PCMC(t_{ref})$ is per capita meat (beef or sheep meat) consumption in year t_{ref} ; $CC_{meat}(t)$ is a correlation coefficient (annual) between per capita meat consumption and per capita animal in year t , $-1 \leq CC_{meat}(t) \leq 1$; and ε_t is a "random" error term. Turkey's per capita beef (cattle meat) and sheep meat consumption projections, $PCMC(t)$ data, between 2018 and 2026 are found from the Organisation for Economic Co-operation and Development (OECD) and shown in Figure 3.1(c) and (d) [OECD, 2018b]. $P_{animal}(t)$ data between 2002 and 2017 [TurkStat, 2018b] is found from TurkStat and shown in Figure 3.1(b). $PCA(t_{ref})$ is calculated using $P_{animal}(t)$ data and $P_{human}(t)$ projections given in Figure 3.1(a) for the year 2017 as 0.1973 for cattle and 0.4167 for sheep. $CC_{meat}(t)$ is assumed as 1.0 for strongest possible agreement between 2018 and 2026. $PCA_{pcmc}(t)$ forecasts between 2018 and 2026 are generated using Equation (3.2) and shown in Figure 3.1(e) and (f). Finally, Turkey's cattle and sheep population between

2018 and 2026 are forecasted using Equations (3.1) and (3.2) and data given in Figure 3.1 (a)-(f). The results are shown in Figure 3.1(g). The aforementioned results can found and analysed in Figure 3.1 [OECD, 2018b], [TurkStat, 2018c], [TurkStat, 2018b].

In Figure 3.1(g), historical $P_{animal}(t)$ data is also extrapolated till 2026 using the statistical functions provided by Microsoft Excel 2010. This is done to generate a baseline forecast for animal population. This forecast is according to a business as usual (BAU) scenario (based on data for 2002-2017). Cattle and sheep population projections given in Figure 3.1(g) may seem to be linear; however, they are semi-empirical functions estimated using Equations (3.1) and (3.2). Cattle per capita projections follow a polynomial type growth pattern with decreasing slope and sheep per capita projections follow an exponential type growth pattern with increasing slope. Overall, cattle population projection has an increasing trend with deceleration and sheep population has an increasing trend with acceleration. When compared to the BAU scenario both projections deviate from the linear extrapolations. It is known that cattle and sheep population might not increase only by birth but also via animal imports (live). As a remark, the animal populations given here are potential maxima because if red meat demand is supplied via red meat imports then livestock population would be smaller.

Milk production data from OECD are used in livestock population estimations [OECD, 2018a]. This is because milk production is directly related to live animal population; whereas milk consumption data can include imported milk.

Turkey's cattle and sheep populations based on per capita milk production data are estimated using Equation (3.3).

$$P_{animal}(t) = P_{human}(t) \times PCA_{pcmp}(t) + \varepsilon_t \quad (3.3)$$

In Equation (3.3), $P_{animal}(t)$ is animal population (cattle or sheep) in year t ; $P_{human}(t)$ is explained in Equation (3.1); $PCA_{pcmp}(t)$ is per capita animal based on per capita milk production in year t ; and ε_t is a "random" error term; $P_{human}(t)$ projections were shown in Figure 3.1(a). $PCA_{pcmp}(t)$ is estimated using Equation (3.4).

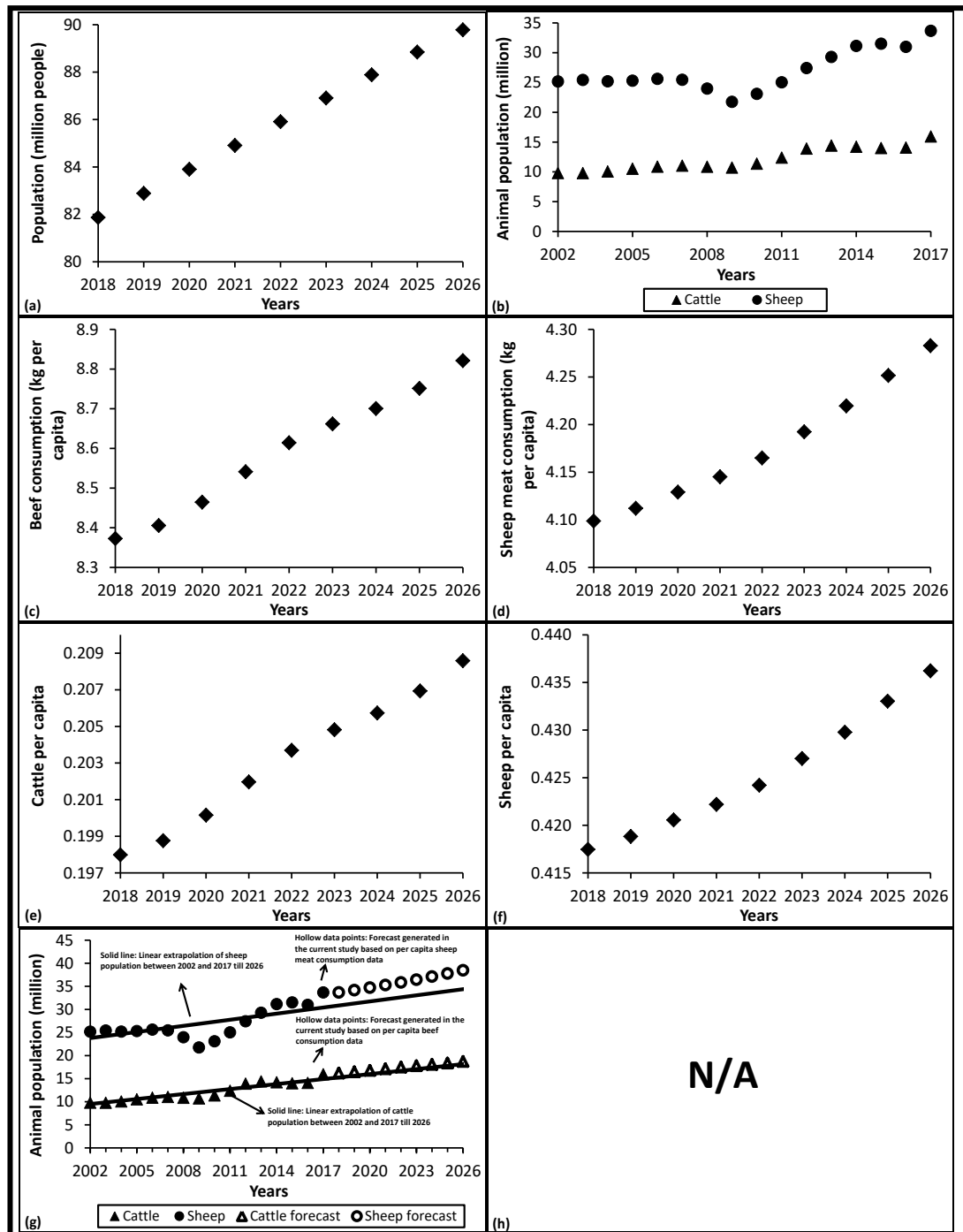


Figure 3.1: All data and calculations are for Turkey (nationwide) (a) Population (people) projection between 2018 and 2026 (b) Livestock (cattle and sheep) population between 2002 and 2017 (c) Beef consumption per capita projection between 2018 and 2026 (d) Sheep meat consumption per capita projection between 2018 and 2026 (e) Cattle per capita forecast between 2018 and 2026 (f) Sheep per capita forecast between 2018 and 2026 (g) Animal (cattle and sheep) population forecast between 2018 and 2026 (h) N/A.

$$PCA_{pcmp}(t) = PCA(t_{ref}) \times \frac{PCMP(t)}{PCMP(t_{ref})} \times CC_{milk}(t) + \varepsilon_t \quad (3.4)$$

In Equation (3.4), $PCA_{pcmp}(t)$ is explained in Equation (3.3); t_{ref} is taken as 2017, $PCA(t_{ref})$ data were estimated in Equation (3.2); $PCMP(t)$ is per capita milk production in year t ; $PCMP(t_{ref})$ is per capita milk production in year t_{ref} ; $CC_{milk}(t)$ is a correlation coefficient (annual) between per capita milk production and per capita animal in year t , $-1 \leq CC_{milk}(t) \leq 1$; and ε_t is a "random" error term.

In the second methodology, Turkey's milk production data between 2017 and 2026 are found from the OECD (in thousand tonnes) [OECD, 2018a]. Then, using Turkey's population projection given in Figure 3.1(a) Turkey's per capita milk production projection is calculated and shown in Figure 3.2(a) [OECD, 2018a]; [TurkStat, 2018c], [TurkStat, 2018a]. Here, it must be emphasized that OECD's timeline data for milk production (in thousand tonnes) between 2002 and 2017 are significantly higher than that of Turkey's Ministry of Agriculture and Forestry's cow milk production data [HAYGEM, 2018], [OECD, 2018a]. Therefore, OECD data should include sheep and goat milk data together with cow milk. As a result, a single milk production per capita forecast (Figure 3.2(a)) is used for estimating cattle and sheep population between 2018 and 2026. Turkey's per capita cattle and sheep population between 2018 and 2026 will grow parallel to its per capita milk production. The reason for this was explained in the paragraph above Equation (3.3). Therefore, $CC_{milk}(t)$ in Equation (3.4) is assumed as 1.0 for strongest possible agreement between 2018 and 2026.

Turkey's per capita cattle and sheep projections based on per capita milk production are generated using Equations (3.3) and (3.4) for a period between 2018 and 2026 and shown in Figure 3.2(b) and (c). As can be seen from Figure 3.2(d), Turkey's cattle and sheep population between 2018 and 2026 are projected using the per capita cattle and sheep projections and Turkey's population projection given in Figure 3.1(a). Finally, the results of per capita milk production based modelling studies can be analyzed from Figure 3.2 [OECD, 2018a], [TurkStat, 2018c], [TurkStat, 2018a].

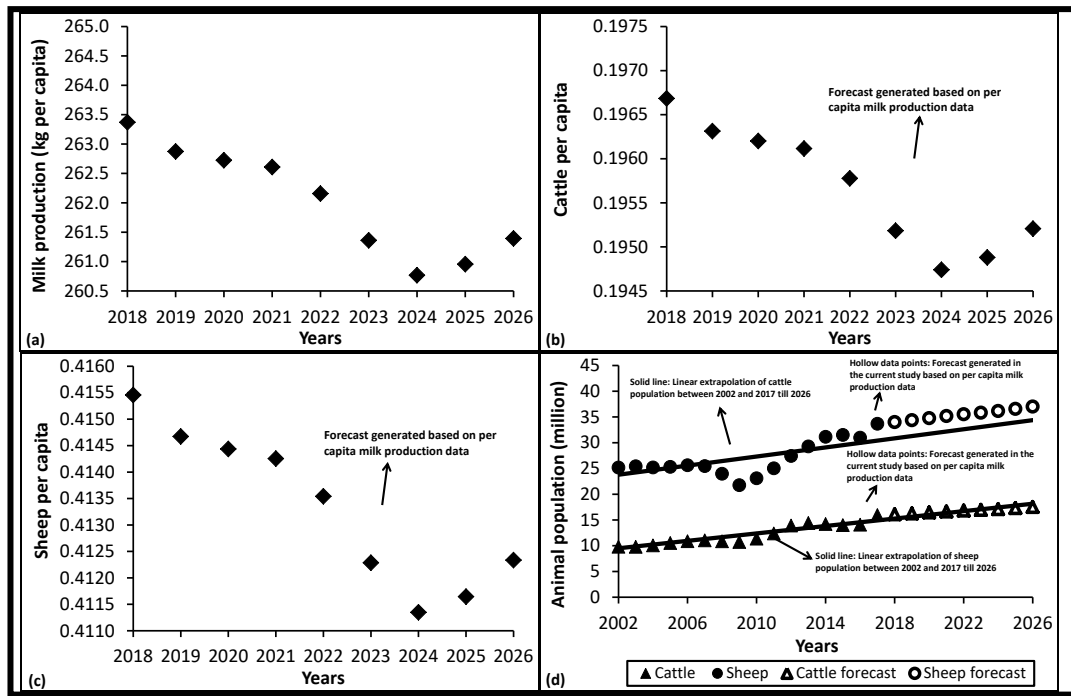


Figure 3.2: All data and calculations are for Turkey (nationwide) (a) Milk production per capita projection between 2018 and 2026 (b) Cattle per capita forecast between 2018 and 2026 (c) Sheep per capita forecast between 2018 and 2026 (d) Animal (cattle and sheep) population forecast between 2018 and 2026.

As can be seen from Figure 3.2(b) and (c), Turkey's milk production based cattle and sheep per capita projections have a decreasing trend between 2018 and 2026. These decreases are not linear but follow a polynomial trend. Overall, Turkey's cattle and sheep population projections based on per capita milk production follow a polynomial growth pattern with deceleration. As can be seen from Figure 3.2(d) cattle population projections are smaller than the BAU scenario. This is also means that Turkey's per capita milk production is decreasing much steeper than its per capita population growth. This is an important finding for milk producers and animal farmers.

3.1.2. Forecasting Biomethane and Electricity Generation from Cattle and Sheep Manure in Turkey till 2026

Biogas can be directly used as a fuel for heat and power generation with small levels of purification [Meier et al., 2015]. However, majority of CO₂ in biogas must be removed for using in motor vehicles and adding to the natural gas grid. This means producing a gas mixture that has the similar characteristics of natural gas

(fuel) [Meier et al., 2015]. First, the concentration of methane in the biogas must be increased by removing majority of the carbon dioxide and other trace gases. This methane rich biogas is now called as biomethane or just methane, which typically contains 95%-97% CH₄, 1%-3% CO₂ and trace amounts of O₂ and H₂S [Cheng et al., 2018], [Ryckebosch et al., 2011], [Urriza-Arsuaga et al., 2019]. This bioprocess is also known as biogas purification and upgrading [Cucchiella et al., 2018], [Omar et al., 2018], [Sarker et al., 2018]. There are various techniques used for removing CO₂ from biogas. Physical/chemical absorption, membrane separation, pressure-swing adsorption, and water scrubbing are some these techniques [Srinuanpan et al., 2018]. CH₄ purified from biogas can be used as a substitute for natural gas [Mittal et al., 2018], [Ryckebosch et al., 2011]. As a note of caution, it must be emphasized that these techniques require significant amount of energy, chemicals and generate wastes and wastewater streams [Srinuanpan et al., 2018]. Therefore, economic feasibility and environmental impacts of purification of methane from biogas must be well analysed.

As stated at the beginning of section 3.1, in this thesis study, Turkey's methane generation potentials from cattle and sheep manure will be calculated rather than biogas generation potentials (which can also be calculated using the average methane content in biogas conversion factors given in Table 2.4) because methane in biogas is a renewable energy source, which can be used for heat and power generation.

The following methodology is used for biomethane and electricity related calculations from animal manure. Biomethane generation from different types of animal manure can be calculated using Equation (3.5). In Equation (3.5), $G_{methane}(t)$ is methane generation per annum (m³ CH₄/year) in year t ; $P_{animal}(t)$ is animal population (animal) in year t ; G_{manure} is manure generation per animal per day (kg fresh animal manure/(day·animal)); $Y_{methane}$ is methane yield from fresh animal manure (m³ CH₄/tonne fresh animal manure); A_{manure} is availability factor of fresh animal manure (%); and ε_t is a "random" error term. Average values for G_{manure} , $Y_{methane}$, and A_{manure} are given in Table 2.6 and P_{animal} projections are given in Figures 3.1 and 3.2.

$$G_{methane}(t) = P_{animal}(t) \times G_{manure} \times A_{manure} \times Y_{methane} + \varepsilon_t \quad (3.5)$$

Using Equation (3.5) and data from Table 2.6, Figures 3.1 and 3.2, Turkey's biomethane generation potential from cattle and sheep manure between 2018 and 2026 are forecasted and shown in Figure 3.3. As can be seen from this figure, Turkey's cattle and sheep manure based biomethane generation could reach up to 1.99 billion m³ and 0.15 billion m³ in 2026, respectively. This means that a total of nearly 2.14 billion m³ of biomethane can be generated from Turkey's cattle and sheep manure in 2026. There is no estimate in the literature to check the soundness of this estimate. However, the methodology explained in the next paragraph can be used to approximately assess the accuracy.

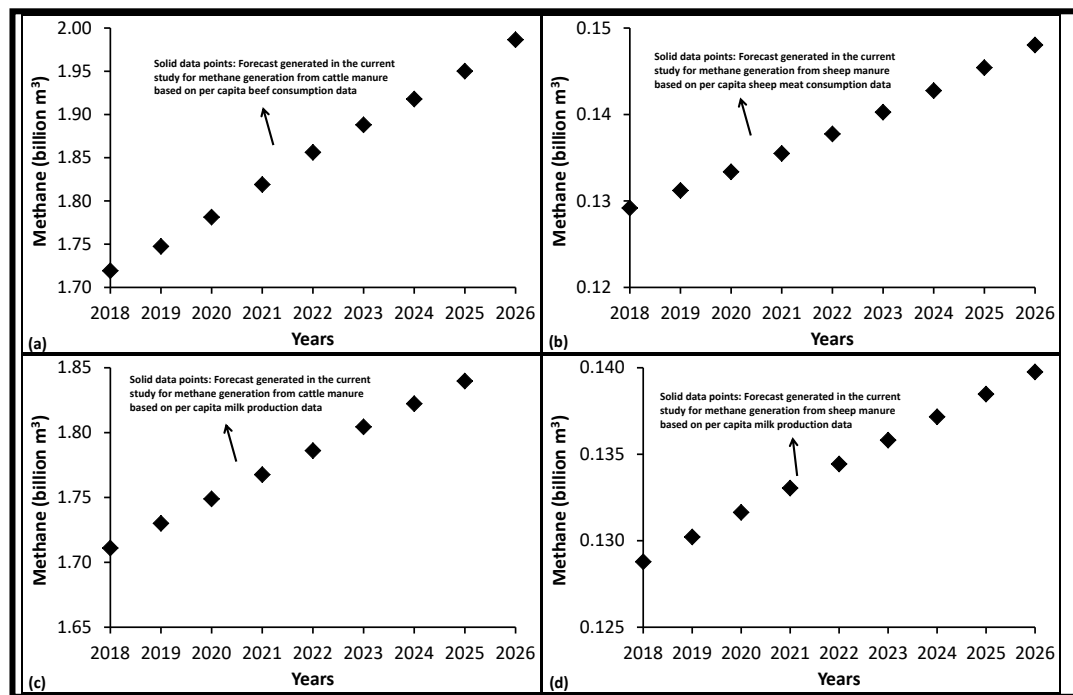


Figure 3.3: All data and calculations are for Turkey (nationwide) (a) Methane generation forecast from cattle manure between 2018 and 2026 (based on meat consumption data) (b) Methane generation forecast from sheep manure between 2018 and 2026 (based on meat consumption data) (c) Methane generation forecast from cattle manure between 2018 and 2026 (based on milk production data) (d) Methane generation forecast from sheep manure between 2018 and 2026 (based on milk production data).

Avcioglu and Turker estimated Turkey's cattle and sheep manure based biogas potential in 2009 as nearly 1.5 billion m³ from a cattle population of nearly 10.8 million and nearly 0.1 billion m³ from sheep population of nearly 26.9 million [Avcioglu and Türker, 2012]. Taking average methane content in cattle manure as 57.8% and sheep manure as nearly 58.5% (see Table 2.6) and based on the

calculations of Avcioglu and Turker [Avcioglu and Türker, 2012]: Turkey's biomethane generation potential in 2009 was nearly 0.9 billion m³ from cattle and nearly 0.1 billion m³ from sheep. In the current study, Turkey's cattle and sheep population in 2026 was estimated at nearly 19 and 39 million. Thus, as a ballpark figure, based on Avcioglu and Turker's calculation [Avcioglu and Türker, 2012]: Turkey's biomethane generation potential in 2026 should be 19/10.8×0.9=1.58 billion m³ from cattle manure and 39/26.9×0.1=0.15 billion m³ from sheep manure. Adding to a total of nearly 1.7 billion m³ biomethane, which is nearly 80% of the current estimate of nearly 2.1 billion m³.

The amount of electricity that can be generated from biogas can be calculated using Equation (3.6) [Abdeshahian et al., 2016], [Hosseini and Wahid, 2014]. In Equation (3.6), E_{biogas} is the amount of electricity generated from biogas per annum (kWh/year) in year t ; EC_{biogas} is the energy content of biogas, which is assumed as 6.0 kWh/m³; $G_{methane,total}$ is total methane generation per annum in year t , which is $G_{methane}$ cattle and sheep values combined calculated via Equation (3.5) (m³ CH₄/year) (Note: data are from per capita meat consumption based modelling in order to estimate the potential maxima); $R_{methane}$ is methane content in biogas (%), average values of which are given in Table 2.6 as 57.8% for cattle and 58.5% for sheep; η is the overall efficiency of biogas conversion to electricity in %, which is assumed as 30.0%; and ε_t is a “random” error term [Abdeshahian et al., 2016], [Hosseini and Wahid, 2014].

$$E_{biogas}(t) = EC_{biogas} \times \frac{G_{methane,total}(t)}{R_{methane}} \times \eta + \varepsilon_t \quad (3.6)$$

In estimating Turkey's electricity generation potential from cattle and sheep manure, methane generation data based on meat consumption model given Figures 3.3(a) and (b) are used. This is because meat consumption based methane generation forecasts are higher than milk production based projections. Therefore, they are used to calculate the potential maximum electricity generation values. The results are shown in part (a) of Figure 3.4 [Melikoglu, 2013c]. As can be seen from this figure, up to 6,600 GWh of electricity (per annum) can be generated from cattle and sheep manure in Turkey till 2026. This is a significant amount and it could be more than 1% of Turkey's electricity demand in 2026 [Melikoglu, 2018].

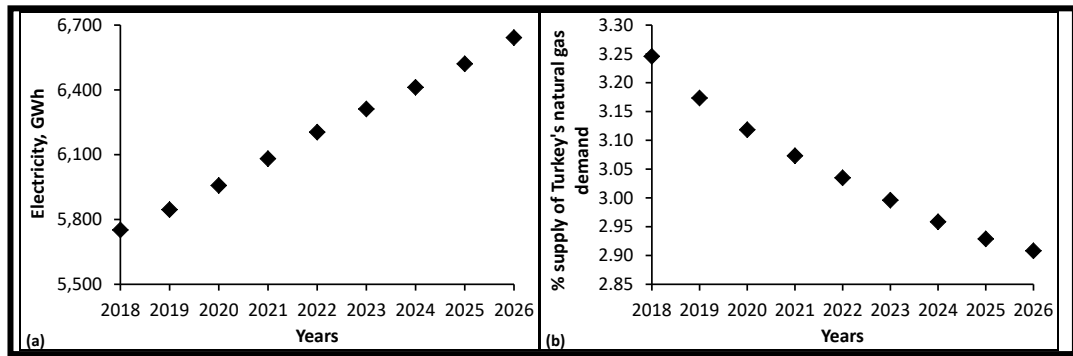


Figure 3.4: Potential calculations for Turkey (nationwide) (a): Electricity generation from cattle and sheep manure originated biomethane between 2018 and 2026 (b) % supply of Turkey's natural gas demand between 2018 and 2026.

As explained above, if methane can be separated from biogas and purified to pipeline standards then it can be used as a direct substitute for natural gas. As a result, potential methane generation values given in Figure 3.3(a) and (b) based on meat consumption data (higher than milk production based projections; therefore, used to calculate the maxima) are used to calculate potential supply rate of Turkey's natural gas demand between 2018 and 2026. Turkey's natural gas demand projections were previously calculated by the thesis advisor of the current study [Melikoglu, 2013c]. The results are shown in Figure 3.4(b). As can be seen from Figure 3.4(b), if collected and processed properly Turkey's cattle and sheep manure based biomethane generation could supply between 2.90% and 3.25% of Turkey's natural gas demand (per annum) between 2018 and 2026 (natural gas projections are from literature methane data from Figure 3.3(a) and (b) in order to assess potential maxima). This is a significant amount considering that Turkey's natural gas demand in 2030 is estimated to reach nearly 80.0 billion m³ if Turkey's Vision 2023 energy targets are realised [Melikoglu, 2013b]. This is a significant amount and clearly shows the importance of biomethane investments in Turkey. However, as stated above, biomethane generation from animal manure is a relatively new topic in Turkey. Therefore, future of biomethane generation must be analysed based on the findings from this study.

As a result, there is a significant potential for methane and electricity generation from cattle and sheep manure in Turkey. However, most of the animal husbandries in Turkey are spread throughout the nation. Therefore, local waste to energy schemes and government subsidies must be given to animal farmers to

increase utilisation of cattle and sheep manure for biogas generation. The future of biogas generation from animal manure in Turkey is further assessed in the next section of this thesis study.

4. FUTURE of HARNESSING BIOGAS and BIOMETHANE FROM ANIMAL MANURE in TURKEY

Results given in this thesis study clearly showed that there is a great potential of biogas and concurrently biomethane generation from animal manure in Turkey. However, biogas generation from cattle, sheep and other types of animal manure is not well established in Turkey. As a result, there are several challenges in front of widespread biogas generation from animal manure. The first challenge is the size of farm based biogas systems. It is reported that farm based biogas harnessing systems have digester volume of between 5 m³ and 10 m³ [Lwiza et al., 2017]. Biomass collection (transportation) is a major cost item for large scale biogas generation [Skovsgaard and Jacobsen, 2017]. As a result, the economics of centralised large scale biogas generation and decentralised small scale biogas generation must be well analysed in Turkey and elsewhere. In a recent study, Lauer and colleagues found that herd size greater than 3,000 cows per farm is required for an economically feasible anaerobic plant operation; for farms up to 3,600 cows on-farm utilisation of biogas has the highest net present value; for farms larger than 3,600 cows the best economic results are attained via the production of biomethane [Lauer et al., 2018]. They also suggested that instead of small size anaerobic digestion plants a higher manure consumption rate could be achieved through co-operative (joint) manure transportation and anaerobic digestion plants [Lauer et al., 2018]. Therefore, establishment of large scale integrated animal husbandries (with bioprocessing options including biogas generation) must be supported by government incentives and promotion of co-operative animal farming options in Turkey and elsewhere.

It is often suggested that decentralised generation and utilisation of biogas can speed up the shift towards sustainable development [Lyytimäki, 2018]. Since animal husbandries are mostly located throughout different regions, biogas generation from animal manure can provide various benefits. Anaerobic digestion of animal manure in small-scale biogas digesters have the following advantages: Biogas harnessing for combined heat and power at farm scale including utilisation at stoves for cooking, lightning, and water boiling; and the utilisation of digestate used as fertilizer [Roubík and Mazancová, 2019]. Digestate when used as an organic fertilizer reduces the consumption of fossil fuel based fertilizers, pesticides, and consequently, fossil fuel

consumption and hence help reducing farm based greenhouse gas emissions [Deng et al., 2017]. Production of biogas from animal manure affects soil organic carbon (SOC) cycle of the farms [Witing et al., 2018]. In a recent study, high carbon input to soil has been observed in the areas involved in biogas production; however, it must be emphasized that this was highly related to the utilisation of digestate [Witing et al., 2018]. Therefore, animal population based feasibility analysis and forecasts must be carried out farm, region and larger scales in Turkey before any potential investments.

Another important issue is the composition of animal manure for biogas generation. It is reported that the composition of biomass (proteins, fats, and carbohydrates) critically affects methane yield via AD [do Carmo Precci Lopes et al., 2018]. The optimum biomass composition must be analysed and monitored for higher yields. The carbon-nitrogen C/N ratio must be optimised to enhance methane generation [Chen et al., 2017]. Animal manures are generally rich in nitrogen; as a result, optimum carbon to nitrogen (C/N) ratio required for anaerobic digestion cannot be attained in some cases [Neshat et al., 2017], [Tufaner and Avşar, 2016]. In order to solve this problem carbon content of animal manure should be increased before anaerobic digestion [Neshat et al., 2017]. Manure can be digested together with two or more feedstock in a process known as anaerobic co-digestion (AcoD) [Hagos et al., 2017], [Ma et al., 2017], [Mata-Alvarez et al., 2000]. The use of a co-substrate generally enhances biogas yield due to supply of missing nutrients from the original feedstock [Mata-Alvarez et al., 2000]. AcoD also helps overcoming drawbacks of single feedstock anaerobic digestion and increase methane yield from biogas plants [Hagos et al., 2017]. AcoD of cattle manure and corn silage is a well-established technology for digestate and biogas production in the EU [Tişma et al., 2018]. Crop straw and animal manure are the most widespread feedstock for biogas production [Wandera et al., 2018]. In Denmark, the main input for biogas generation is manure, which is mixed with different co-substrates in order to enhance the yield [Skovsgaard and Jacobsen, 2017]. Therefore, co-digestion of animal manure with other agricultural wastes must be well analysed before any potential investments in Turkey and elsewhere.

Finally, the main motivators behind rapid expansion of biogas facilities in the EU are supportive government policies and economic subsidies to produce electricity from biomass [D'Imporzano et al., 2018]. Therefore, the future of biogas generation

in Turkey should be supported by the private sector, government, EU and international funds/incentives.

5. CONCLUSIONS

In this thesis study, first a global guide providing average values for: fresh manure yield per animal per day (kg/day), total solids in different types of animal manure (%), availability factors (%) of different types of animal manure, methane content (%) in biogas generated from different types of animal manure, and methane yield from different types of animal manure (m^3/tonne fresh matter) are prepared for cattle, sheep, chicken and pig manure. It is believed that this valuable information given in Table 2.6 can be used by researchers around the globe for energy and biomass related calculation from different types of animal manure. Then, from global to local, biogas and concurrently biomethane generation potential of cattle and sheep manure in Turkey till 2026 is forecasted based on meat consumption and milk production projections. It is estimated that Turkey's cattle and sheep population could reach up to 18.7 million and 39.2 million, respectively in 2026. At these animal populations, it estimated that up to 2.1 billion m^3 of methane (per annum) can be generated from cattle and sheep manure in Turkey till 2026. This amount of methane can supply 2.9% of Turkey's natural gas demand (per annum) and generate up to 6,600 GWh (per annum) of electricity till 2026. Biogas generation and harnessing from animal manure is a relatively new topic for Turkey. Therefore, it is suggested that nationwide planning must be carefully made before any large scale investments. Finally, it is suggested animal manure based biogas generation in Turkey must be supported by the government, EU and international funds/incentives if nationwide distribution of small, mid, and large scale farm based systems are wanted.

REFERENCES

- Abdelsalam E., Samer M., Abdel-Hadi M. A., Hassan H. E., Badr Y., (2018), "Influence of laser irradiation on rumen fluid for biogas production from dairy manure", *Energy*, 163, 404–415.
- Abdeshahian P., Lim J. S., Ho W. S., Hashim H., Lee C. T., (2016), "Potential of biogas production from farm animal waste in Malaysia", *Renewable and Sustainable Energy Reviews*, 60, 714–723.
- Abouelenien F., Nakashimada Y., Nishio N., (2009), "Dry mesophilic fermentation of chicken manure for production of methane by repeated batch culture", *Journal of Bioscience and Bioengineering*, 107 (3), 293–295.
- Achinas S., Achinas V., Euverink G. J. W., (2017), "A Technological Overview of Biogas Production from Biowaste", *Engineering*, 3 (3), 299-307.
- Achinas S., Li Y., Achinas V., Euverink G. J. W., (2018), "Influence of sheep manure addition on biogas potential and methanogenic communities during cow dung digestion under mesophilic conditions", *Sustainable Environment Research*, 28, 240–246.
- Afazeli H., Jafari A., Rafiee S., Nosrati M., (2014), "An investigation of biogas production potential from livestock and slaughterhouse wastes", *Renewable and Sustainable Energy Reviews*, 34, 380-386.
- Angelidaki I., Ellegaard L., (2003), "Codigestion of manure and organic wastes in centralized biogas plants", *Applied Biochemistry and Biotechnology*, 109 (1), 95–105.
- Astals S., Ariso M., Galí A., Mata-Alvarez J., (2011), "Co-digestion of pig manure and glycerine: Experimental and modelling study", *Journal of Environmental Management*, 92 (4), 1091–1096.
- Avcioğlu A. O., Türker U., (2012), "Status and potential of biogas energy from animal wastes in Turkey", *Renewable and Sustainable Energy Reviews*, 16 (3), 1557–1561.
- Bujoczek G., Oleszkiewicz J., Sparling R., Cenkowski S., (2000), "High Solid Anaerobic Digestion of Chicken Manure", *Journal of Agricultural Engineering Research*, 76 (1), 51–60.
- Burg V., Bowman G., Haubensak M., Baier U., Thees O., (2018), "Valorization of an untapped resource: Energy and greenhouse gas emissions benefits of converting manure to biogas through anaerobic digestion", *Resources, Conservation and Recycling*, 136, 53–62.

Chen L., Cong R.-G., Shu B., Mi Z.-F., (2017), “A sustainable biogas model in China: The case study of Beijing Deqingyuan biogas project”, *Renewable and Sustainable Energy Reviews*, 78, 773–779.

Chen Q., Liu T., (2017), “Biogas system in rural China: Upgrading from decentralized to centralized?”, *Renewable and Sustainable Energy Reviews*, 78, 933–944.

Cheng Y., Yuan T., Deng Y., Lin C., Zhou J., Lei Z., Zhang, Z., (2018), “Use of sulfur-oxidizing bacteria enriched from sewage sludge to biologically remove H₂S from biogas at an industrial-scale biogas plant”, *Bioresource Technology Reports*, 3, 43–50.

Cucchiella F., D’Adamo I., Gastald, M., Miliacca M., (2018), “A profitability analysis of small-scale plants for biomethane injection into the gas grid”, *Journal of Cleaner Production*, 184, 179–187.

D’Imporzano G., Pilu R., Corno L., Adani F., (2018), “*Arundo donax* L. can substitute traditional energy crops for more efficient, environmentally-friendly production of biogas: A Life Cycle Assessment approach”, *Bioresource Technology*, 267, 249–256.

Deng L., Liu Y., Zheng D., Wang L., Pu X., Song L., Wang Z., Lei Y., Chen Z., Long Y., (2017), “Application and Development of Biogas Technology for the treatment of Waste in China”, *Renewable and Sustainable Energy Reviews*, 70, 845–851.

Do Carmo Precci Lopes A., Mudadu Silva C., Pereira Rosa A., de Ávila Rodrigues, F., (2018), “Biogas production from thermophilic anaerobic digestion of kraft pulp mill sludge”, *Renewable Energy*, 124, 40–49.

Ferella F., Cucchiella F., D’Adamo I., Gallucci K., (2019), “A techno-economic assessment of biogas upgrading in a developed market”, *Journal of Cleaner Production*, 210, 945–957.

Ferrer I., Gamiz M., Almeida M., Ruiz A., (2009), “Pilot project of biogas production from pig manure and urine mixture at ambient temperature in Ventanilla (Lima, Peru)”, *Waste Management*, 29 (1), 168–173.

Ganzoury M. A., Allam N. K., (2015), “Impact of nanotechnology on biogas production: A mini-review”, *Renewable and Sustainable Energy Reviews*, 50, 1392–1404.

Hagos K., Zong J., Li D., Liu C., Lu X., (2017), “Anaerobic co-digestion process for biogas production: Progress, challenges and perspectives”, *Renewable and Sustainable Energy Reviews*, 76, 1485–1496.

Hamelin L., Naroznova I., Wenzel H., (2014), “Environmental consequences of different carbon alternatives for increased manure-based biogas”, *Applied Energy*, 114, 774–782.

HAYGEM, (2018), Turkey's 2017 livestock data, Republic of Turkey Ministry of Agriculture And Forestry - General Directorate of Livestock.

Holm-Nielsen J. B., Al Seadi T., Oleskowicz-Popiel P., (2009), "The future of anaerobic digestion and biogas utilization", *Bioresource Technology*, 100, 5478–5484.

Hosseini S. E., Wahid M. A., (2014), "Development of biogas combustion in combined heat and power generation", *Renewable and Sustainable Energy Reviews*, 40, 868–875.

Huang J. J. H., Shih J. C. H., (2018), "The potential of biological methane generation from chicken manure", *Biotechnology and Bioengineering*, 23 (10), 2307–2314.

Hung C.-Y., Tsai W.-T., Chen J.-W., Lin Y.-Q., Chang Y.-M., (2017), "Characterization of biochar prepared from biogas digestate", *Waste Management*, 66, 53–60.

Kadam R., Panwar N. L., (2017), "Recent advancement in biogas enrichment and its applications", *Renewable and Sustainable Energy Reviews*, 73, 892-903.

Kafle G. K., Kim S. H., (2013), "Anaerobic treatment of apple waste with swine manure for biogas production: Batch and continuous operation", *Applied Energy*, 103, 61–72.

Kanwar S. S., Kalia A. K., (1993), "Anaerobic fermentation of sheep droppings for biogas production", *World Journal of Microbiology and Biotechnology*, 9 (2), 174–175.

Kaparaju P., Rintala J., (2005), "Anaerobic co-digestion of potato tuber and its industrial by-products with pig manure", *Resources, Conservation and Recycling*, 43 (2), 175–188.

Lauer M., Hansen J. K., Lamers P., Thrän D., (2018), "Making money from waste: The economic viability of producing biogas and biomethane in the Idaho dairy industry", *Applied Energy*, 222, 621–636.

Li Y., Park S. Y., Zhu J., (2011), "Solid-state anaerobic digestion for methane production from organic waste", *Renewable and Sustainable Energy Reviews*, 15, 821–826.

Li Y., Zhang R., Chen C., Liu G., He Y., Liu X., (2013), "Biogas production from co-digestion of corn stover and chicken manure under anaerobic wet, hemi-solid, and solid state conditions", *Bioresource Technology*, 149, 406–412.

Lijó L., González-García S., Bacenetti J., Moreira M. T., (2017), "The environmental effect of substituting energy crops for food waste as feedstock for biogas production", *Energy*, 137, 1130-1143.

Lwiza F., Mugisha J., Walekhwa P. N., Smith J., Balana B., (2017), “Dis-adoption of household biogas technologies in central uganda”, *Energy for Sustainable Development*, 37, 124–132.

Lyytimäki J., (2018), “Renewable energy in the news: Environmental, economic, policy and technology discussion of biogas”, *Sustainable Production and Consumption*, 15, 65–73.

Ma G., Neibergs J. S., Harrison J. H., Whitefield E. M., (2017), “Nutrient contributions and biogas potential of co-digestion of feedstocks and dairy manure”, *Waste Management*, 64, 88–95.

Makara A., Kowalski Z., (2018), “Selection of pig manure management strategies: Case study of Polish farms”, *Journal of Cleaner Production*, 172, 187–195.

Mao C., Feng Y., Wang X., Ren G., (2015), “Review on research achievements of biogas from anaerobic digestion”, *Renewable and Sustainable Energy Reviews*, 45, 540–555.

Mata-Alvarez J., Macé S., Llabrés P., (2000), “Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives”, *Bioresource Technology*, 74 (1), 3–16.

Meier L., Pérez R., Azócar L., Rivas M., Jeison D., (2015), “Photosynthetic CO₂ uptake by microalgae: An attractive tool for biogas upgrading”, *Biomass and Bioenergy*, 73, 102–109.

Melikoglu M., (2013a), “Vision 2023: Assessing the feasibility of electricity and biogas production from municipal solid waste in Turkey”, *Renewable and Sustainable Energy Reviews*, 19 (0), 52–63.

Melikoglu M., (2013b), “Vision 2023: Feasibility analysis of Turkey’s renewable energy projection”, *Renewable Energy*, 50 (0), 570–575.

Melikoglu M., (2013c), “Vision 2023: Forecasting Turkey’s natural gas demand between 2013 and 2030”, *Renewable and Sustainable Energy Reviews*, 22 (0), 393–400.

Melikoglu M., (2016), “The role of renewables and nuclear energy in Turkey’s Vision 2023 energy targets: Economic and technical scrutiny”, *Renewable and Sustainable Energy Reviews*, 62, 1–12.

Melikoglu M., (2017), “Vision 2023: Status quo and future of biomass and coal for sustainable energy generation in Turkey”, *Renewable and Sustainable Energy Reviews*, 74, 800–808.

Melikoglu M., (2018), “Vision 2023: Scrutinizing achievability of Turkey’s electricity capacity targets and generating scenario based nationwide electricity demand forecasts”, *Energy Strategy Reviews*, 22, 188–195.

- Meyer A. K. P., Ehimen E. A., Holm-Nielsen J. B., (2018), “Future European biogas: Animal manure, straw and grass potentials for a sustainable European biogas production”, *Biomass and Bioenergy*, 111, 154–164.
- Mittal S., Ahlgren E. O., Shukla P. R., (2018), “Barriers to biogas dissemination in India: A review”, *Energy Policy*, 112, 361–370.
- Moreda I. L., (2016), “The potential of biogas production in Uruguay”, *Renewable and Sustainable Energy Reviews*, 54, 1580–1591.
- Morero B., Groppelli E. S., Campanella E. A., (2017), “Evaluation of biogas upgrading technologies using a response surface methodology for process simulation”, *Journal of Cleaner Production*, 141, 978–988.
- Murto M., Björnsson L., Mattiasson B., (2004), “Impact of food industrial waste on anaerobic co-digestion of sewage sludge and pig manure”, *Journal of Environmental Management*, 70 (2), 101–107.
- Neshat S. A., Mohammadi M., Najafpour G. D., Lahijani P., (2017), “Anaerobic co-digestion of animal manures and lignocellulosic residues as a potent approach for sustainable biogas production”, *Renewable and Sustainable Energy Reviews*, 79, 308–322.
- Ngwabie N. M., Chungong B. N., Yengong F. L., (2018), “Characterisation of pig manure for methane emission modelling in Sub-Saharan Africa”, *Biosystems Engineering*, 170, 31–38.
- Niu Q., Hojo T., Qiao W., Qiang H., Li Y.-Y., (2014), “Characterization of methanogenesis, acidogenesis and hydrolysis in thermophilic methane fermentation of chicken manure”, *Chemical Engineering Journal*, 244, 587–596.
- Nuchdang S., Phalakornkule C., (2012), “Anaerobic digestion of glycerol and co-digestion of glycerol and pig manure”, *Journal of Environmental Management*, 101, 164–172.
- OECD, (2018a), *DAIRY - OECD-FAO Agricultural Outlook 2017-2026*, Organisation for Economic Co-operation and Development.
- OECD, (2018b), *Meat consumption (indicator)*, Organisation for Economic Co-operation and Development.
- Omar B., Abou-Shanab R., El-Gammal M., Fotidis I. A., Kougias P. G., Zhang Y., Angelidaki I., (2018), “Simultaneous biogas upgrading and biochemicals production using anaerobic bacterial mixed cultures”, *Water Research*, 142, 86–95.
- Omer A. M., Fadalla Y., (2003), “Biogas energy technology in Sudan”, *Renewable Energy*, 28, 499–507.

Qiao W., Yan X., Ye J., Sun Y., Wang W., Zhang Z., (2011), “Evaluation of biogas production from different biomass wastes with/without hydrothermal pretreatment”, *Renewable Energy*, 36 (12), 3313–3318.

QLD, (2018), Manure production data, Queensland Government - Department of Agriculture and Fisheries.

Rasi S., Veijanen A., Rintala J., (2007), “Trace compounds of biogas from different biogas production plants”, *Energy*, 32, 1375–1380.

Roubík H., Mazancová J., (2019), “Small-scale biogas plants in central Vietnam and biogas appliances with a focus on a flue gas analysis of biogas cook stoves”, *Renewable Energy*, 131, 1138–1145

Ryckebosch E., Drouillon M., Vervaeren H., (2011), “Techniques for transformation of biogas to biomethane”, *Biomass and Bioenergy*, 35 (5), 1633–1645.

Sahota S., Shah G., Ghosh P., Kapoor R., Sengupta S., Singh P., Vijay V., Sahay A., Vijay V. K., Thakur I. S., (2018), “Review of trends in biogas upgradation technologies and future perspectives”, *Bioresource Technology Reports*, 1, 79-88.

Sarker S., Lamb J. J., Hjelme D. R., Lien K. M., (2018), “Overview of recent progress towards in-situ biogas upgradation techniques”, *Fuel*, 226, 686–697.

Scarlat N., Dallemand J.-F., Fahl F., (2018), “Biogas: Developments and perspectives in Europe”, *Renewable Energy*, 129, 457–472.

Sefeedpari P., Rafiee S., Akram A., (2012), “Providing electricity requirements by biogas production and its environmental benefit in sample dairy farms of Iran”, *International Journal Renewable Energy Research*, 2 (3), 384–7.

Selvaggi R., Pappalardo G., Chinnici G., Fabbr, C. I., (2018), “Assessing land efficiency of biomethane industry: A case study of Sicily”, *Energy Policy*, 119, 689–695.

Sun Q., Li H., Yan J., Liu L., Yu Z., Yu X., (2015), “Selection of appropriate biogas upgrading technology-a review of biogas cleaning, upgrading and utilisation”, *Renewable and Sustainable Energy Reviews*, 51, 521–532.

Surendra K. C., Takara D., Hashimoto A. G., Khanal S. K., (2014), “Biogas as a sustainable energy source for developing countries: Opportunities and challenges”, *Renewable and Sustainable Energy Reviews*, 31, 846–859.

Skovsgaard L., Jacobsen H. K., (2017), “Economies of scale in biogas production and the significance of flexible regulation”, *Energy Policy*, 101, 77–89.

Srinuanpan S., Cheirsilp B., Prasertsan P., (2018), “Effective biogas upgrading and production of biodiesel feedstocks by strategic cultivation of oleaginous microalgae”, *Energy*, 148, 766–774.

Teymoori Hamzehkolaei F., Amjady N., (2018), “A techno-economic assessment for replacement of conventional fossil fuel based technologies in animal farms with biogas fueled CHP units”, *Renewable Energy*, 118, 602–614.

Tišma M., Planinić M., Bucić-Kojić A., Panjičko M., Zupančič G. D., Zelić B. (2018), “Corn silage fungal-based solid-state pretreatment for enhanced biogas production in anaerobic co-digestion with cow manure”, *Bioresource Technology*, 253, 220–226.

Tufaner F., Avşar Y., (2016), “Effects of co-substrate on biogas production from cattle manure: a review”, *International Journal of Environmental Science and Technology*, 13 (9), 2303–2312.

TurkStat, (2017a), Number of livestock, 2001-2017, Turkish Statistical Institute.

TurkStat, (2017b), Youth in statistics, 2017, Turkish Statistical Institute.

TurkStat, (2018a), Population of province/district centers and towns/villages by years and sex, Turkish Statistical Institute.

TurkStat, (2018b), Turkey: Number of livestock, 2002-2017, Turkish Statistical Institute.

TurkStat, (2018c), Turkey: Population by years, 2018-2030, Turkish Statistical Institute.

Urriza-Arsuaga I., Bedoya M., Orellana G., (2019), “Luminescent sensor for O₂ detection in biomethane streams”, *Sensors and Actuators B: Chemical*, 279, 458–465.

USDA, (2018), RCA Issue Brief #7 December 1995, Animal Manure Management.

Wandera S. M., Qiao W., Algapani D. E., Bi S., Yin D., Qi X., Liu Y., Dach J., Dong R., (2018), “Searching for possibilities to improve the performance of full scale agricultural biogas plants”, *Renewable Energy*, 116, 720–727.

Wang Y., Wu X., Tong X., Li T., Wu F., (2018), “Life cycle assessment of large-scale and household biogas plants in northwest China”, *Journal of Cleaner Production*, 192, 221–235.

Web 1, (2018), <http://www.hurriyetdailynews.com/turkeys-population-hits-new-high-over-80-million-tuik-126647>, (Data accessed: 13/01/2019).

Web 2, (2018), <https://data.oecd.org/gdp/gross-domestic-product-gdp.htm>, (Data accessed: 19/02/2019).

Web 3, (2018), <https://www.bbc.com/news/business-45113472>, (Data accessed: 13/01/2019).

Web4,(2018),<https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=TR> (Data accessed: 10/01/2019).

Web 5, (2018), <https://www.theguardian.com/world/2018/aug/13/turkey-financial-crisis-lira-plunges-again-amid-contagion-fears>, (Data accessed: 19/02/2019).

Witing F., Prays N., O’Keeffe S., Gründling R., Gebel M., Kurzer H.-J., Daniel-Gromke J., Franko U., (2018), “Biogas production and changes in soil carbon input - A regional analysis”, *Geoderma*, 320, 105–114.

Xie S., Lawlor P. G., Frost J. P., Hu Z., Zhan X., (2011), “Effect of pig manure to grass silage ratio on methane production in batch anaerobic co-digestion of concentrated pig manure and grass silage”, *Bioresource Technology*, 102 (10), 5728–5733.

Zaidi A. A., RuiZhe F., Shi Y., Khan S. Z., Mushtaq K., (2018), “Nanoparticles augmentation on biogas yield from microalgal biomass anaerobic digestion”, *International Journal of Hydrogen Energy*, 43, 14202–14213.

Zareei S., (2018), “Evaluation of biogas potential from livestock manures and rural wastes using GIS in Iran”, *Renewable Energy*, 118, 351–356.

Zeng Y., Xiao L., Zhang X., Zhou J., Ji G., Schroeder S., Liu G., Yan Z., (2018), “Biogas desulfurization under anoxic conditions using synthetic wastewater and biogas slurry”, *International Biodeterioration and Biodegradation*, 133, 247-255.

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