ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

THE EFFECTS OF BIODEGRADABLE WASTE DIVERSION ON LANDFILL GAS POTENTIAL IN TURKEY

M.Sc. THESIS

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

KENTSEL ATIK DEPOLAMA SAHALARINA GİDEN BİYOBOZUNUR ATIKLARIN AZALTILMASININ TÜRKİYE'DEKİ ÇÖP GAZI (LFG) POTANSİYELİNE OLAN ETKİLERİ

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To my dear mom & dad,

FOREWORD

First of all, I would like to thank to Assoc. Prof. Osman Atilla Arıkan, PhD. for giving me the idea of this important study, shedding light on the potential LFG amount of Turkey till 2040 and revealing the electricity generation potential based on LFG as a 70% foreign-dependent country in energy sector, and showing me the way.

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Hasan Suphi ALTAN
Environmental Engineer
Investments & Corporate Communication Specialist

TABLE OF CONTENTS

Page

ABBREVIATIONS

App : Appendix
ATSDR : Agency for Toxic Substances and Disease Registry
EEA : European Environment Agency
EEEW : Electrical & Electronical Equipment Waste
EMRA : Electricity Market Regulatory Authority
EPA : Envrionmental Protection Agency
EUROSTAT : Statistics Authority of Europe
GDoRE : General Directorate of Renewable Energy
GHG : Greenhouse Gas
GMI : Global Methane Initiative
KAAP : Solid Waste Master Plan
LFG : Landfill Gas
LFGTE : Landfill Gas to Electricity
LMOP : Landfill Methane Outreach Program
LNG : Liquid Natural Gas
MoE&U : T.R. Ministry of Environment and Urbanisation
MSW : Municipal Solid Waste
NMOC : Nonmethanic Organic Compound
SEPA : Scottish Environmental Protection Agency
SWMP : Solid Waste Master Plan
TUIK : Statistics Authority of Turkey
TURKSTAT : Statistics Authority of Turkey

LIST OF TABLES

Page

LIST OF FIGURES

INVESTIGATION ON THE EFFECTS OF REDUCTION ON BIODEGRADABLE WASTE GOING TO THE LANDFILLS ON TURKEY'S FUTURE LANDFILL GAS POTENTIAL

SUMMARY

As part of European Union acquis adaptation process, Turkey's waste management systems along with other important areas got in a fast change and development period. With the issuance of The Regulation of Sanitary Landfilling of Waste in 2010, the procedure for landfilling waste was defined, certain terms were put to motion for rehabilitation of disorderly waste dump-sites and necessary precautions were taken to prevent formation of any future disorderly waste dumping activities. These developments introduced vast changes, the disorderly waste disposal sites that reached to almost 2000 in 2009, were swiftly shut down; along with fast introduction of proper waste disposal sites, which processed ever-growing amount of urban wastes. In scope of related regulations, the landfill gas produced at the waste disposal sites was required by law to be collected and burned; and used for renewable energy in the power plants if it is financially feasible. In 2010, with the introduction of Turkish Ministry of Energy and Natural Resources' program to support renewable energy, 10 years of fixed priced purchase by the government was guaranteed for the power produced by other renewable resources as well as landfill gas and therefore production of energy with the usage of landfill gas was given incentive from the government. In keeping with acquired experience in the field, the power plants that produce energy with landfill gas that have 1 MW and more of installed capacity became financially feasible with the given incentives. In other words, it became possible to have landfill gas to electricity plants at the sites that produce approximately 500 m^3/hour of landfill gas or sites that serve cities with 750,000 populations in consideration with the country's current urban waste characterization and waste produced per capita. However by scope of the Regulation of Sanitary Landfilling serious goals are set for diversion of biodegradable waste sent to landfills. According to this, biodegradable wastes that sent to landfills will be decreased at 3 stages and finally in 2025, %35 of the biodegradable wastes would be sent to landfills compared to total production biodegradable wastes it 2005. However, a decrease in biodegradable materials going to landfill sites may influence the amount of landfill gas for future years and the feasibilities may become negative which will end up with many problems like shutting down the plants which are on operation due to the financial stress of operators. The purpose of this thesis is to see the effects of biodegradable waste diversion from the landfills on Turkey's future landfill gas potential. For that purpose, first of all, current situation in MSW waste and LFG management has been evaluated. Three different scenarios are evaluated in this study in order to see the effects of biodegradable waste diversion on landfill gas production potential. The first scenario is the baseline scenario that no diversion is considered, the second scenario is the full consistence to the regulations scenario and the third one is the consistence to the regulations with a five years lag scenario.

First, annual waste amounts that sent in landfills in Turkey and its characteristics were determined. Country population and waste disposal amounts come up by TUIK data, and missing data of some years derived by graphical method. For determination of waste characterization, data from Solid Waste Master Plan's final report is used. At SWMP report country divided into different regions and waste characteristics of every different area. Aforementioned waste characteristics data is critically important. Data derived 2003-2040 but region's population comparatively taken weighted mean produces different region characteristics.

For determination of landfill gas amount "Central-Eastern Europe Landfill Gas Model Version 0.1" was used in this study The most important factor that selection of this model is the parameters, which based on are compatible with Middle-east countries waste characteristics and commonly usage of this model.

Previously created material classification of Turkey's average waste characteristics obtained by urban mixed characterization of SWMP. Because of this, transformation and derivation of acquired different data of waste characterization at first stage used for model input. For example, at SWMP paper, cardboard and high volume cardboards categorized differently but at the model this materials gathered in one and named as "paper and cardboard". Waste characterization and total amount of waste going to landfill site was determined for each scenario for the years between 2003-2040.

According to the principle of this model, a calculations are run linked with a series of following years' total waste amount together with a single waste characteristics in accordance with data formulization below **(S.1)**.

$$Q_{LFG} = \sum_{t=1}^{n} \sum_{j=0.1}^{1} 2kL_0 \left[\frac{M_i}{10}\right] (e^{-kt_{ij}}) (MCF) (F) \quad \textbf{(S.1)}$$

For that reason the model was run for 38 times for each scenario which means that 114 times total. As an example for Scenario 1; the waste characterization of 2003 was entered to the model and "output table for 2003" was formed for 100 years between 2003 – 2102. Then, the waste characterization of 2004 was entered to the model and "output table for 2004" was formed and same process was repeated with each years' data till 2040 and 38 output table was generated. In the next step, the results of each output table was used and average LFG production amount for each year was calculated in accordance with the general formula given below **(S.2)**.

$$Q_{LFG,n} = \frac{\sum_{i=2003}^{n} Q_{LFG}(i)}{n - 2003} \quad \textbf{(S.2)}$$

The same method was applied for all scenarios and potential landfill gas amounts in between 2003 – 2102 was determined.

The installed LFGTE plant capacity of Turkey is approximately 180 MWe in 2015. Most of the plants use 80% of their installed capacities in whole year and keeps reserve capacity. Therefore, actual electricity from LFGTE plants in Turkey is approximately 144 MWh. It's seen in the results that, Turkey's LFGTE generation potential in 2016 is 205 MW. This means that around 70% of total LFGTE generation potential of Turkey is being used at the end of 2015.

As main result, landfill gas potential in 2040 will be the half of the situation that no biodegradable waste diversion done if it's obeyed to the legislation provisions. It's possible to recover 73% of landfill gas in average conditions. It's calculated that the maximum potential electricity generation in LFGTE plants will be 376 MWh in 2040 if there is no biodegradable diversion. However it may decrease up to 187 MWh if diversion applied properly. Even if 5 years of delay seen on the application of biodegradable waste diversion, there will be approximately 30,000 m^3/h more LFG production potential in 2023 in comparison with the full adaptation case, which means that 21,900 m^3/h more LFG can be collected or 36 MWh more electricity can be generated. In other words, if 5 years of lag seen on the application, LFGTE generation potential of Turkey increases 15 % in 2023. It should be kept in mind that 36 MW plant can serve electricity energy for one million persons' living purposes.

Biodegradable waste diversion will cause dramatic decrease on LFG recovery in accordance with the decrease of LFG potential in Turkey. However, it may also create some great opportunities if diverted organics to be handled properly. It's crucial to manage diverted organics in order to get maximum benefit. The gap which is going to be occur in LFGTE plants' electricity generation potential with the decrease of LFG can be closed by recovering the potential energy of diverted organics in anaerobic digesters, co-digesters or in other (thermal) organics recovery plants. It's certain that the degradation period in landfills takes long years which gives us the opportunity to recover its potential in a long time. However, a lot more energy can be recovered from the same amount of biodegradable material in a shorter time in closed reactors. At that point, the consequence of the residues of these anaerobic digesters must be thought on.

As a brief conclusion, diversion of biodegradables will cause dramatic decrease in Turkey's cumulative landfill gas potential in future, which will especially influence the further investments on LFG recovery projects. Therefore, alternative biodegradable material recovery technologies should be developed in order to fill the gap which will occur with the decrease on LFG.

KENTSEL ATIK DEPOLAMA SAHALARINA GİDEN BİYOBOZUNUR ATIKLARIN AZALTILMASININ TÜRKİYE'DEKİ ÇÖP GAZI (LFG) POTANSİYELİNE OLAN ETKİLERİ

ÖZET

Avrupa Birliği müktesebatı uyum süreci kapsamında, Türkiye'de birçok alanda olduğu gibi atık yönetim sisteminde de hızlı bir değişim ve gelişim sürecine girilmiştir. 2010 yılında yayınlanan Atıkların Düzenli Depolanmasına Dair Yönetmelik ile atık düzenli depolamanın ne şekilde yapılması gerektiği tanımlanmış, vahşi depoların ıslah edilerek ilerleyen süreçte hiçbir surette düzensiz bir depolama yapılmamasına yönelik hükümler getirilmiştir. Bu gelişmeyle birlikte 2009 yılında sayısı 2000 civarında olan düzensiz çöp döküm alanları hızla kapanmaya başlamış ve aynı hızda düzenli depolama tesislerinin sayısı ve bu tesislerde bertaraf edilen kentsel atık miktarında artış görülmüştür. Söz konusu yönetmelik kapsamında atık depolama sahalarında oluşan çöp gazının toplanması ve yakılması, eğer finansal olarak fizibil ise elektrik üretim santrallerinde enerji geri kazanımı amacıyla kullanılması zorunlu tutulmaktadır. Yine 2010 yılında Enerji ve Tabii Kaynaklar Bakanlığı'nın başlattığı yenilenebilir enerji kaynaklarını destekleme mekanizması ile diğer yenilenebilir enerji kaynakları ile birlikte çöp gazından enerji üretimi tesislerinde üretilen elektriğe 10 yıllık sabit fiyat üzerinden alım garantisi getirilmiş, çöp gazından elektrik üretimine devlet teşviki verilmiştir. Edinilen tecrübeye göre, verilen teşvik ile birlikte 1 MW ve üzerinde kurulu güce sahip olacak çöp gazından elektrik üretim tesisleri finansal olarak fizibil hale gelmiştir. Bir başka deyişle, yaklaşık 500 m³/saat çöp gazı debisi elde edilen sahalarda veya ülkemizin günümüz koşullarındaki kentsel atık karakterizasyonu ve kişi başına düşen atık miktarı göz önünde bulundurulduğunda ortalama 750.000 kişilik nüfusa hizmet veren düzenli depolama sahalarında çöp gazından enerji üretimi tesisleri yapılabilir hale gelmiştir. Ancak, AB müktesebatı uyum süreci kapsamında 2010 yılında yayınlanan atıkların düzenli depolanmasına dair yönetmelik kapsamında ülke genelinde düzenli depolama sahalarına gönderilen biyobozunur atıkların azaltılmasına dair ciddi hedefler konmuştur. Buna göre düzenli depolama sahalarına gönderilen biyobozunur atıklar 3 kademede azaltılacak ve nihai olarak 2025 yılında, 2005 yılında üretilen biyobozunur atıkların %35'i düzenli depolama tesisine gönderilebilecektir. Söz konusu biyobozunur atık azaltımının Türkiye'deki kentsel atık karakterizasyonuna ve nihayetinde düzenli depolama tesislerinde oluşan çöp gazı miktarının ciddi miktarda azalmasına neden olacağı, bu nedenle bugün yatırım yapılan tesislerin ilerleyen süreçte fizibil yatırımlar olmayacağı düşünülmektedir. Bu tezin amacı, düzenli depolama sahalarındaki biyobozunur atık azaltımının Türkiye'nin gelecekteki çöp gazı potansiyeline olan etkilerini görmektir. Bunun için ilk olarak mevcut durum ortaya konmuş ve Türkiye'de düzenli depolama sahalarına gönderilen yıllık atık miktarları ve karakteristikleri tespit edilmiştir. Çalışma kapsamında üç farklı senaryo ele alınmış, düzenli depolama sahalarına gönderilen biyobozunur atıklardaki azaltımın gelecekteki çöp gazı potansiyeline olan etkilerini tespit edilmiştir. Oluşturulan üç senaryodan ilki yönetmelik hedeflerinin olmaması, yani herhangi bir

atık azaltımı yapılmaması halinde, ikincisi yönetmeliğe tam uyum sağlanması halinde, üçüncüsü ise yönetmeliğe uyumun 5 yıl gecikmeli olarak gerçekleşmesi halinde çöp gazı potansiyelinin nasıl etkileneceğini ortaya koymaktadır.

İlk olarak yıllık atık bertaraf miktarları ve ülke nüfusu TUİK verileri göre ele alınmış, eksik yıllara ait veriler grafik yönteminden yararlanılarak türetilmiştir. Atık karakteristiğinin tespit edilmesinde Katı Atık Ana Planı nihai raporundaki verilerden faydalanılmıştır. KAAP raporunda ülke farklı bölgelere ayrılmış ve her bir bölgenin atık karakteristiği tespit edilmiştir. Söz konusu atık karakteristik verileri, bu çalışmada kritik önem taşımaktadır. Veriler 2003-2040 yılları arasında türetilmiş, farklı bölgelerin karakteristikleri, söz konusu bölgenin nüfusuyla orantılı olarak ağırlıklı ortalaması alınarak 2003-2040 yılları arasında Türkiye ortalama atık karakteristiği oluşturulmuştur.

Çöp gazı miktarının analizi için Global Methane Initiative EPA tarafından geliştirilen ve birinci dereceden bozunmaya dayalı "Central-Eastern Europe Landfill Gas Model Version 0.1" modeli kullanılmıştır. Söz konusu model EPA tarafından yayınlanan Landfill Gas Emissions Model (LandGEM) version 3.02'nin geliştirilmiş versiyonudur. Bu modelin seçilmesinin en büyük nedeni, modelde baz alınan belli katsayıların Ortadoğu ülkeleri atık karakteristiklerine uygun olması ve modelin sektörde yaygın olarak kullanılıyor olmasıdır.

Bir önceki basamakta oluşturulan Türkiye ortalama atık karakteristiğindeki malzeme sınıflandırması KAAP kapsamında yapılan kentsel karışık karakterizasyonuna göre elde edilmiştir. Bu nedenle ilk etapta, elde edilen atık karakterizasyonundaki farklı verilerin dönüşümü yapılarak model girdisi olarak kullanılabilecek atık karakterizasyonu oluşturulmuştur. Örnek olarak; KAAP'ta kağıt, karton, ve yüksek hacimli karton farklı farklı sınıflandırılmaktayken, kullanılan modelde bu malzemeler tek bir kalemde "kağıt ve karton" olarak sınıflandırılmıştır. Her bir senaryo için benzer şekilde 2003-2040 yılları arasındaki atık karakteristiği ve düzenli depolama sahasına gönderilecek atık miktarları belirlenmiştir.

Model çalışma prensibine göre modele takip eden yıllara ait atık miktarı ile tek bir atık karakteristiği veri olarak girilmekte olup aşağıdaki genel formülizasyona göre hesaplama yaptırılmaktadır **(Ö.1)**.

$$Q_{LFG} = \sum_{t=1}^{n} \sum_{j=0.1}^{1} 2kL_0 \left[\frac{M_i}{10}\right] (e^{-kt_{ij}}) (MCF) (F) \qquad \textbf{(Ö.1)}$$

Bu nedenle model her bir senaryo için 38 defa olmak üzere toplamda 114 defa çalıştırılmıştır. Örnek olarak; 1. Senaryo için 2003 yılı karakterizasyonu modele girilerek 2003 – 2102 yılları arasında 100 yıllık çöp gazı miktarını veren "2003 yılı çıktı tablosu" oluşturulmuş, 2004 yılı karakterizasyonu girilerek "2004 yılı çıktı tablosu" oluşturulmuş ve bu işlem 2040 yılına kadarki veriler ile tekrar edilerek 38 adet çıktı tablosu elde edilmiştir. Bir sonraki basamakta ise söz konusu çıktı tablolarındaki veriler kullanılarak aşağıdaki formulizasyona göre her bir yılın ortalama çöp gazı miktarı tespit edilmiştir **(Ö.2)**.

$$Q_{LFG,n} = \frac{\sum_{i=2003}^{n} Q_{LFG}(i)}{n - 2003} \qquad \textbf{(Ö.2)}$$

Aynı yöntem diğer iki senaryo için de uygulanmış, üç senaryo için de 2003 – 2102 yılları arasındaki çöp gazı miktarları tespit edilmiştir.

Sonuç olarak, söz konusu mevzuat hükümlerine tam uyum gösterilmesi halinde 2040 yılındaki çöp gazı potansiyelinin, herhangi bir atık azaltımı yapılmaması haline kıyasla yarı yarıya düşeceği tespit edilmiştir. Ortalama koşullar altında sahada oluşan çöp gazının %73'ünün geri kazanılması mümkündür. Buna göre, herhangi bir biyobozunur atık azaltımı olmaması halinde 2040 yılında çöp gazından enerji üretim tesislerinde elde edilebilecek maksimum elektrik enerjisi potansiyeli 376 MWh'dır. Ancak, mevzuat hükümlerine tamamen uygum gösterilmesi halinde bu potansiyel 187 MWh'a kadar düşecektir. Mevzuat hükümlerine sadece 5 yıl gecikmeli uyulması halinde ise, gecikme olmamasına kıyasla 2023 yılında yaklaşık 30.000 m^3/saat daha fazla çöp gazı elde edilebileceği yani 21.900 m^3/saat çöp gazının toplanarak 36 MWh daha fazla elektrik üretilebileceği görülmektedir.

Düzenli depolama sahalarındaki biyobozunur atık azaltımı, Türkiye'deki çöp gazı potansiyelindeki düşüş ile birlikte geri kazanılabilecek çöp gazı miktarında da çok ciddi bir düşüşe neden olacaktır. Ancak bu durum, düzenli depolama sahasına gönderilmeyen biyobozunur atıkların doğru bir şekilde yönetilmesi ile büyük fırsatlar doğurabilir. Bu nedenle, ayrılan organik atıkların maksimum fayda sağlayacak şekilde yönetilmesi oldukça önemlidir. Düzenli depolama sahalarına gönderilmesi engellenen biyobozunur atıkların sebep olacağı çöp gazı miktarındaki düşüş ile, çöp gazından enerji üretim tesislerinde üretilen elektrik miktarında oluşacak olan açık, söz konusu organik maddelerin potansiyel enerjisinin; anaerobik çürütücülerde, birlikte çürütme tesislerinde veya diğer termal geri kazanım tesislerinde geri kazanılması ile kapatılabilecektir. Düzenli depolama sahalarındaki bozunma proseslerinin uzun yıllar alması nedeniyle buradaki potansiyelin geri kazanılması da uzun zaman almaktadır. Ancak kapalı reaktörlerde, aynı miktarda biyobozunur materyal ile çok daha kısa sürelerde daha fazla enerjiyi geri kazanmak mümkündür. Bu noktada anaerobik çürütücülerde oluşan rezüdünün akıbetinin ne olacağı ise üzerinde ayrıca düşünülmesi gereken bir başka konudur.

Sonuç olarak, katı atık depolama sahalarına gönderilen biyobozunur atıkların azaltılması, Türkiye'nin gelecekteki kümülatif çöp gazı miktarında ciddi düşüşlere neden olacak ve özellikle bu alanda yapılacak gelecekteki çöp gazı geri kazanım yatırımlarını etkileyecektir. Ancak, alternatif biyobozunur atık geri kazanım teknolojileri üzerine çalışmalar yapılarak, çöp gazı alanında oluşacak olan açık kapatılabilir.

1. INTRODUCTION

1.1 Significance and Importance of the Study

Due to the adaption of European Union Acquis, Turkish Waste Management legislations are being developed in order to have better solid waste and environmental management systems. The traditional method of MSW disposal in Turkey was dumping the waste in open dumps which's number was approximately 2000 in 2009 (N. Gamze Turan, 2009). However, the number of sanitary landfill sites have increased rapidly in last 10 years. Also the amount of waste sent to open dumpsites decreased at an equal rate. According to the regulation, all the dumpsites shall be rehabilitated and there won't be any dumping activities any more. Thus, the disposal method has been shifted into sanitary landfilling and landfilling the municipal solid waste is the most applied disposal method in Turkey today.

There are some strict targets in this regulation. The biodegradable waste amount going to the landfills will be decreased dramatically in future years in three steps (in 2015, 2018 and 2025). The biodegradable waste amount going to the landfill sites will be the 35 % of the generated biodegradable waste amount in 2005 at the end. Similar goals had place in Europe Landfilling Directive (1999/31/EC) and all the member countries have been working hard to reach the goals. Moreover, there is recent trend on organic waste diversion in United States. For example, all the food waste will be banned from landfills in 2020 in Vermont State (Stege, 2014).

It's been thought that organic or biodegradable waste diversion may have critical impacts on the amount of future landfill gas potential. For example, there have been methane reduction at landfills in California (US), a long-time organics diverter, as more and more organics are pulled out of landfills through diversion programs. There is a concern that increased organic diversion will effect future landfill gas to energy projects in the US (Zimlich, 2015). In addition, the number of LFG plants have decreased in parallel with the diversion of biodegradable MSW in Europe. However, there is no study done on the effects of biodegradable waste diversion on LFG potential in Turkey. Turkey is unfortunately foreign-dependent for conventional energy sources. Therefore, Landfill Gas to Energy projects are one of the most important renewable energy projects because of being uninterrupted facilities and capability of running more than %80 availability for electricity generation during whole year. There is a feed-in-tariff mechanism for the investors to make investments of cities' landfill gas potential in order to build up LFGTE plants and operate for more than 10 years. According to the experiences, these projects are feasible together with the incentives especially for plants which have more than 1 MWe installed power. However, a decrease in biodegradable materials going to landfill sites may influence the amount of landfill gas for future years and the feasibilities may become negative which will end up with many problems like shutting down the plants which are on operation due to the financial stress of operators. Furthermore, this possibility may result unfeasible projects and stop the investments, which may cause some serious environmental problems as a result of uncontrolled LFG emissions.

1.2 Purpose and Scope of the Study

The main purpose of this thesis is to determine the effects of biodegradable waste diversion going to the landfills on Turkey's future landfill gas potential. For that purpose, first, current situation in MSW and LFG management have been evaluated. Then, three senarios have been evaluated. The first scenario is the scenario that no diversion is considered, the second scenario is the full consistence to the landfill regulation and the third one is the consistence to the regulations with a five years lag period. The landfill gas generation potential till 2040 have been calculated based for three scenarios and the results have been compared. At the end, some MSW management policies and the fields to make investments have suggested in terms of the results.

1.3 Hypothesis

It's being thought that landfill gas potential of Turkey will decrease dramatically due to the decrease of biodegradable waste going to the landfill sites according to the goals given in Turkish waste management regulations.

2. LANDFILL GAS (LFG)

2.1 What is LFG?

Landfill gas (LFG) is a mixture of different gases produced by anaerobic activities of microorganisms within landfill sites. It's mainly consisted of methane and carbon dioxide together with a little portion of nitrous gases and some other trace compounds. Landfill gas is generally known by it's potential to explode, bad odor and effect on climate change. However, it can be used to generate energy by using proper methods and make the landfilled waste an alternative energy source. In today's World, energy generation by using local resources is one of the most important topic in nationalities' agenda.

In order to sustain landfill sites' security, landfill gas should be taken out of the site and to be controlled. In many countries, it's directly burned by using flares. By using this method, the greenhouse effect of landfill gas is reduced. But, it may not be a good idea to burn the potential energy resource without using it's potential if the amount is sufficient.

Landfill gas production occurs mainly in four phases. The first phase is the aerobic phase where aerobic bacteria consumes oxygen in order to break down the long molecular chains of complex carbohydrates, proteins and lipids and carbon dioxide is produced. Anaerobic activities starts with the second phase where some organic acids and alcohols are produced together with carbon dioxide and hydrogen. These organic acids are consumed in the third phase where methanogens activity increases. At the fourth phase, LFG remains relatively constant and continues approximately 20 years, and generally contains 50-55% methane by volume, 45-50% carbon dioxide, and 2-5% other gases, such as sulfides. The four phases are summarized in the graph below (LMOP, 2015).

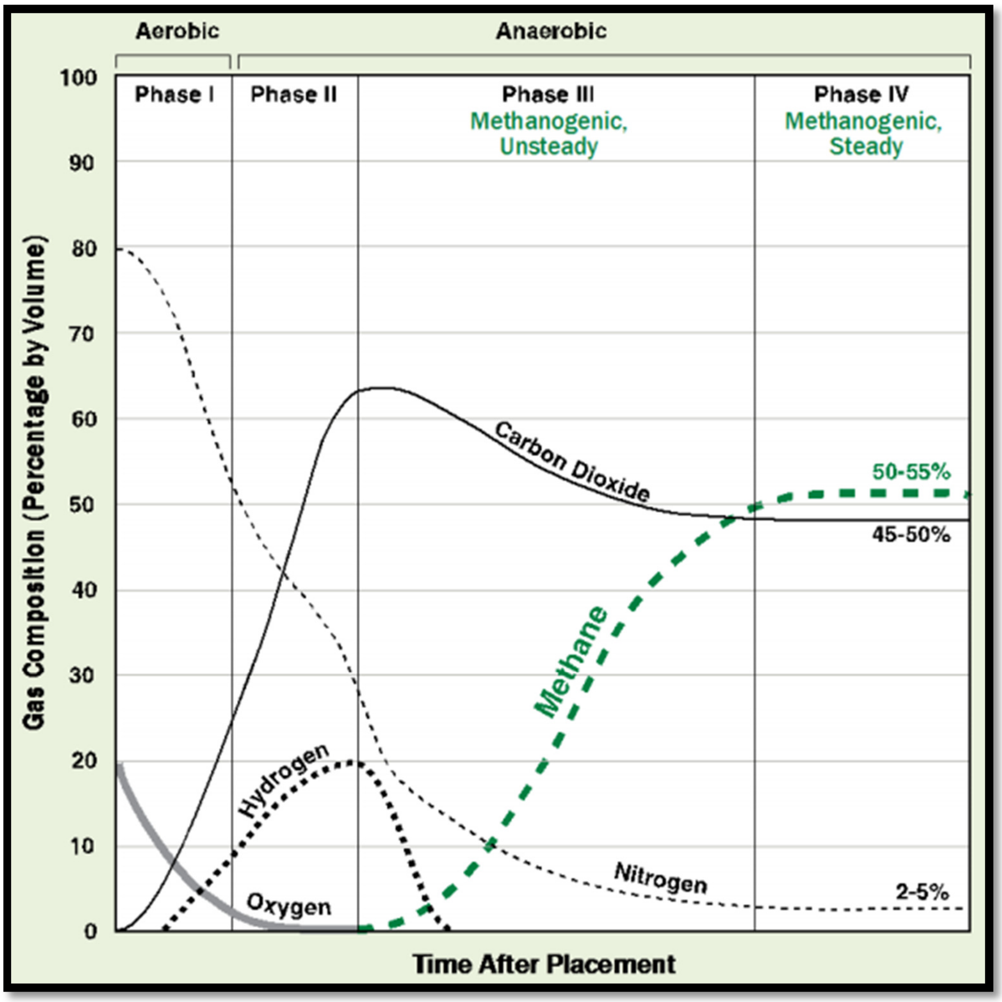

Figure 2.1 : Gas compositions within landfill site in different phases (LMOP, 2015).

2.2 Parameters Affecting LFG Quality and Quantity

The activities ocuring within the sites depend on complex natural mechanisms influenced by some physical, chemical and biological parameters which are are explained below.

2.2.1 Physical parameters

There are many physical parameters, which strictly influences the quality and the quantity of landfill gas, such as landfilled waste amount and composition, compression ratio, age of waste, moisture content, temperature etc…

2.2.1.1 Waste amount and composition

Landfill gas generation potential is directly linked with the amount and the composition of the waste. Landfill gas is produced as a result of anaerobic decomposition of organics within landfill body. The biodegradability of waste content is the key issue in order to define the landfill gas production rate correctly. After waste is dumped into a landfill site, first the rapidly biodegradable organic matters degrade. This will start the initial production of landfill gas in landfill sites. There are always some slowly biodegradable organic matters in municipal solid waste landfill sites which causes landfill gas generation lasts for long periods like 15 to 20 years. According to the experinces, one tonne of waste produces 50 to 240 m^3 gas within its whole degradation period. The difference within this range is related with its composition. The more biodegradable waste goes to the landfill, the more LFG is produced by the microbial activity. Highly degradable organic matter like food waste produces LFG rapidly that causes it to be consumed quickly. On the other hand less degradable organics like paper will produce LFG slower than food waste over a longer time (GMI, 2012).

2.2.1.2 Age of waste

Age of waste is one of the most important parameter which should be known in order to calculate potential landfill gas production amount for further years. After landfilling the waste, it should be covered and isolated from atmosphere as quick as possible to overcome the oxygen to oxidize organic content within waste and cause aerobic decomposition. If anaerobic conditions can be supplied right after dumping the waste, then ladfill gas production may be seen for the next 20 years which is directly linked with the operational condition of landfill site, like compaction ratio, leachate management, landfill gas extraction systems and so on. The highest gas production is usually seen from 5 to 7 years after the waste have been landfilled. Appreciable amounts of LFG is usually produced in 1 to 3 years. Also, nearly all the gas is produced within 20 years. LFG production may continue for more than 50 years due to the precence of hardly degradable organic matters (ATSDR, 2001).

2.2.1.3 Moisture content

Moisture content within the landfill site is very important parameter for landfill gas production. Water balance within landfill body should be supplied for the sustainability of the gas production. Due to the waste composition, compaction ratio, daily cover application and some other factors, moisture content within the landfill site may differ from one point to another. Moisture content affects k values (methane generation rate constant) and waste decay rates. The decay rates and k values are very low at dry sites however they are higher in wetter ones. Annual precipitation data can be used as an indicator in order to have information about moisture content within the site (US EPA, n.d.). 40% or higher moisture content based on the wet weight of waste promotes LFG production especially in a capped landfill (ATSDR, 2001). Furthermore, methanogenic decomposition has a very small possibility of occuring below 20% moisture content (Commonealth of Massachusetts, 2015).

2.2.1.4 Temperature

The temperature within landfill site directly affects landfill gas generation rate and activity of the microbial life. Degradation rate in landfill site and landfill gas generation rate decreases when the temperature within landfill site decreases. At that point, waste depth is one of the most important factor on landfill site temperature. It's stated that internal temperature of landfill sites differ between 30 to 60ºC independent from outside climatic temperature except shallow and uncontrolled landfill sites in very cold climates (US EPA, n.d.).

2.2.2 Chemical parameters

There are many chemical parameters, which affect the quality and the quantity of landfill gas including pH, nutrient and oxygen concentrations within the site and toxic matter. These chemical parameters have direct effect on biological activities within the site.

2.2.2.1 pH

pH has affect on landfill gas production which is linked with the metabolic activities of microbial consortia. Genarally the pH of waste and leachate within landfill sites is between 5 to 9. Waste composition is one of the key factor, which sets the pH level in site. However, this rage is quite large that differences within the range may have big influences on microorganisms within landfill body. When it is too asidic within the site, especially methanogenic phase gets slower and this will end up the quality and the quantity of landfill gas get worse. It's known that methanogens are much more sensitive than any other microorganisms living in landfill sites. Most of the methanogens live in pH between 6 to 8 (D. Isik, 2013); however, acidogens live in lower pH ranges.

2.2.2.2 Nutrients

All microorganism needs sufficient amount of nutrients in order to sustain their metabolic activities like growing and producing energy for themselves. Sanitary landfill sites for especially municipal solid wastes are generally nutrient rich environments according to the mixed waste composition in it which will be sufficient enough to sustain proper amount of landfill gas.

2.2.2.3 Oxygen concentration

Due to the active control system in landfill sites, oxygen may leak into the site from the cracks at the surface because of excess vacuum applied to the gas collection wells. Oxygen may leak into the site due to the aggressively operation of gas collection system (GMI, 2012). Excess oxygen may consume organics within the site that may end up with the reduction of landfill gas quality and quantity which is important if there is energy generation at the end.

2.2.3 Biological parameters

As well as physical and chemical parameters, there are also biological parameters affecting the quality and quantity of landfill gas that are important to take into consideration. Landfill gas is a kind of product, which is produced by anaerobic activities of microorganisms. Anaerobic microorganisms keep on their metabolic activities in order to survive and sustain the energy for their survival by series of biochemical reactions. At this point, some syntrophic and competitive metabolic activities are seen. To ensure the effects of biological parameters on LFG potential, anaerobic metabolic mechanism and pathways should be evaluated carefully.

2.2.3.1 Anaerobic metabolical mechanism

Due to its completely closed structure, landfill sites can be assumed as giant anaerobic reactors. Therefore, the metabolic mechanism within landfill sites will be similar as it is in biogas plants' anaerobic reactors. Serious of reactions are occurring in anaerobic environments due to the laws of thermodynamics. There are many kinds of microorganisms woking together as syntrophy or competition in these environments. All the environmental conditions have effects on their metabolic activities with their pathways. Main metabolical activities occurring in anaerobic environments are Hydrolysis, Acidogenesis, Acetogenesis and Methanogenesis. There must be a balance in each main step in order to preserve the sustainability of anaerobic metabolic activities within the sites. A summarized pathway is given in the Figure 2.2 (SEPA, 2004).

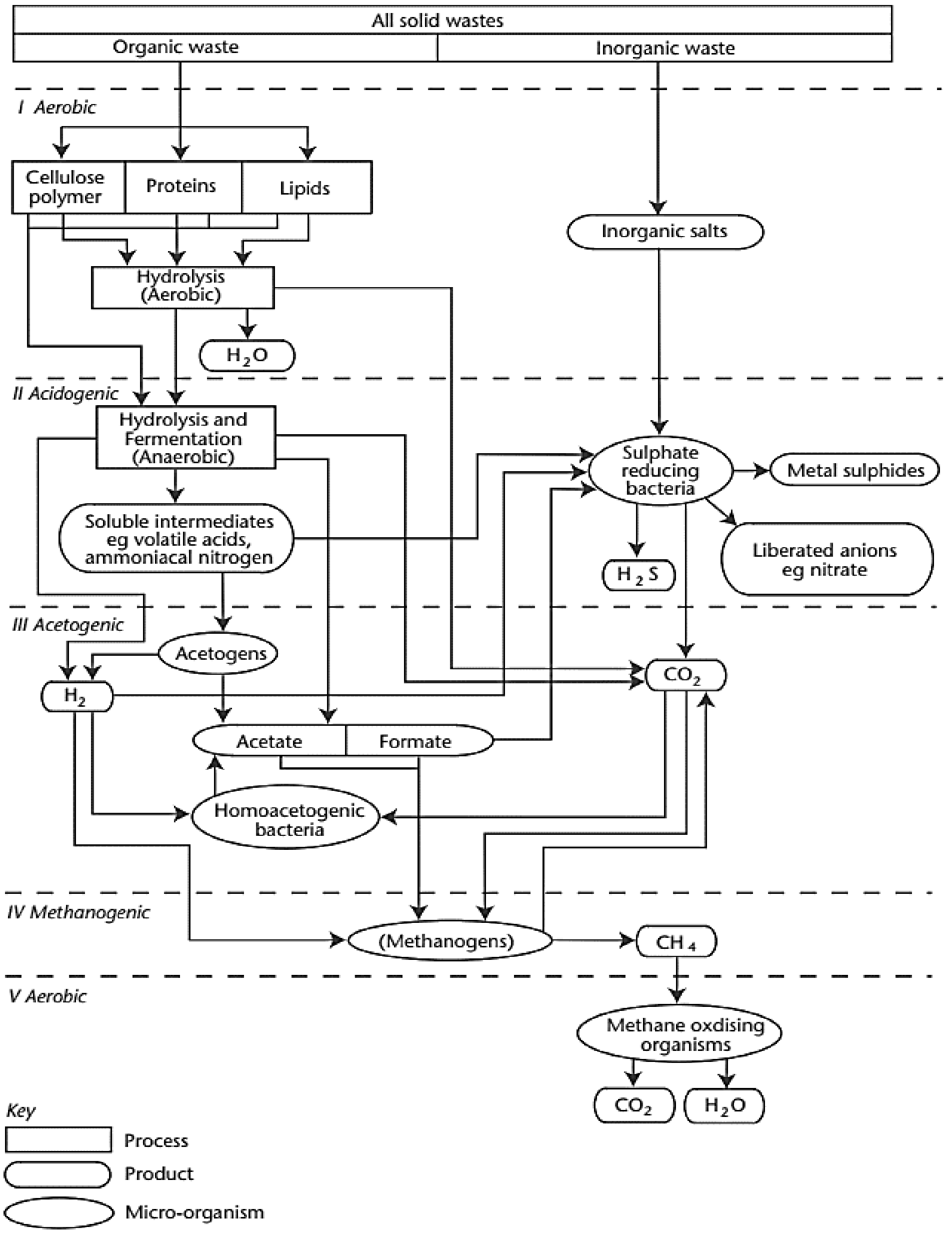

Figure 2.2 : Major steps in simultaneously occuring acetogenic and methanogenic activities (SEPA, 2004).

2.3 LFG Collection Systems

Landfill gas can be collected with passive or active gas collection systems (ATSDR, 2001). Whether the system is active or passive, all the wells should be placed on the landfill in order to reach and control as much as LFG as it can be. Passive gas collection systems use the pressure of landfill and gas concentrations. They can be installed during landfilling of the waste or after closure (ATSDR, 2001). The main idea is to prevent the increase of LFG pressure within the site and provide the ventilation of site. It’s better to convey the gas to the flares in order to reduce the greenhouse gas effect of landfill sites. A typical passive gas collection well cross-section is given in the Figure 2.3.

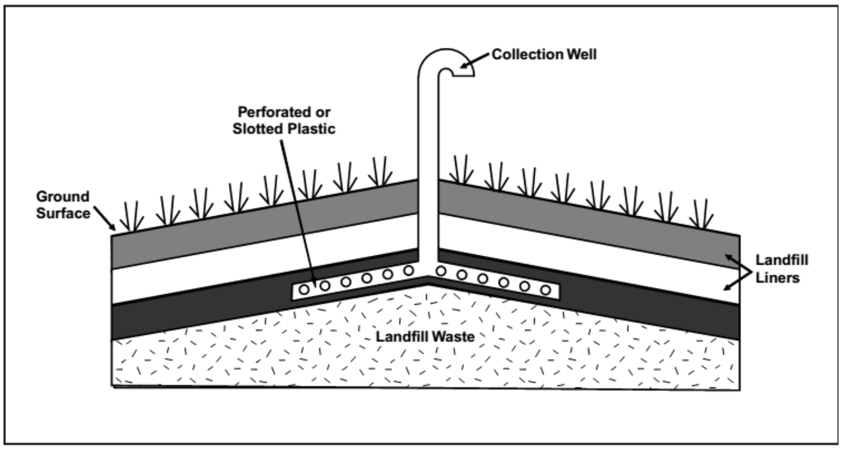

Figure 2.3 : Passive gas collection system (ATSDR, 2001)

The efficiency of passive gas collection system depends on how well the gas is contained within the landfill and environmental conditionsWhen the pressure in the landfill is insufficient to push the gas to the venting device, passive systems fail to remove landfill gas effectively. For these reasons, in areas with a high risk of gas migration passive collection systems are not reliable enough for use (ATSDR, 2001).

Active landfill gas collection systems are the most effective gas control systems. A vacuum is applied to the gas extraction wells in order to direct the gas through the intended location. An active gas collection system must have a gas moving equipment including vacuum boosters and piping which can reach all the site together with the gas collection wells. The numbers or types (horizontal or vertical) of wells depends on the type, depth, and compaction ratio of the waste. Also an active system should have the gas quality and quantity monitoring system (ATSDR, 2001). Gas collection wells can be horizontal or vertical as shown in Figure 2.4.

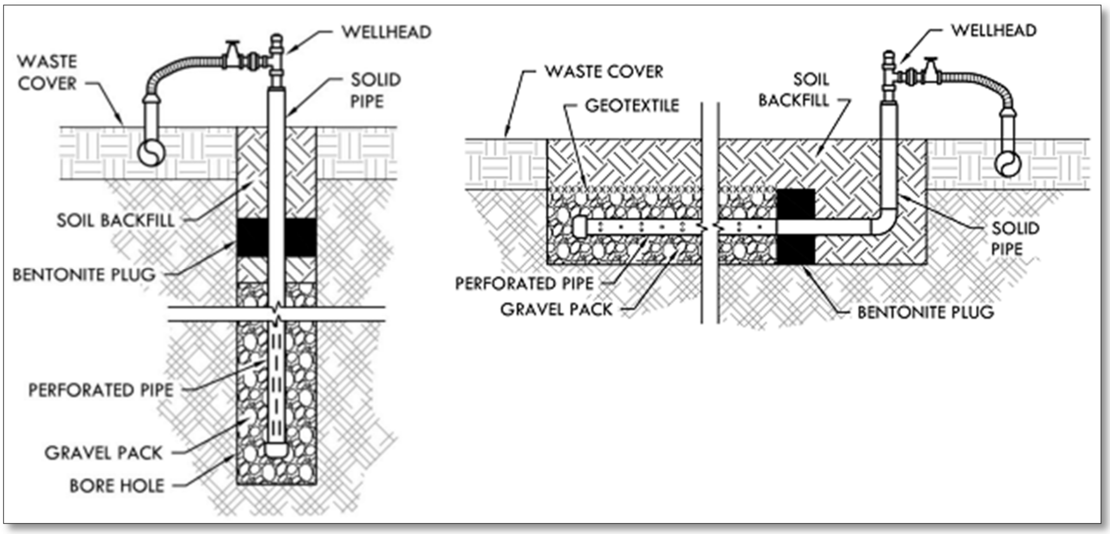

Figure 2.4 : Vertical and horizontal gas extraction well cross-section (LMOP, 2015).

Advantages of vertical wells are minimal disruption of landfill operations if placed in closed area of landfill, having a common design and being reliable and accessible for inspection and pumping. However, they have some disadvantages like increased operation and maintenance required if installed in active area of landfill, difficulty of finding appropriate equipment and delayed gas collection if installed after site or cell closed.

On the other hand, possibility of earlier collection of LFG, reduced need for specialized construction equipment and allowing extraction of gas from beneath an active tipping area on a deeper site can be listed as advantages of horizontal wells. Yet, they have some disadvantages like increased likelihood of air intrusion until sufficiently covered with waste and being more prone to failure because of flooding or landfill settlement (GMI, 2012).

2.4 LFG Treatment

Gas treatment is a multi-stage operation that can reduce environmental emissions and engine maintenance costs if the LFG is used for energy recovery purposes. Treatment activities bring up some financial costs for the operator but it improves the gas supply quality to meet the requirements of engine manufacturers or reach the environmental emission standards. Landfill gas treatment is mainly divided in two parts which is pre-treatment of gas and in-engine (thermal) treatment. Also pre-treatment can be classified as primary and secondary treatment as listed below (Browell, 2010).

Table 2.1 : Landfill gas treatment alternatives (Browell, 2010).

Pre Treatment Technologies: Primary Pre - Treatment	Pre Treatment Technologies: Secondary Pre - Treatmnt	In Engine & Exhaust Treatment
Water/Condensate Knockout	Activated Carbon Filtration	In-Engine Treatments
Particulate Filtration	Hydrogen Sulphide Pre-Treatment	Exhaust after Treatments
	Pre-Treatment of Halogenated Organics	
	Siloxane Pre-Treatment	
	Gas Clean-Up to Pipeline/Vehicle Fuel Quality	
	Developmental Technologies	

Especially the hydrogen sulphide and other sulphur gases should be treated since this compounds lead to chemical corrosion of the gas engine if there is energy recovery system. Also the removal of halogenated organics will help overcoming the chemical corrosion in the gas engines and potential emissions of acid gases like hydrogen chloride (HCl), hydrogen flouride (HF) and PCDDs/PCDFs (dioxins and furans). Furthermore, silicon compounds causes physical effects to the gas engines, thus it's better to be removed (Browell, 2010).

Liquid water capturing, foam removal, vapour reduction and refrigeration activities should be applied in order to water and condensate knockout. Also particles can be controlled by using cyclone separators or passing the gas through a filter pad generally made of stainless steel wire. A further particulate filtering may be applied by using ceramic filter packs. In order to remove sulphur gases and halogenated compounds, activated carbon filtration, dry scrubbing, membrane separation, pressure swing processes, liquid absorbtion / solvent scrubbing processes, water scrubbing processes or cryogenic processes may be applied (Browell, 2010).

Siloxanes are volatile compounds that evaporate and come out from the landfill and digester gases to be combusted either harmlessly in a flare, or harmfully inside internal combustion equipment. An example of silica build-up on heads and scrapped pistons of different branded engines are given below (XEBEC Adsorption Inc., 2007)

Figure 2.5 : Silica build-up on heads and scrapped pistons of different branded engines.

According to the investigations done, one third of all landfill sites have a severe siloxane problem (XEBEC Adsorption Inc., 2007). Silicon levels in engine oil is given in Figure 2.6.

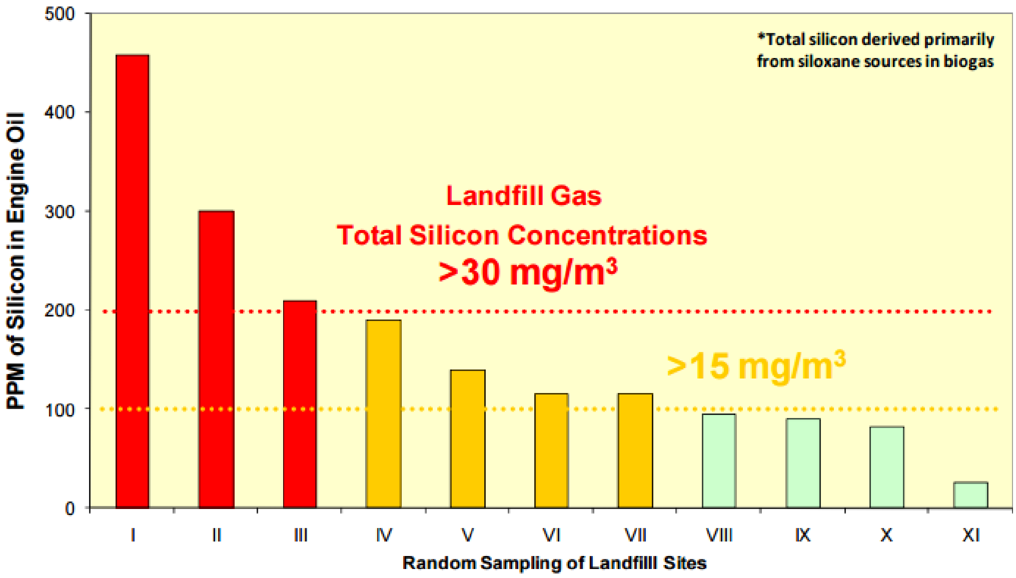

Figure 2.6 : PPM of silicon in engine oil (XEBEC Adsorption Inc., 2007).

There are some tretment systems used for siloxane removal. Regenerative adsorption systems can be given as an example in order to remove siloxane within the landfill gas before feeding it to the internal combustion engines (XEBEC Adsorption Inc., 2007). On the other hand, activated carbon adsorption is another method in application to adsorb siloxane (Browell, 2010).

2.5 Uses of LFG

Landfill gas is an important source because of being an alternative for fossil fuels in order to generate energy. Especially in large-scale landfills, it's better to use landfill gas in order to generate electricity. But on the other hand, for smaller ones, it can be directly used for heating activities. Landfill gas can be fed into the natural gas grid in many countries after a purification process.

2.5.1 Electricity generation

Due to the high percentage of methane within landfill gas, it has always been critical to manage it properly and make use of it if it's possible. It's reported that the heat value of landfill gas is equal to 9.8 kcal/m^3 in standard temperatures and pressure of dry gas (The Engineering Toolbox, n.d.). Due to the high calorific value, LFG can be used in internal combustion engines in order to generate electricity. At that point, approximately 40% of the energy potential is recovered as electricity and the other part comes out as heat. It's possible to recover this heat with cogeneration or trigeneration processes. The feasibility of installing a landfill gas recovery system depends on factors such as the availability of users, landfill gas generation rates, and the potential environmental impacts. In general, following factors makes landfill gas to energy projects feasible (ATSDR, 2001);

- The amount of waste in place at a landfill is greater than approximately 1 million tons.
- The waste is greater than 10 m deep and is stable enough for well installation.
- The landfill area is greater than 35 acres.
- The landfill is composed of refuse that can generate large quantities of landfill gas composed of 35% or more of methane.
- If a landfill is still open, active landfill operation will continue for several more years

- If a landfill is already closed, a short time (no more than a few years) has elapsed since closure
- The energy user is located nearby or in an area accessible to the landfill
- The climate is conducive to gas production

2.5.2 Direct uses of LFG

Landfill gas can be directly used in any process which needs some gas fuels for heating purposes. For example, landfill gas can be piped to a nearby industry, commercial business, school or government building where it is combusted in a boiler to provide steam for an industrial process or heat for a building (ATSDR, 2001). Also methane can be purified in order to achieve natural gas standards and it can be fed into the natural gas pipeline. The creation of pipeline-quality, or high-Btu, gas from LFG is becoming more prevalent. Also creating some alternative fuels such as biodiesel or ethanol is becoming popular processes as direct use of LFG. Furthermore, LFG to CNG (compressed natural gas, or LFG to LNG (liquidified natural gas) projects are coming out in order to increase the alternative usage areas of LFG (LMOP, 2015).

2.6 Environmental Effects of LFG

LFG has different impacts on environment. Methane is 25 times (21 times according to some other sources) harmful to the environment than carbondioxide as an air polluter (LMOP, 2015). Landfill gas contains 50 percent methane and 50 percent carbondioxide by volume (US EPA, 2011). It also involves, small amount of nitrogen, oxygen and hydrogen and also less than 1 percent nonmethane organic compounds (NMOCs) and trace amounts of inorganic compounds (US EPA, 2011). LFG gas composition is given in Table 2.2 (Tchobanoglous G, 1993).

Table 2.2 : LFG gas composition (Tchobanoglous G, 1993).

Component	Percent by Volume	Characteristics
methane	45-60	Methane is a naturally occurring gas. It is colorless and odorless. Landfills are the single largest source of U.S. man-made methane emissions.
catbon dioxide	40-60	Carbon dioxide is naturally found at small concentrations in the atmosphere (0.03%). It is colorless, odorless and slightly acidic.
nitrogen	2-5	Nitrogen comprises approximately 79% of the atmosphere. It is odorles, tasteless and colorless.
oxygen	0.1-1	Oxygen comprises approximately 21% of the atmosphere. It is odorless, tasteless and colorless.
ammonia	0.1-1	Ammonia is a colorless gas with a pungent odor.
NMOCs (non-methane organic compourds)	0.01-0.6	NMOCs are organic compounds (i.e., compounds that contain carbon). (Methane is an organic compound but is not considered an NMOC.) NMOCs may occur naturally or be formed by synthetic chemical processes. NMOCs most commonly found in landfills include acrylonitrile, benzene, 1,1-dichloroethane, 1,2-cis dichloroethylene, dichloromethane, carbonyl sulfide, ethyl-benzene, hexane, methyl ethyl ketone, tetrachloroethylene, toluene, trichloroethylene, vinyl chloride, and xylenes.
sulfides	0-1	Sulfides (e.g., hydrogen sulfide, dimethyl sulfide, mercaptans) are naturally occurring gases that give the landfill gas mixture its rotten-egg smell. Sulfides can cause unpleasant odors even at very low concentrations.
hydrogen	0-0.2	Hydrogen is an odorless, colorless gas.
carbon monoxide	0-0.2	Carbon monoxide is an odorless, colorless gas.

Using the landfill gas is an environmentally friend approach when reduction of GHG emission is taken into consideration. It’s also an economically feasible process because of being local and sustainable. By using LFG, it’s also prevented to burn fossil fuels for that amount of energy generated by LFG.

Reducing greenhouse gas emissions is one of the most important topic of todays world. Countries may use the carbon credits taken as a result of generating electricity by incinerating landfill gas, for carbon emission trade globally. It’s seen in Figure 2.7 that 11% of all greenhouse gases is based on landfills in the world (GMI, 2010).

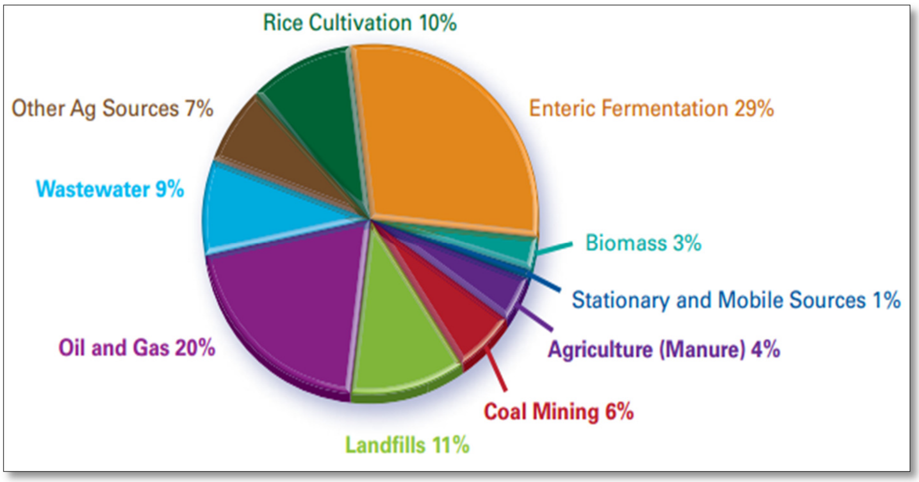

Figure 2.7 : Sources of GHG emissions in the world.

It's also seen in Figure 2.8 that, 14 % of greenhouse gas emissions is methane (B. Metz, 2007).

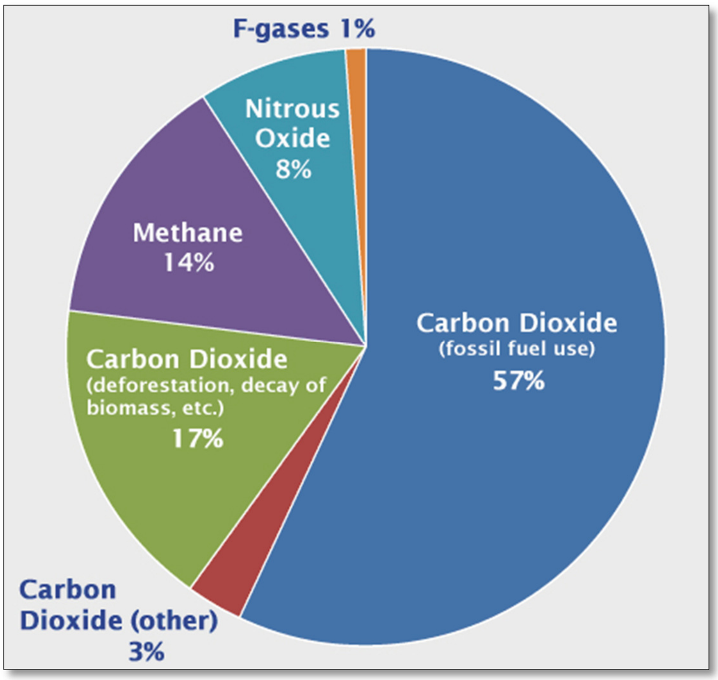

Figure 2.8 : Distribution of GHG emissions by gases.

2.7 LFG Modelling

There are different landfill gas models developed can be classified as zero order, first order and second order decay models or mathematical and numerical models. First order decay models are generally used all over the world; however, numerical models can lead much more precise results (H. Kamalan, 2011) A summarized table is given below with detailes of mostly used models (Table 2.3).

Table 2.3 : List of different LFG prediction models and their specifications (H. Kamalan, 2011).

Models	Formula	Notes
EPER Germany	$M_e = M \times BDC \times BDC_f \times F \times D \times C$	Zero order Based on amount of waste, proportion of biodegradable carbon, biodegradable, …
SWANA zero order	$Q = \frac{ML_o}{(t_o - t_1)}$	Zero order model Based on weight of waste, time and methane generation potential
IPCC	$Q = (MSWT \times MSWF \times MCF \times DOC \times DOCF \times F \times 16/12 - R) \times (1 - OX)$	Zero order model Based on waste landfilled and degradable organic carbon There are tables and some formula to calculate IPCC model parameters
SWANA	$Q = ML_o e^{-kt}$	
TNO	$\alpha_t = \varsigma 1.87 AC_o k_1 e^{-k_1 t}$	First order Based on carbon content, Information on organic content of waste components are not completed
LandGEM	$Q_{CH_4} = \sum_{i=1}^{n} kL_o M_i (e^{-kt})$	First order Based on US waste composition, inert material and other non-hazardous wastes, User friendly in spreadsheet environment
GasSim	-	First order, multiphase model There in no complete set of equations in the manual Calculation modules in the program are protected
Afvalzorg	$\alpha_t = \varsigma \sum_{i=1}^{3} 1.87 AC_{0,i} k_{1,i} e^{-k_{1,i} t}$	First order, multiphase model Based on Netherlands wastes characteristics Wastes are classifies in 3 categories in terms of decay rate For some waste categories, no organic matter or carbon content data were available
EPER France	$FE_{CH_4} = \sum_x FE_0 \times (\sum_{1,2,3} A_i \times p_i \times k_i \times e^{-k_i t})$	First order, multiphase model Dimensions left and right in the equation do not match in the formula but in the spreadsheet it is solved Normalization factor seems that is not included in the spreadsheet
Mexico	$Q_M = \sum_{i=1}^{n} 2kL_o M_i (e^{-kt})$	First order model Speared sheet environment A year lag in methane production Based on USA waste composition Potential methane generation capacity and decay rate are provided based on precipitation
LFGGEN	$Q_s = L_o \frac{2k}{k(t_p - t_o) + 2}$ $k = \frac{-\ln 0.01}{t_{99} - t_p}$	Methanogenesis is preceded by a lag phase The first stage of methanogenesis is represented by a linearly increasing generation rate The second stage of methanogenesis is represented by first-order kinetics, with an exponentially decreasing generation rate Based on USA waste composition
Halvadakis		Complex mathematical model Follow the carbon from Solid Carbon up to Carbon in CH_4 Too hard to be calibrated and used
Numerical	$f_i = k_i \sum a_{mn}$	Very effective Accurate results Applicable for each landfill

3. LANDFILL GAS MANAGEMENT

3.1 LFG Management in US

LFG to energy projects have 40 years of history in United States where the first landfill gas to energy project was started in 1975 in Palos Verdes, CA (Kirsten Cappel, 2015). The U.S. Environmental Protection Agency's Landfill Methane Outreach Program (LMOP) as a voluntary assistance program that helps to reduce methane emissions from landfills by encouraging the recovery and beneficial use of landfill gas (LFG) as a renewable energy resource was established in 1994. Till today, more than 600 projects have been assisted (Kirsten Cappel, 2015). A historical timeline of LFG energy industry is given in figure.

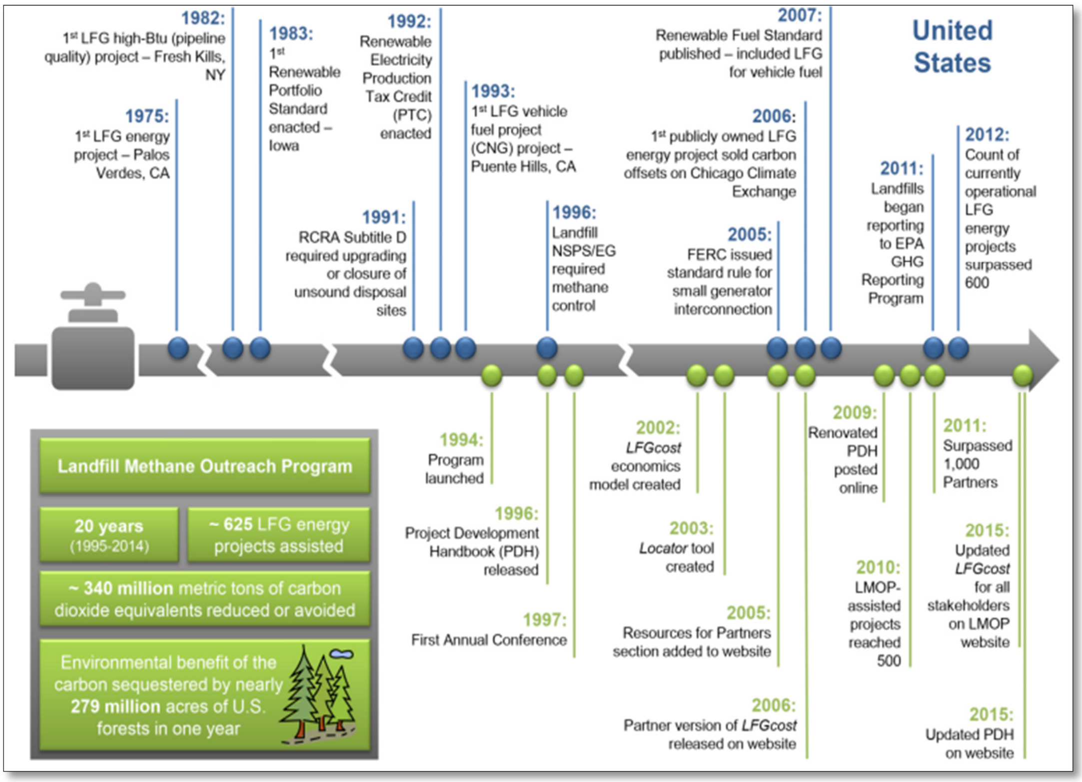

Figure 3.1 : Timeline of US LFG energy industry (Kirsten Cappel, 2015).

It's seen in the Figure 3.2 that, there are 621 operational projects which is totally 1,978 MW and 450 candidate landfills with 850 MW Potential (LMOP, 2013). The growth of projects is given in Figure 3.3.

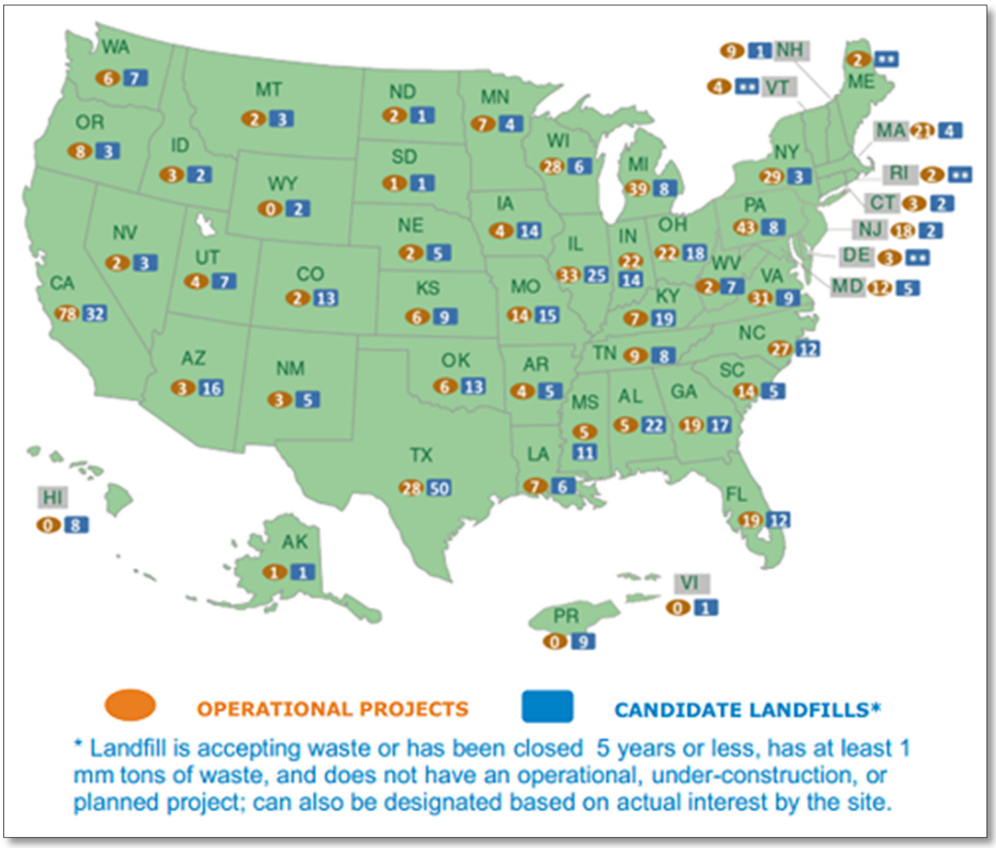

Figure 3.2 : Number of LFG projects in US (Kirsten Cappel, 2015).

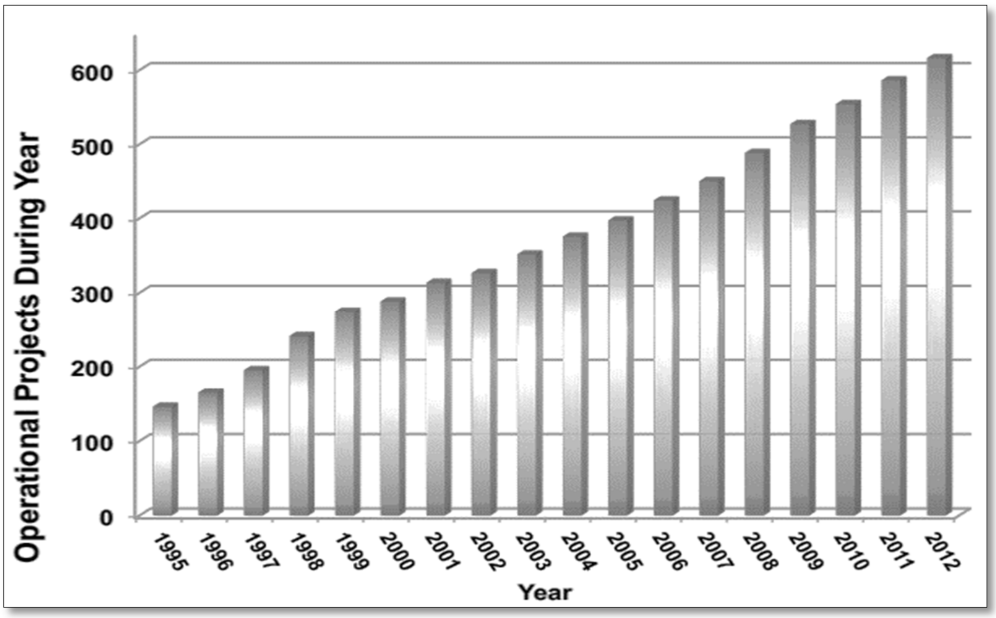

Figure 3.3 : LFG energy project growth over time in US (LMOP, 2013).

Both direct use and electricity generation projects have been experienced in US. Reciprocating engines are the mostly used electro-mechanic equipment used in landfill gas to energy projects in US with 1,301 MW capacity (Figure 3.4). Boilers are the most preferred direct-use method by using LFG and direct thermal usage comes next (Figure 3.5). High BTU projects are the third LFG energy projects in US with 147.4 mmscfd capacity (1 mmscfd = 28,252.14 m^3/day at 15^{o}C).

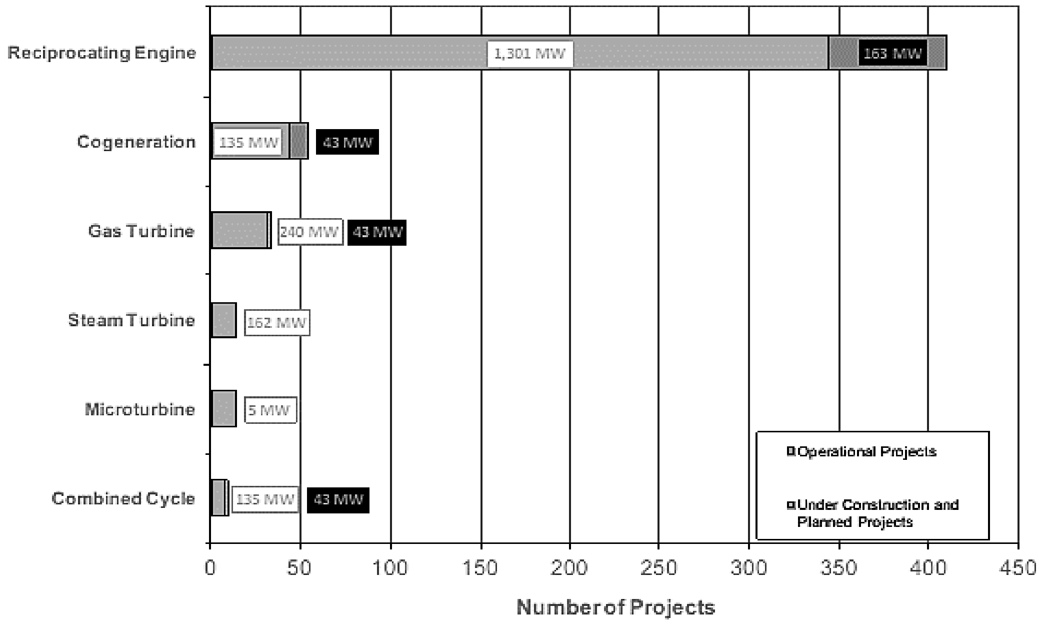

Figure 3.4 : Technology trends of electricity generation LFG projects in US (LMOP, 2013).

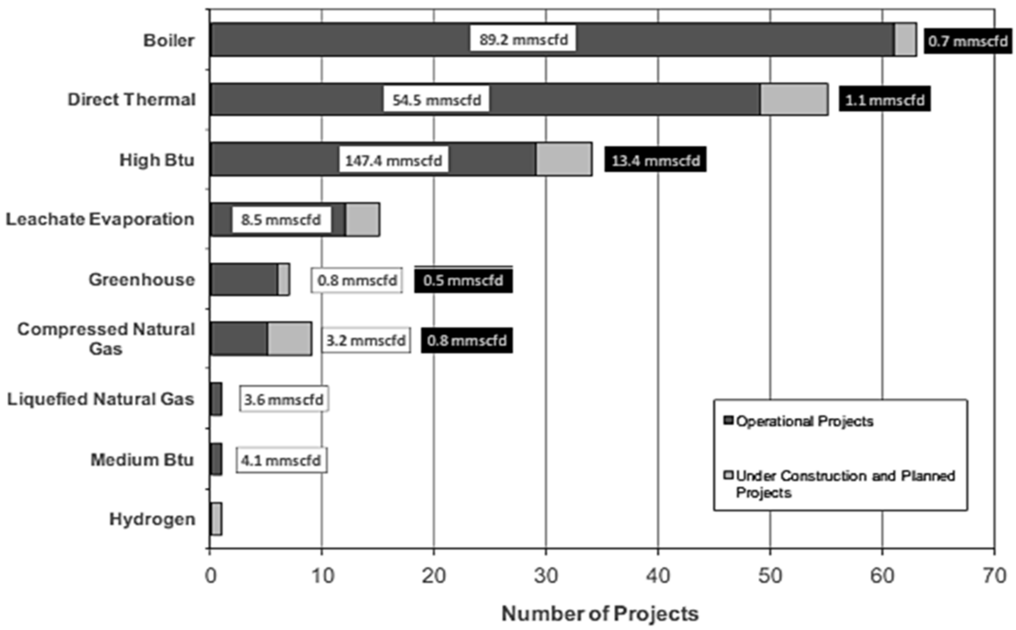

Figure 3.5 : Technology trends of direct use LFG projects in US (LMOP, 2013).

3.2 LFG Management in Europe

The first principle in European waste management policies is the prevention and minimization of waste within the source and decreasing the hazardousness level. The second level is the reuse of waste or recovering energy by using them. The final step is to burn the waste without giving harm to environment or landfilling it if the waste can not be reused or recovered.

Europe Landfilling Directive (1999/31/EC) defines the technical concepts of waste landfilling in order to minimize or reduce the negative effects of wastes on environment and designates the design criteria of landfill sites together with controlling and monitoring it.

Figure 3.6 : Municipal waste landfilling rates in 32 European countries, 2001 and 2010 (EEA, 2013).

Figure 3.6 shows the MSW landfilling rates for 32 European countries in 2001 and 2010. It's clearly seen in the figure that there is a serious decrease in MSW landfilling for all 32 European countries in 2010 when it's compared with the 2001 data, which means that the directive has critical impacts on MSW disposal activities.

It's seen in Figure 3.7 that while landfilling of MSW is decreasing between years 2001 to 2010, incineration of MSW increases slightly. On the other hand, the ratio of recycling activities increased faster than incineration.

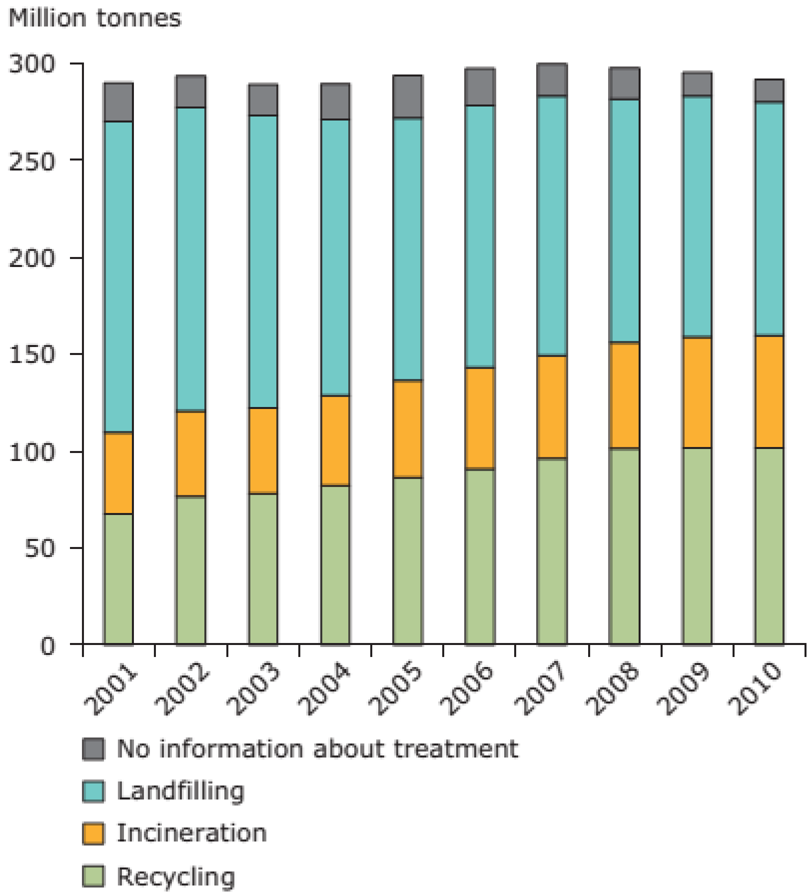

Figure 3.7 : Development of MSW management in 32 European countries (EEA, 2013).

The objective of the landfill directive is to reduce the landfilled biodegradable urban waste amount to 75% of the amount generated in 1995 in 2006, to 50% in 2009 and 35% in 2016 for the member counties and defined serious penalties for the ones not abide. Twelve countries have been given a four-year derogation with the target years. Furthermore, Ireland has been given a four-year derogation for the 2006 and 2009 targets, Portugal for the 2009 and 2016 targets, Slovenia for the 2016 target and Croatia for all three targets (EEA, 2013). This four-year derogation was given to the countries that uses landfilling as MSW disposal over 80% in 1995 (Burnley, 2001).

It's obligatory to improve themselves according to a plan to reach the aims given above or to be closed, before 2009 for the existing landfill sites. These liabilities resulted large scale and technical investments.

Figure 3.8 : Bio-waste recycling as a percentage of municipal waste generation in 32 European countries, 2001 and 2010 (EEA, 2013).

All EU countries except Iceland, Malta, Portugal and Luxembourg have serious improvements on recycling biodegradable waste between 2001 to 2010. The results of the obligatory targets can be summarized as; all the 12 countries without derogation period landfilled less than 75% of biodegradables compared to the generated amount in 1995 which means that fulfilled the target in 2006. Only one country missed the 2009 target and other 11 countries landfilled less than 50% of biodegradable MSW compared to the generated amount in 1995. Furthermore, 7 countries have already fulfilled 2016 targets. Seven countries with a derogation period achieved the first target which is in 2010. However only Estonia and United Kingdom achieved the second target which is in 2013. The other countries were unable to divert the sufficient amount of biodegradable waste from landfills (EEA, 2013).

According to the figure given below, number of LFG plants increased till 1999. It's clearly seen in the same figure that the yearly LFG plant addition in Europe started to decrease with the publication of directive in 1999. The number of LFG plants have decreased in parallel with the biodegradable MSW diversion in Europe.

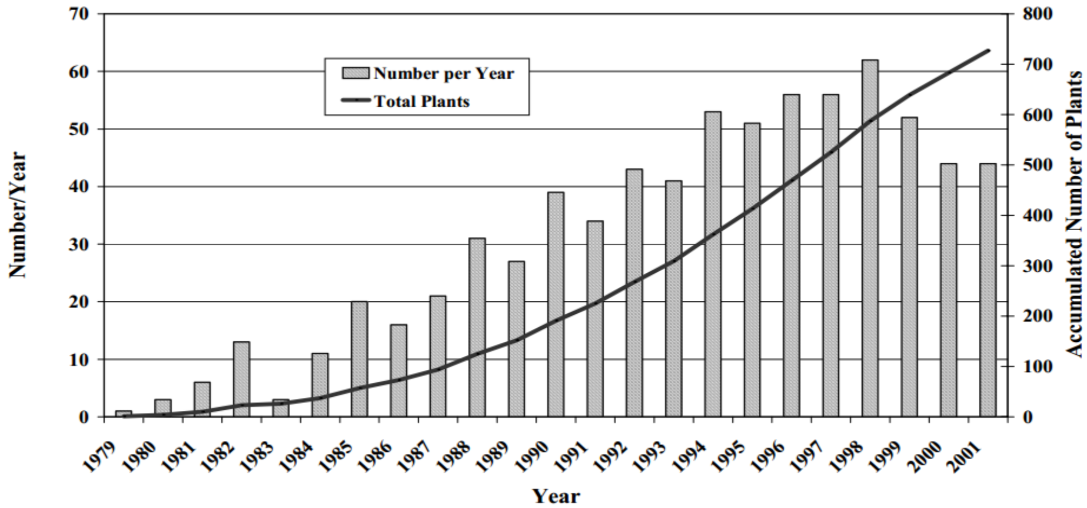

Figure 3.9 : Number of LFG plants in Europe (Willumsen, 2004).

3.3 LFG Management in Turkey

3.3.1 Municipal solid waste generation in Turkey

According to the latest data given by TUIK, waste generation per capita is 1,14 kg/cap/day in summer time and 1,09 kg/cap/day in winter. It is reported as 1,12 kg/cap/day as yearly average. Historical data about Turkey's daily waste generation per capita is given in Figure 3.10.

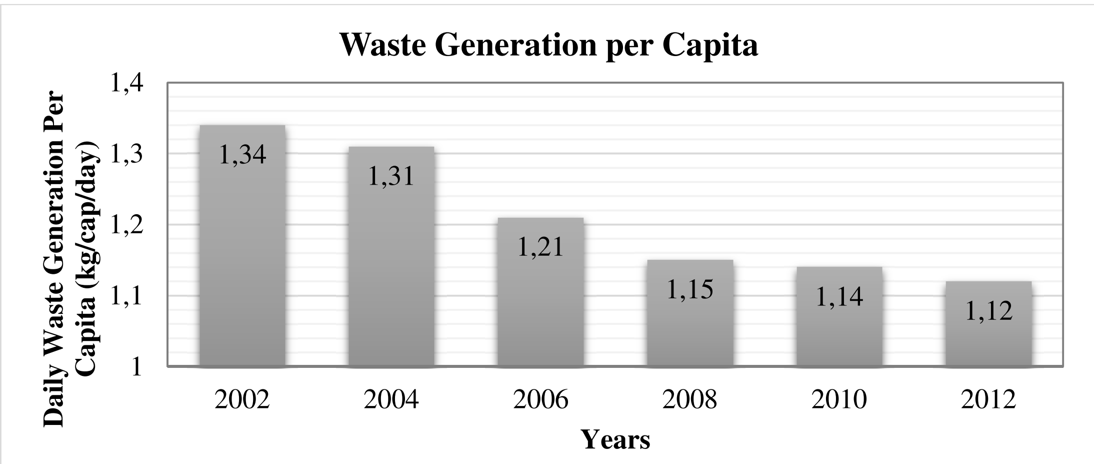

Figure 3.10 : Average waste generation per capita in Turkey (TUIK, 2015).

According to EUROSTAT 2012 data, the average of annual urban waste produced per capita by EU-27 countries was 492 kg/cap/year while that produced in Turkey was 407 kg/cap/year based on TURKSTAT data (MoE&U, 2013).

3.3.2 Municipal solid waste characteristics in Turkey

Waste characterizations were defined for the years between 2003 – 2023 (between 2003 – 2020 and 2010 – 2030 for some regions) year by year for each regions in Solid Waste Master Plan (KAAP). The average MSW characteristics in 2015 for Turkey was estimated and given in Figure 3.11. According to the same report, Turkey's historical waste characteristics are given in the Figure 3.12 and Table 3.1 (MIMKO, 2006). More than 60% of Turkish MSW is biodegradable.

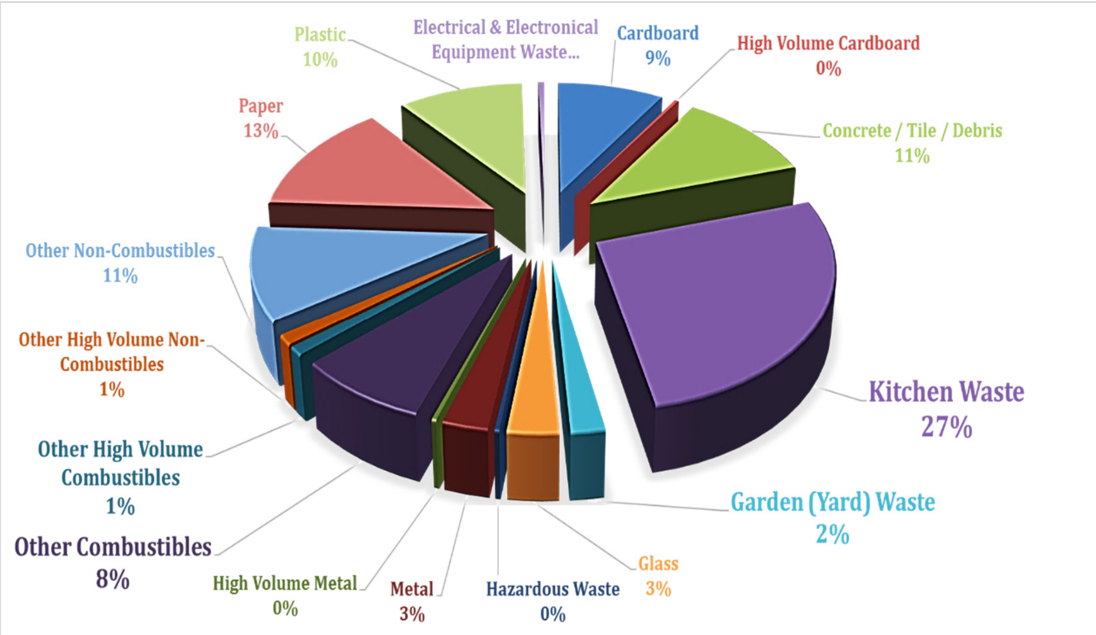

Figure 3.11 : MSW characteristics of Turkey in 2015.

It's clearly seen in both Figure 3.11 and Figure 3.12 that, the percentage of foodwaste is always approximately 30% which is rapidly biodegradable. Paper and cardboard comes next with a percentage of 22%.

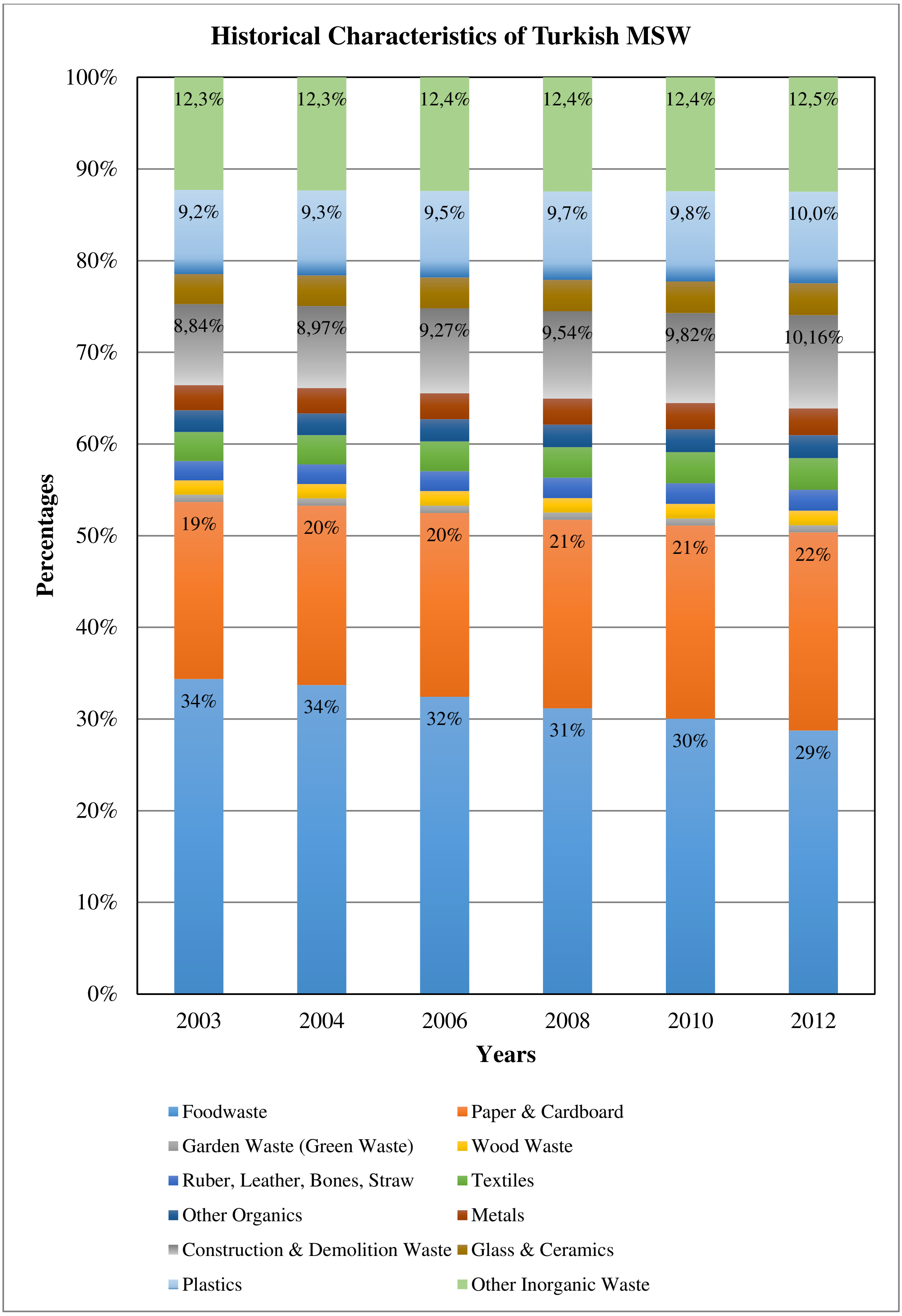

Figure 3.12 : Historical trends of MSW characteristics in Turkey.

Table 3.1 : Change of MSW characteristics in Turkey.

Waste Composition (%)	2003	2004	2006	2008	2010	2012
Food waste	34.4%	33.7%	32.4%	31.2%	30.0%	28.7%
Paper & Cardboard	19.3%	19.6%	20.1%	20.6%	21.1%	21.6%
Garden Waste (Green Waste)	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%
Wood Waste	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%
Ruber, Leather, Bones, Straw	2.1%	2.1%	2.2%	2.2%	2.3%	2.3%
Textiles	3.2%	3.2%	3.3%	3.3%	3.4%	3.4%
Other Organics	2.4%	2.4%	2.4%	2.5%	2.5%	2.5%
Metals	2.8%	2.8%	2.8%	2.8%	2.9%	2.9%
Construction & Demolition Waste	8.8%	9.0%	9.3%	9.5%	9.8%	10.2%
Glass & Ceramics	3.3%	3.3%	3.4%	3.4%	3.4%	3.5%
Plastics	9.2%	9.3%	9.5%	9.7%	9.8%	10.0%
Other Inorganic Waste	12.3%	12.3%	12.4%	12.4%	12.4%	12.5%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

The historical trends of biodegradable materials are given in Figure 3.13 and Figure 3.14 as percentages and tonnages. The slight decrease in food waste and increase in paper and cardboard can be clearly seen in these figures.

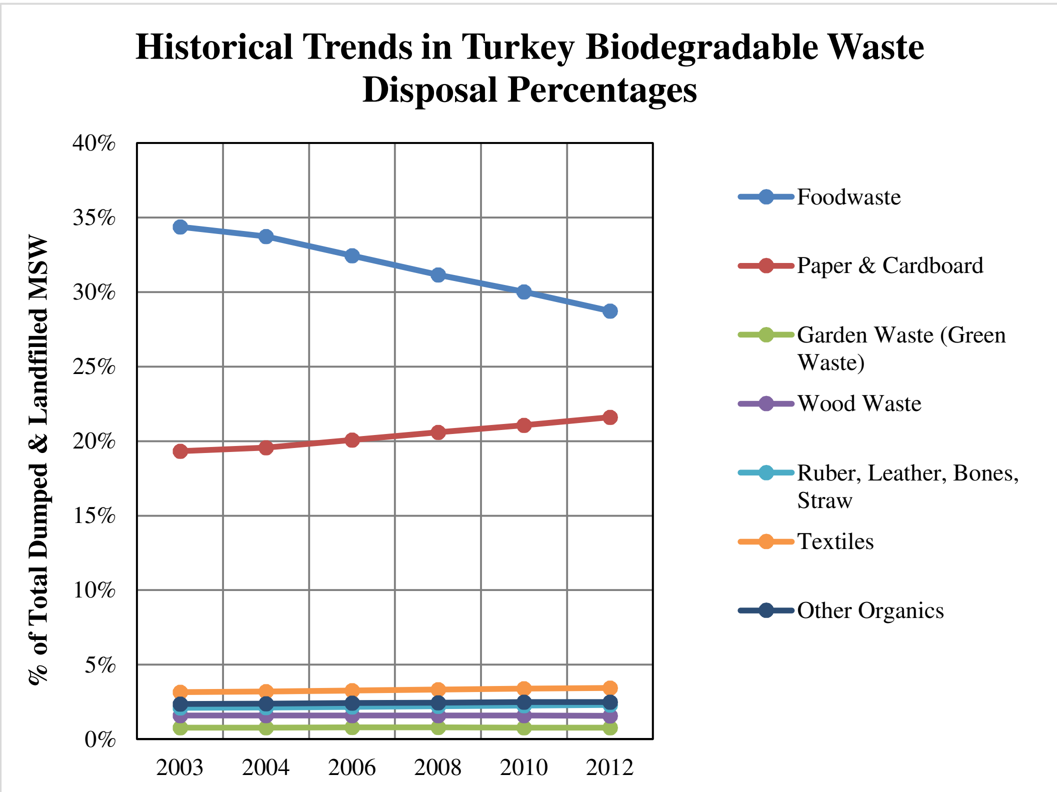

Figure 3.13 : Historical trends in Turkey biodegradable waste disposal.

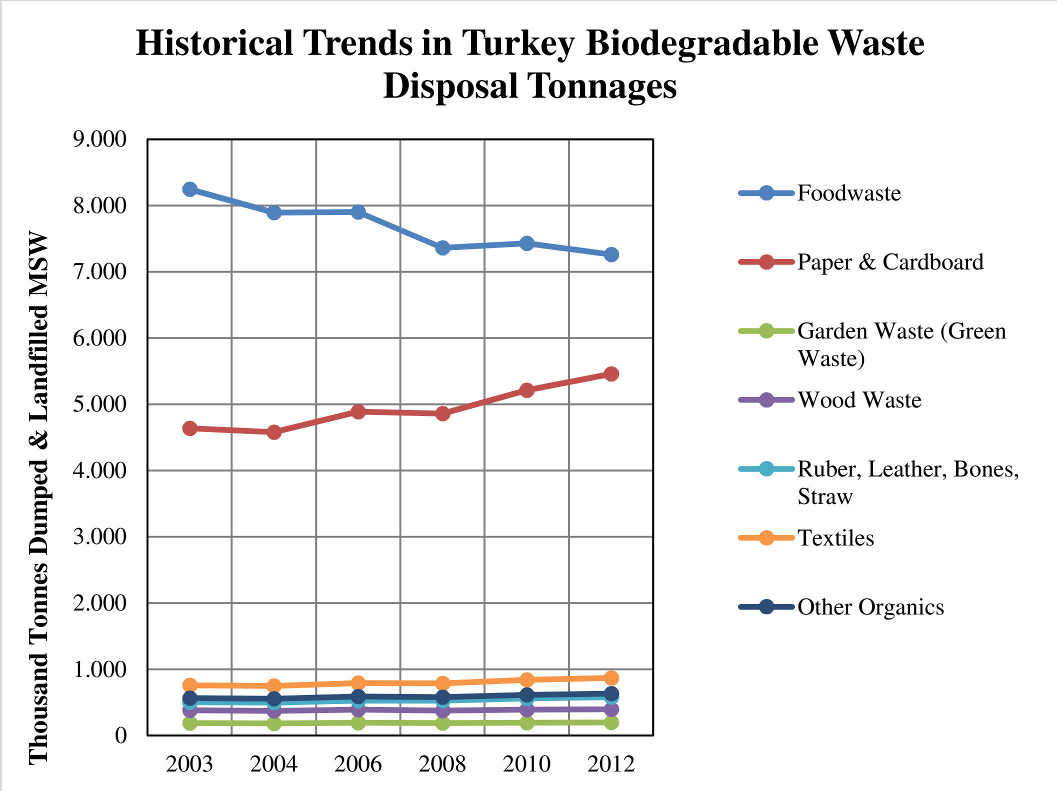

Figure 3.14 : Historical trends in Turkey biodegradable waste disposal tonnages.

3.3.3 Municipal solid waste management in Turkey

Currently, sanitary landfilling is the most common solid waste disposal method. By passing years, it's being worked on shifting the waste management mechanism from landfilling urban waste towards reusing and recovering it first, then landfilling the useless part of it with regulations.

By 2015, within the scope of The Ministry of Environment and Urbanisation of Turkey, there are 15 laws, 81 regulations, 31 annunciations, and so on directly related with "Environment" topic (T.C. Cevre ve Sehircilik Bakanligi, 2015).

Reducing the amount of waste after any activity is an obligatory subject in Turkish Environmental Law. According to the Article 3.f. of 2872 numbered Environmental Law, It's essential to use environmentally friend technology during all the activities which lessens waste production at source and allows recovery of waste produced, for the purpose of efficient use of natural resources and energy (T.C. Cevre ve Sehircilik Bakanligi, 1983). According to the Waste Management Regulation, The Ministery prepares or makes prepared waste management plans in order to monitor waste reduction and generates an information network in order to provide use of most proper technologies (T.C. Cevre ve Sehircilik Bakanligi, 2015).

Due to the main solid waste disposal method in Turkey is sanitary landfilling, "Regulation on Sanitary Landfilling of Waste" which is published in 2010 has additional importance. Temporary 1st article of this regulation states that, within 5 years after this regulation come into operation, there will be 25 % reduction by mass of total biodegradable waste produced in 2005, within 8 years 50 % reduction by mass and within 15 years 65% reduction by mass (T.C. Cevre ve Sehircilik Bakanligi, 2010). In other words, biodegradable waste reduction going to landfill sites is an obligation in Turkey for the next years.

According to the same regulation, collection and disposal of landfill gas is obligatory. Article 8.2 in Regulation on Sanitary Landfilling of Waste states that, all the landfill gas occurring in the sanitary landfill sites which accepts biodegradable waste for disposal, shall be collected and disposed by direct incineration of the gas or used in landfill gas to energy plants to generate electricity if it's economically feasible (T.C. Cevre ve Sehircilik Bakanligi, 2010). Related with the same regulation, a draft of Annunciation on Biodegradable Waste Management is prepared. The main scope is this annunciation is to control and manage all the biodegradable wastes and dispose them without giving harm to the environment and human health. Also defining the management and criteria of material recovery plants in order to reduce the amount of biodegradable waste to be disposed in sanitary landfill sites. It's indicated in the annunciation that municipalities are responsible to separate the biodegradable and non-biodegradable waste in source and make the input material ready for the material recovery facilities.

It's seen in the figure that regulations have serious effects on MSW management in Turkey.In late nineteenth century, nearly all the waste was dumped on land without proper controls. Today, there are still dumpsites around Turkey, but there is a rapid increase in sanitary landfill sites (TUIK, 2015).

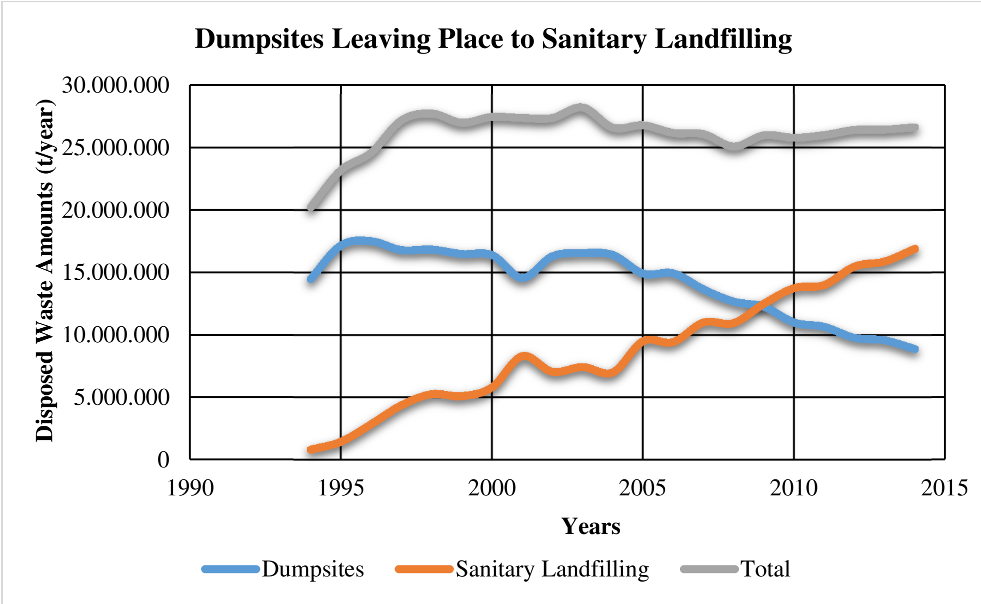

Figure 3.15 : Dumpsites leaving place to sanitary landfilling (TUIK, 2015).

Today, nearly all the MSW is disposed in dumpsites or in landfills in Turkey (Figure 3.17). There were 15 landfills in urban areas in 2003 and this number rose to 38 in 2008, 59 in 2011, and 69 in 2012. Moreover there are 29 landfills in phase of construction and construction tender, and 21 in the stage of planning-project. The numbers of MSW sanitary landfill sites for different years are given in the Figure 3.16.

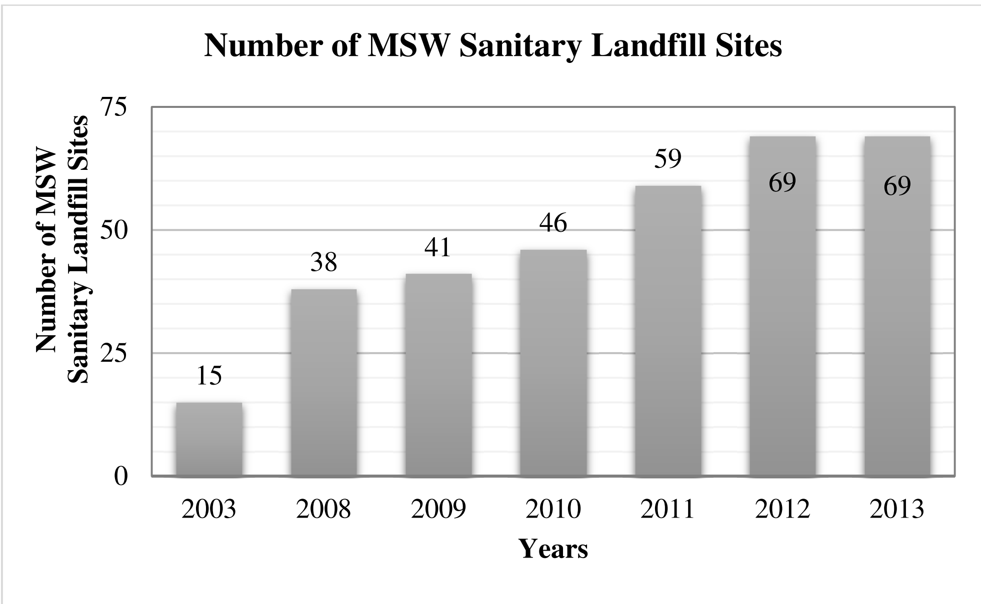

Figure 3.16 : Number of MSW sanitary landfill sites (MoE&U, 2013).

As of 2013, the ratio of the population benefiting from the landfill facilities to the total population of municipalities was 69%. It is aimed to increase this rate to 77% by 2017.

In addition, it is also planned to renovate all the current landfill facilities and to increase the rate of the population benefiting from those services to 100% by the end of 2023 (MoE&U, 2013).

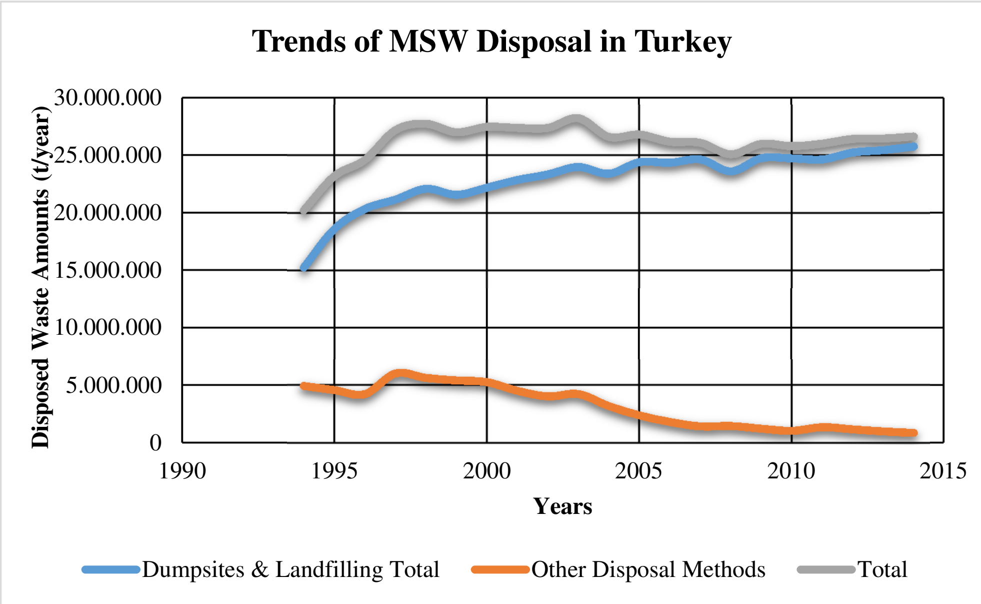

Figure 3.17 : Trends of MSW disposal in Turkey (TUIK, 2015)

In order to see the current situation, a map of MSW landfills and a map of organic MSW distibution are given in Figure 3.18 and Figure 3.19. The distribution data are given in 5 groups according to the tonnages in both figures for the last years records. The sizes of green-brown circles in Figure 3.18 indicates the scales of MSW landfills for each city. It also classifies the organic part in brown and inorganic part in green. Also the dustbin images in Figure 3.19 are scaled in accordance with the amount of organic waste amounts for each cities. When both figures are examined carefully, it’s seen that number of cities are changing in each groups. As an example for the cities given in red color; there are 16 cities including Kayseri, which have MSW between 437,000 – 6,473,000 t/year. However in Figure 3.19, there are 15 cities in this group where Kayseri is excluded. Theese differences are caused by the difference of MSW characteristics of each cities.

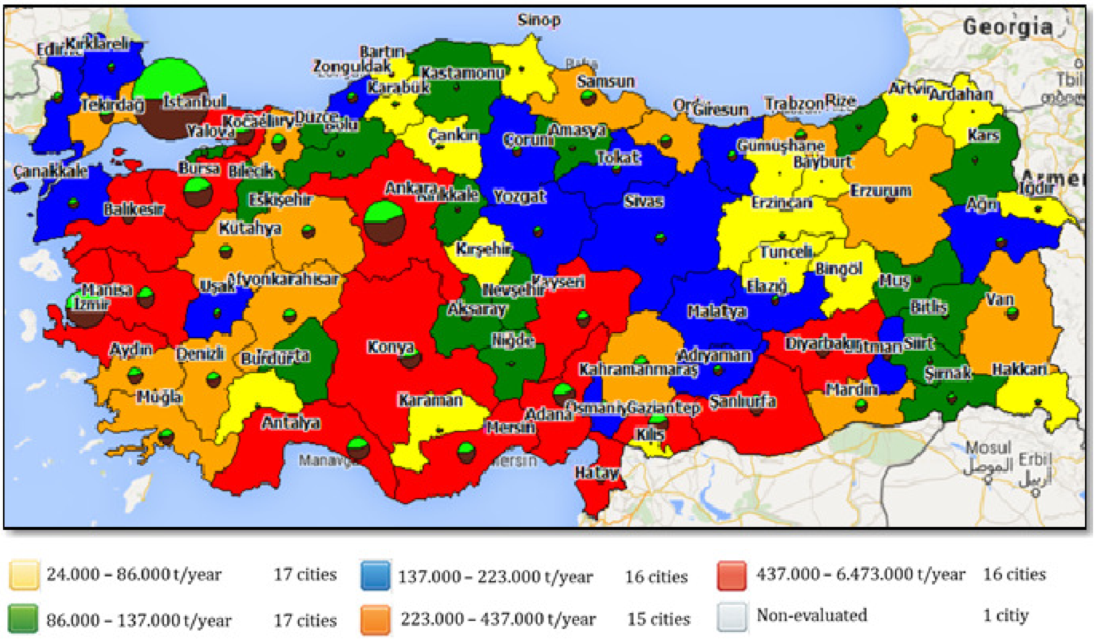

Figure 3.18 : Map of MSW landfills (GDoRE, 2015).

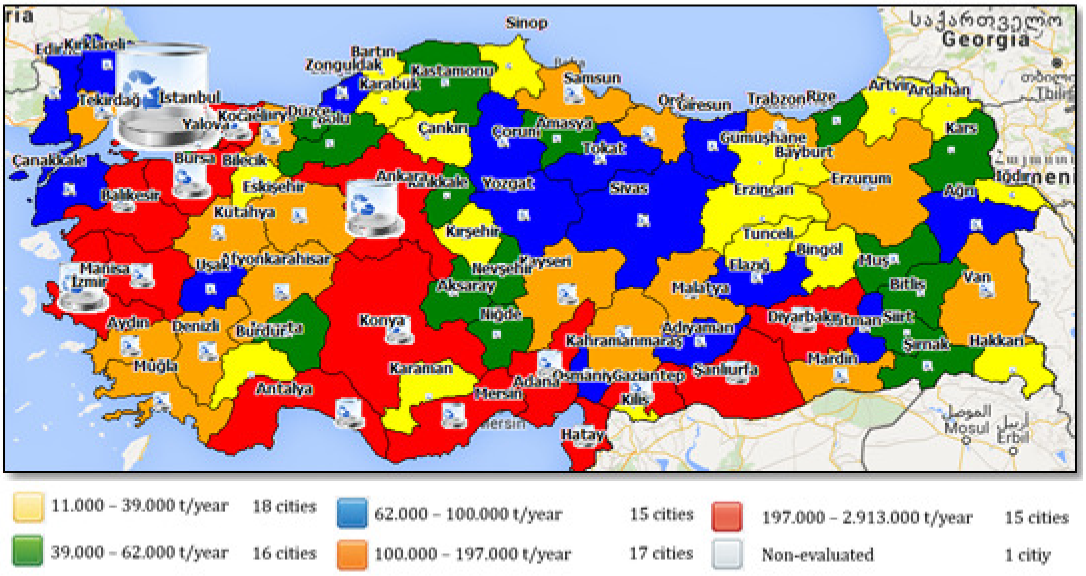

Figure 3.19 : Map of organic MSW distribution (GDoRE, 2015).

3.3.4 LFG management in Turkey

According to the Regulation of Sanitary Landfilling in Turkey, all the landfill gas (LFG) must be collected with an active or passive collection system and to be burned or converted into energy in landfill gas to energy plants. Turkey has a developing market in landfill gas to energy business since 2008 and today there are 53 licensed biomass plants (Energy Market Regulatory Authority, 2015). This biomass plants listed in Energy Market Regulatory Authority include both the biogas plants and landfill gas plants which has an electricity generation license in order to generate electricity and sell it to the market. Today, there are more than 25 LFGTE (Landfill Gas to Energy) plants in Turkey and the number is still increasing. Also according to the list published by EMRA involving licensed LFGTE plants given in Table 3.2, total installed power in Turkey is more than 175 MWe today (Electricity Market Regulatory Authority, 2015).

Table 3.2 : Licensed LFGTE plants in Turkey (EMRA, 2015).

Operation Began	**Plant Name**	**City**	**Installed Power (MW_e)**
25.10.2007	Odayeri Çöp Gazı Santralı	İstanbul	33.807
04.08.2006	Mamak Katı Atık Alanı Enerji Üretim Tesisi	Ankara	25.434
20.11.2008	Sincan Çadırtepe Biyokütle Enerji Sanrali	Ankara	22.656
25.10.2007	Kömürcüoda Çöp Gazı Santralı	İstanbul	16.98
04.02.2010	ITC Adana Enerji Üretim Tesisi	Adana	15.565
01.12.2011	ITC Bursa Hamitler Tesisi	Bursa	9.8
11.08.2011	Her Enerji Kayseri Katı Atık Depo Sahası Biyogaz otoprodüktör Santrali	Kayseri	5.782
24.03.2011	Aslım Enerji Üretim Tesisi	Konya	5.66
27.08.2009	Gaziantep Büyükşehir Belediyesi Katı atık Depolama Alanı	Gaziantep	5.655
06.10.2011	Kocaeli Çöp Biyogaz Santrali Biyokütle Projesi	Kocaeli	5.093
27.02.2013	Arel Enerji Manavgat Biyokütle Tesisi	Antalya	3.6
01.05.2014	Tatlar Köyü-Sincan-Ankara	Ankara	3.2
03.09.2015	Trabzon Rize Çöp Gazı Santrali	Trabzon	2.826
15.10.2015	Sivas Çöp Gaz Elektrik Üretim Tesisi	Sivas	2.826
23.10.2014	Amasya Çöp Gaz Elektrik Üretim Tesisi	Amasya	2.4
04.06.2014	ITC Aksaray Üretim Tesisi	Aksaray	1.415
17.06.2010	Bolu Çöp Biyogaz Projesi	Bolu	1.131
08.10.2015	Dilovası Çöp Biyogaz Santrali	Kocaeli	1.063
03.10.2012	Kırıkkale Çöp Gazı Santrali Biyokütle Projesi	Kırıkkale	1.003
24.09.2008	Karatepe Katı Atık Bertaraf Tesisi	Tekirdağ	0.8
27.10.2010	Kumkısık Lfg Santrali	Denizli	0.635
05.10.2004	Kemerburgaz Çöp	İstanbul	0.588

Map of LFGTE facilities' distribution in Turkey is given in Figure 3.20.

Figure 3.20 : Map of LFGTE facilities distribution in Turkey.

Some pictures of various LFGTE are shown in Figure 3.21, 3.22 and 3.23.

Figure 3.21 : LFGTE plant in Istanbul (Turkish Time, 2011).

Figure 3.22 : LFGTE plant in Gaziantep (CEV, 2010).

Figure 3.23 : LFGTE plant in Ankara (ITC Turkiye).

3.3.4.1 Feed-in-tariff mechanism

Turkey as a developing country is approximately 70% foreign dependent on energy resources. Due to one of the most important principle on nationalities' energy strategies, each country should supply uninterrupted and sustainable energy to the citizens. In this context, it's decided to diversify energy resources and increase the importance of natural and renewable energy resources in 2010. According to The Law on Usage of Renewable Energy Resources for Generating Electricity, the government gives 10 years electricity buy guarantee in fixed prize for different kinds of resources (T.C. Enerji ve Tabii Kaynaklar Bakanligi, 2011). The rates are given in Table 3.3.

Feed-in-tariff mechanism is a great opportunity for the investors to construct and operate LFGTE plants in order to use landfilled waste as alternative energy resource. By the application of the Law on Usage of Renewable Energy Resources for Generating Electricity, it becomes economically feasible to evaluate organic materials within biomass plants or directly use the landfill gas to generate electricity. According to the licenses given by Electricity Market Regulatory Authority, current installed capacity on biomass plants and landfill gas to energy plants in Turkey is more than 270 MWe (Electricity Market Regulatory Authority, 2015).

Table 3.3 : Eletricity selling prices to be applied for different sources (EMRA, 2015).

The Type of Generation Type Based on Renewable Energy Resoruce	Price (US$cent / kWh)
Hydroelectricity Generation Plant	7.3
Wind Energy to Electricity Generation Plant	7.3
Geothermal Energy to Electricity Generation Plant	10.5
Biomass Energy to Electricity Generation Plant (Landfill Gas to Energy is also included)	13.3
Solar Energy to Electricity Generation Plant	13.3

As it’s clearly seen in the Table 3.3, feed-in-tariff mechanism is also applied for landfill gas to energy plants same as biogas plants. There is also additional incentives for projects which have locally produced parts. Additional feed-in-tariff rates are given in Table 3.4 for biomass projects. When renewable energy generation is considered in Turkey, landfill gas to electricity generation is one of the most important alternative energy generation method.

Table 3.4 : Additional incentives for biomass projects if locally produced parts are used (EMRA, 2015).

Locally Produced Parts	**Additional incentives (US$ cents/kWh)**
Fluid based steam boiler	0.8
Fluid or gas fired steam boiler	0.4
Gassing and gas cleaning group	0.6
Steam or gas turbine	2.0
Engine	0.9
Generator and power electronics	0.5
Cogeneration System	0.4

4. METHOD

4.1 Scenarios and Assumptions

Three different scenarios are evaluated in this study in order to see the effects of biodegradable waste diversion on landfill gas production potential. The first scenario is the baseline scenario that no diversion is considered, the second scenario is the full consistence to the regulations scenario and the third one is the consistence to the regulations with a five years lag scenario.

Because the main solid waste disposal method in Turkey is sanitary landfilling, "Regulation on Sanitary Landfilling of Waste" which was published in 2010 has additional importance. Temporary 1st article of this regulation states that, within 5 years after this regulation come into operation, there will be 25 % reduction by mass of total biodegradable waste produced in 2005, within 8 years 50 % reduction by mass and within 15 years 65% reduction by mass (T.C. Cevre ve Sehircilik Bakanligi, 2010). For that purpose, 2005, 2010, 2015, 2018 and 2025 are the key years.

It's calculated as below that total produced biodegradable waste amount in 2005 in Turkey is 16,903,615 tonnes/year **(4.1)**.

$$\text{Bio. Waste } (2005) = \frac{26{,}810{,}000 \cdot 63.1}{100} = 16{,}903{,}615 \qquad \textbf{(4.1)}$$

Where;

26,810,000 is total waste produced in Turkey,

63.1 is percentage of biodegradable waste for Turkey.

* It's assumed in this calculation that waste disposal amounts are equal to waste generation amounts.

Total mixed MSW and biodegradable waste amounts going to landfills for the key years are given in Table 4.1 for each scenario. The biodegradable waste amount in 2015 was calculated below **(4.2)**.

$$\text{Bio. Waste}\ (2015) = 16{,}903{,}615 \cdot 0.75 = 12{,}677{,}711\ \text{t/year} \qquad \textbf{(4.2)}$$

Table 4.1 : Total mixed MSW & biodegradable waste amounts going to landfills for each scenario.

		Scenario 1 (Baseline)	Scenario 2 (Full Consistence)	Scenario 3 (5 Years Lag)
Biodegradable Waste Going Landfills (tonnes/year)	**2010**	15,243,995	15,243,995	15,243,995
	2015	15,824,919	12,677,711	13,960,853
	2018	16,052,806	8,451,807	13,190,968
	2025	16,450,012	5,916,265	7,727,367
Total Waste Disposed in Landfills (tonnes/year)	**2010**	24,748,029	24,748,029	24,748,029
	2015	26,323,970	23,176,761	24,459,903
	2018	27,092,141	19,491,143	24,230,303
	2025	28,680,519	18,146,772	19,957,874

4.1.1 Scenario 1

It's assumed in the first scenario that all the mixed MSW will be disposed in landfills for today and in the future without any biodegradable waste diversion. Therefore, this scenario will be called as baseline scenario. The waste characteristics are different for each year and the results of extended waste characterization (percentages of each material in MSW) between 2003 – 2040 are given in Table 5.5 to 5.12 in Results section. Linked with the characterization data, tonnages for each material within MSW going to the landfill site between 2003 – 2040 are given in App. C. The sum of each material amount will give the total MSW amount going to the landfill site between related years which will be the inputs of model for all the calculations in this scenario. Yearly landfilled waste amounts are given in Table 4.2 for this scenario.

Table 4.2 : Total landfilled MSW amount as model input for scenario 1 (2003 – 2040).

Years	**Landfilled MSW** tonnes/year	**Years**	**Landfilled MSW** tonnes/year	**Years**	**Landfilled MSW** tonnes/year
2003	23,998,245	**2016**	26,585,024	**2029**	29,403,635
2004	23,417,291	**2017**	26,841,257	**2030**	29,565,308
2005	24,420,000	**2018**	27,092,141	**2031**	29,718,429
2006	24,369,477	**2019**	27,337,739	**2032**	29,863,006
2007	24,655,000	**2020**	27,578,013	**2033**	29,998,706
2008	23,624,579	**2021**	27,812,745	**2034**	30,125,562
2009	24,765,000	**2022**	28,041,983	**2035**	30,243,321
2010	24,748,029	**2023**	28,265,340	**2036**	30,351,637
2011	24,655,000	**2024**	28,482,396	**2037**	30,450,593
2012	25,255,163	**2025**	28,680,519	**2038**	30,540,503
2013	25,460,000	**2026**	28,871,953	**2039**	30,621,298
2014	25,775,000	**2027**	29,056,444	**2040**	30,692,977
2015	26,323,970	**2028**	29,233,783		

4.1.2 Scenario 2

Scenario 2 is assumed as a full consistence scenario for the goals given in Regulation on Sanitary Landfilling. In that scenario, total yearly biodegradable waste to be landfilled at the end of 2015 will be 12,677,711 tonnes/year, at the end of 2018 will be 8,451,807 tonnes/year and at the end of 2025 5,916,265 tonnes/year.

It's assumed in this scenario that biodegradable waste reduction was started just after the regulation published in 2010.

It's also assumed that there would be a linear reduction from 2010 to 2015, 2015 to 2018 and 2018 to 2025.

Another assumption in this scenario is about the distribution of different kind of biodegradable materials within the same year. It's assumed that total biodegradable waste reduction in one year to another will be same for each portion (food waste, paper & cardboard, garden waste, wood waste, rubber, leather, bones, straw, textiles and other organics) of biodegradable materials going to landfill site.

Final assumption in this scenario is about biodegradable waste going to the landfill site after 2025. The regulation defines the biodegradable waste going to the landfill sites till 2025 but tells nothing after this year. It's assumed that the maximum total biodegradable waste amount will be as it's in 2025. In other words, total biodegradable waste going to the landfills will be constant (5,916,265 tonnes/year) after 2025.

Interpolation method was used in order to calculate the amounts of each and total biodegradable material going to the landfills. Example calculation for linear biodegradable waste reduction is given below **(4.3)**, **(4.4).**

$$\% \text{ Decrease} = \frac{\text{BW (2015)}}{\text{BW (2010)}} = \frac{12{,}677{,}711}{15{,}243{,}995} = 83\% \qquad \textbf{(4.3)}$$

$$\begin{aligned} \text{BW (2011)} &= \text{BW (2010)} + (2011 - 2010) \cdot \frac{\text{BW (2015)} - \text{BW (2010)}}{2015 - 2010} \\ &= 15{,}243{,}995 + (2011 - 2010) \cdot \frac{12{,}677{,}711 - 15{,}243{,}995}{2015 - 2010} \\ &= 14{,}730{,}738 \text{ tonnes/year} \end{aligned} \qquad \textbf{(4.4)}$$

Where;

BW = Biodegradable Waste Amount (tonnes/year)

The composition of waste (tonnages for each materials within MSW going to landfill) between 2003 – 2040 are given as tonages in App. D where the total waste amount to be landfilled had been calculated in order to use as an input in the model as it's done in Baseline Scenario. There will be no difference with the inorganic part in mixed municipal solid waste to be landfilled. Therefore, the decrease in biodegradable materials will effect compositions (percentages) of each material in waste body. The Waste characteristic inputs for Scenario 2 are calculated as in the example below **(4.5)** and given in Table 5.13 to 5.20 in the Results section.

$$\begin{aligned} \%_{\text{Foodwaste}} (2011) &= \frac{\text{M}_{\text{Foodwaste}}(2011)}{\text{M}_{\text{Total}}(2011)} \cdot 100 = \frac{7{,}180{,}443}{24{,}273{,}687} \cdot 100 \\ &= 30.0\% \end{aligned} \qquad \textbf{(4.5)}$$

According to the data given in App. D, total MSW amounts to be landfilled for Scenario 2 are calculated and the results for yearly mixed waste landfilling are given in the Table 4.3.

Table 4.3 : Total MSW amount to be landfilled as model input for scenario 2 (2003 – 2040).

Years	**Landfilled MSW** tonnes/year	**Years**	**Landfilled MSW** tonnes/year	**Years**	**Landfilled MSW** tonnes/year
2003	23,998,245	**2016**	21,975,289	**2029**	18,774,009
2004	23,417,291	**2017**	20,733,405	**2030**	18,916,522
2005	24,420,000	**2018**	19,491,143	**2031**	19,091,917
2006	24,369,477	**2019**	19,296,291	**2032**	19,240,128
2007	24,655,000	**2020**	19,093,348	**2033**	19,385,173
2008	23,624,579	**2021**	18,909,840	**2034**	19,526,992
2009	24,765,000	**2022**	18,719,915	**2035**	19,665,395
2010	24,748,029	**2023**	18,505,110	**2036**	19,800,146
2011	24,273,687	**2024**	18,348,472	**2037**	19,931,205
2012	24,076,838	**2025**	18,146,772	**2038**	20,058,637
2013	23,712,054	**2026**	18,305,493	**2039**	20,182,335
2014	23,396,075	**2027**	18,469,774	**2040**	20,302,219
2015	23,176,761	**2028**	18,621,522		

4.1.3 Scenario 3

Due to the limited financial capabilities of municipalities in Turkey, It would take some time to reach the goals. Therefore, the same reduction goals are postponed for 5 years and same calculations had done as in Scenario 3. In this scenario, total yearly biodegradable waste to be landfilled at the end of 2020 will be 12,677,711 tonnes/year, at the end of 2023 will be 8,451,807 tonnes/year and at the end of 2030 5,916,265 tonnes/year.

It's assumed in this scenario that biodegradable waste reduction was started just after the regulation published in 2010.

It's also assumed that there would have been a linear reduction from 2010 to 2020, 2020 to 2023 and 2023 to 2030.

It's again assumed that total biodegradable waste reduction in one year to another will be same for each portion (food waste, paper & cardboard, garden waste, wood waste, rubber, leather, bones, straw, textiles and other organics) of biodegradable materials going to landfill site as in Scenario 2.

It's assumed that the maximum total biodegradable waste amount will be as it's in 2030 where the similar approach has applied in the calculations of Scenario 2. In other words, total biodegradable waste going to the landfills will be constant (5,916,265 tonnes/year) after 2030.

The composition of waste between 2003 – 2040 are given as tonages in App. E which are calculated with the same enterpolation method like in Scenario 2. The total waste amount to be landfilled are calculated in order to use as an input in the model as it's done in Scenario 1 and Scenario 2. According to the data given in App. E, total MSW amounts to be landfilled for Scenario 3 are calculated and the results for yearly mixed waste landfilling are given in the Table 4.4. Also the waste characteristics were calculated as in Scenario 2 and the results are given in Table 5.21 to 5.28 in Results section.

Table 4.4 : Total MSW amount to be landfilled as model input for scenario 3 (2003 – 2040).

Years	Landfilled MSW tonnes/year	Years	Landfilled MSW tonnes/year	Years	Landfilled MSW tonnes/year
2003	23,998,245	**2016**	24,410,437	**2029**	19,136,229
2004	23,417,291	**2017**	24,320,559	**2030**	18,916,522
2005	24,420,000	**2018**	24,230,303	**2031**	19,091,917
2006	24,369,477	**2019**	24,141,043	**2032**	19,240,128
2007	24,655,000	**2020**	24,043,693	**2033**	19,385,173
2008	23,624,579	**2021**	22,813,770	**2034**	19,526,992
2009	24,765,000	**2022**	21,577,431	**2035**	19,665,395
2010	24,748,029	**2023**	20,316,211	**2036**	19,800,146
2011	24,530,315	**2024**	20,159,573	**2037**	19,931,205
2012	24,590,095	**2025**	19,957,874	**2038**	20,058,637
2013	24,481,939	**2026**	19,754,374	**2039**	20,182,335
2014	24,422,589	**2027**	19,556,435	**2040**	20,302,219
2015	24,459,903	**2028**	19,345,962		

4.2 Landfill Gas Modelling

In this study, Central-Eastern Europe Landfill Gas Model Version 0.1 developed for Global Methane Initiative. The model uses Excel spreadsheet software to estimate LFG generation and recovery from landfill site based on following informations.

- The amounts of waste disposed at the site annually.
- The opening and closing years of site operation.
- The methane generation rate (k) constant.
- The potential methane generation capacity (L_0).
- The methane correction factor (MCF).
- The fire adjustment factor (F).
- The collection efficiency of the gas collection system.

The model estimates LFG generation using the following first-order exponential equation which was modified from the U.S. EPA's Landfill Gas Emissions Model (LandGEM) version 3.02 (SCS Engineers, 2014).

$$Q_{LFG} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} 2kL_0 \left[\frac{M_i}{10}\right] (e^{-kt_{ij}}) (MCF) (F) \quad \textbf{(4.6)}$$

Where;

Q_{LFG} = maximum expected LFG generation flow rate (m^3/yr)

i = 1 year time increment

n = (year of the calculation) – (initial year of waste acceptance)

j = 0.1 year time increment

k = methane generation rate (1/yr)

L_0 = potential methane generation capacity (m^3/ton)

M_i = mass of solid waste disposed in the i^{th} year (ton)

t_{ij} = age of the jth section of waste mass Mi disposed in the i^{th} year (decimal years)

MCF = methane correction factor

F = fire adjustment factor

It's reported that the annual waste disposal rates, k and L_0 values, MCF, and fire adjustment factor are used in the above equation to estimate the LFG generation rate for a given year from cumulative waste disposed up through that year (SCS Engineers, 2014). The prediction for landfill gas amount depends on the biodegradable portion of the waste to be landfilled. The model applies separate equations for different types of biodegradable waste in for different categories according to the waste decay rates.

1. Very fast decaying waste – food waste and other organics.
2. Medium fast decaying waste – garden waste (green waste).
3. Medium slow decaying waste – paper and cardboard, textiles.
4. Slowly decaying waste – wood, rubber, leather, bones, straw

Total LFG generation of whole waste is always calculated by summing up all the results for each calculations.

Due to the main objective in this study is to work on the potential landfill gas production not to work on the recovery from site, the inputs related with the production potential were taken into consideration. Also it would be difficult to make a cumulative recovery assumption for allover Turkey for only one site specification in order to see the recovery potential, since the operational conditions differ in a wide range site by site. Here are the main model inputs, which were always constant for all calculations done by model for different waste amounts of 3 scenarios and different waste characteristics, listed below;

- There are 5 different climate zone options in model that can be chosen. Moderate (500-599 mm/yr) condition is selected in order to demonstrate average results.
- It's assumed that the landfilling started in 2003 and it will continue till 2040.
- The cumulative total MSW amount in site will be 1,046,921,067 tonnes in 2040.
- The density of waste was assumed as 0.80 tonnes/m³.

- The estimated growth in annual disposal is calculated as 0,7% between the years 2003 – 2040 and used as an input.

- There are 4 different definition in order to demonstrate site operation as 1=Open Dump Site, 2= Controlled Landfill or Dump Site, 3=Sanitary Landfill and 4=Unknown. Controlled Landfill or Dump Site (number 2) was selected as an average.

- It's assumed that there are no impact of fire in sites.

- No change has done in model with the L_0 of 4 different types of organic wastes since it's developed for the Central-Eastern Europe Region which may suit with Turkish waste characteristics. Fast-decay Organic Waste L_0 was set to 70 m^3/t, Medium fast decay Organic Waste L_0 was set to 93 m^3/t, Medium slow decay Organic Waste L_0 was set to 182 m^3/t and Slow-decay Organic Waste L_0 was set to 200 m^3/t. $L_{0,Average}$ for each calculations will be linked with the related year's waste characteristics.

- The total MSW and biodegradable waste amounts going to the landfill as inputs for 3 scenarios were given in Table 4.2, 4.3 and 4.4.

In order to define the input characteristics data for model, first of all the results of waste composition calculations (data extension) done between 2003 – 2040 should be converted into the correct variables for the model. The extended data variables according to the characterization given in Solid Waste Master Plan (KAAP) differs from the model inputs as listed in 16 different material types below.

1. Cardboard
2. High Volume Cardboard
3. Concrete / Tile / Debris
4. Kitchen Waste
5. Garden (Yard) Waste
6. Glass
7. Hazardous Waste

8. Metal
9. High Volume Metal
10. Other Combustibles
11. Other High Volume Combustibles
12. Other High Volume Non-Combustibles
13. Other Non-Combustibles
14. Paper
15. Plastic
16. Electrical & Electronical Equipment Waste

However, the model input characterization ingredients are as follows.

1. Food Waste
2. Paper and Cardboard
3. Garden Waste (Green Waste)
4. Wood Waste
5. Rubber, Leather, Bones, Straw
6. Textiles
7. Other Organics
8. Metals
9. Construction and Demolition Waste
10. Glass and Ceramics
11. Plastics
12. Other Inorganic Waste

Therefore, variable conversion was done as follows,

Food waste	= Kitchen Waste
Paper & Cardboard	= Cardboard + High Vol Cardboard + Paper

Garden Waste (Green Waste)	= 40% x Garden (Yard) Waste
Wood Waste	= 60% x Garden (Yard) Waste + 40% Other High Volume Combustibles
Ruber, Leather, Bones, Straw	= 30% x Other Combustibles
Textiles	= 45% x Other Combustibles
Other Organics	= 25% x Other Combustibles + 60% Other High Volume Combustibles
Metals	= Metal + High Volume Metal
Construction & Demolition Waste	= 95% Concrete / Tile / Debris
Glass & Ceramics	= 5% Concrete / Tile / Debris + Glass
Plastics	= Plastic
Other Inorganic Waste	= EEEW + Hazardous Waste + Other Non-Combustibles + Other High Volume Non-Combustibles

Since the model works with a single waste characterization data, it was run for 38 x 3 = 114 times for 3 scenarios with 38 years' waste characteristics in order to have 3 average output. As an example on Scenario 1, all the previous assumptions in this section is applied as input parameters to the model. Total MSW amounts between 2003 – 2040 is also entered as input (A summarized graph about total MSW inputs for the model is given in Figure 4.1.). Then the model was run with the characteristics of 2003 and an output table named "Scenario 1 – 2003" was formed. Then, the model was run with the characteristics of 2004 and an output table named "Scenario 2 – 2004" was formed. The result for 2003 was not used in the 2004-output table. Same approach was applied till 2040 and 38 output tables were generated for Scenario 1. Thus, model was run for 38 x 3 = 114 times and 38 x 3 = 114 output tables were formed. To calculate the average results, given closed formula is used **(4.7)**. Its open form is also given below **(4.8)**.

$$Q_{LFG,n} = \frac{\sum_{i=2003}^{n} Q_{LFG}(i)}{n - 2003} \quad \textbf{(4.7)}$$

$$Q_{LFG,2003} = Q_{LFG}(2003) \quad \textbf{(4.8)}$$

$$Q_{LFG,2004} = \frac{Q_{LFG}(2003) + Q_{LFG}(2004)}{2}$$

$$Q_{LFG,2005} = \frac{Q_{LFG}(2003) + Q_{LFG}(2004) + Q_{LFG}(2005)}{3}$$

$$\ldots$$

$$Q_{LFG,2040} = \frac{\sum_{i=2003}^{2040} Q_{LFG}(i)}{2040 - 2003}$$

The average results were calculated for each year as in the example for Scenario 1 below **(4.9)**.

$$Q_{LFG,2003} = 0\ \mathrm{m^3/h} \quad \textbf{(4.9)}$$

$$Q_{LFG,2004} = \frac{21{,}784 + 21{,}588}{2} = 21{,}686\ \mathrm{m^3/h}$$

$$Q_{LFG,2005} = \frac{40{,}836 + 40{,}482 + 40{,}154}{3} = 40{,}491\ \mathrm{m^3/h}$$

$$\ldots$$

$$Q_{LFG,2040} = \frac{318{,}323 + 317{,}728 + 317{,}494 \ldots 305{,}092}{38} = 311{,}438\ \mathrm{m^3/h}$$

The same calculation was done for all scenarios.

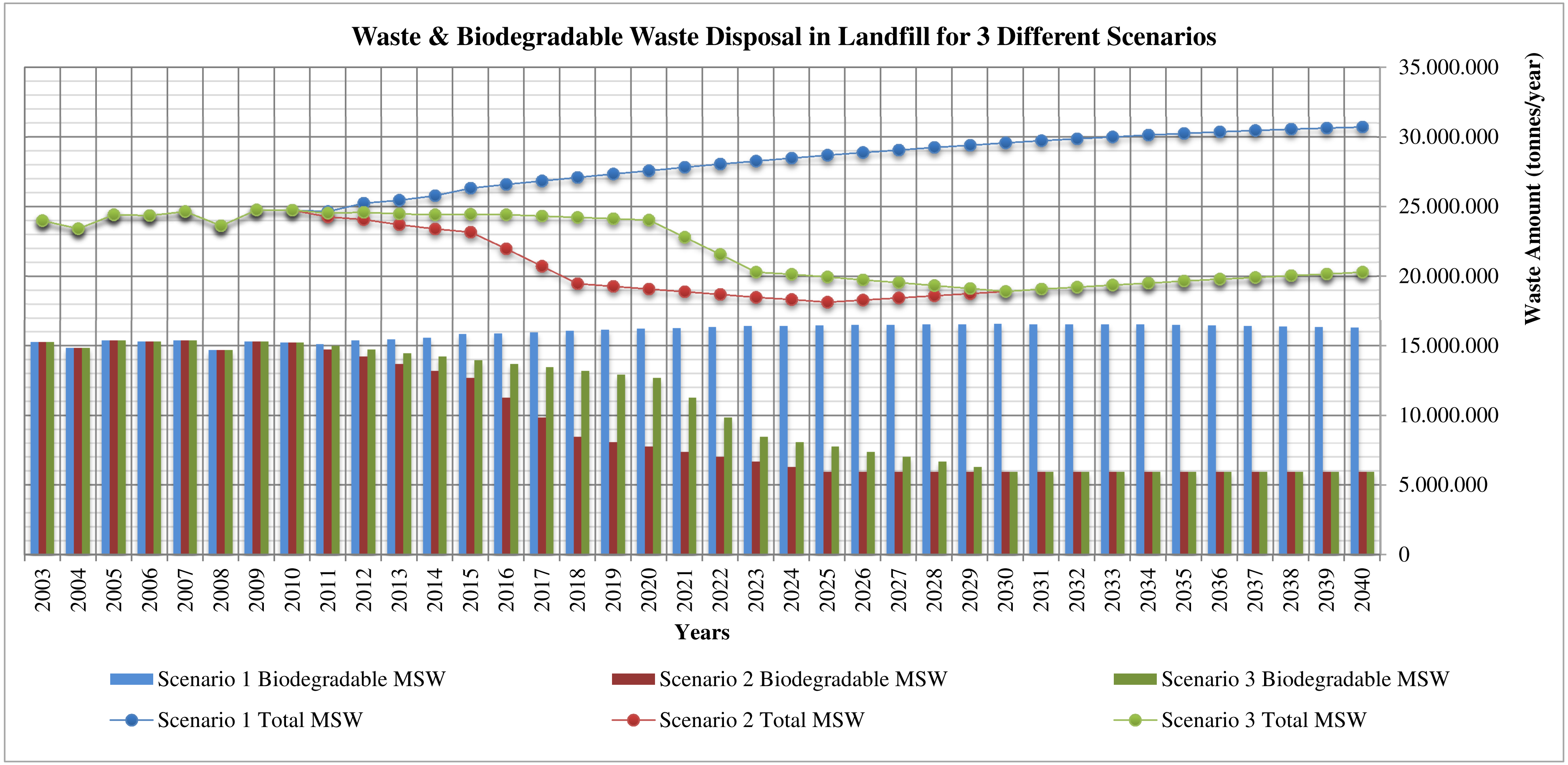

Figure 4.1 : Waste & biodegradable waste disposal in landfill for 3 different scenarios.

5. RESULTS

5.1 Estimation of Missing Data in Population Projections and Waste Statistics

Turkish Statistical Institute (TUIK) is a reliable statistics data bank, where the government guarantees all the data. For that purpose, waste data in TUIK is taken into consideration in order to see the current picture. The amounts of waste to be disposed with different waste disposal activities are given in the tables in App A. (TUIK, 2015).

"Dumpsites" data row in Table A.3 represents the sum of "metropolitan municipality dumpsites", "municipality dumpsites" and "other dumpsites" rows given in the Table A.1. Also the "Dumpsites & Landfilling Total" data row in Table A.2 is sum of Dumpsites and Sanitary Landfilling in the same table. This variable derivation is done in order to see all the similar anaerobic disposal activities in once.

In order to have much more precise calculations, the missing data for all the waste disposal activities were created by using the trends in the real statistical data graphs showing in Figure 5.1 to 5.11.

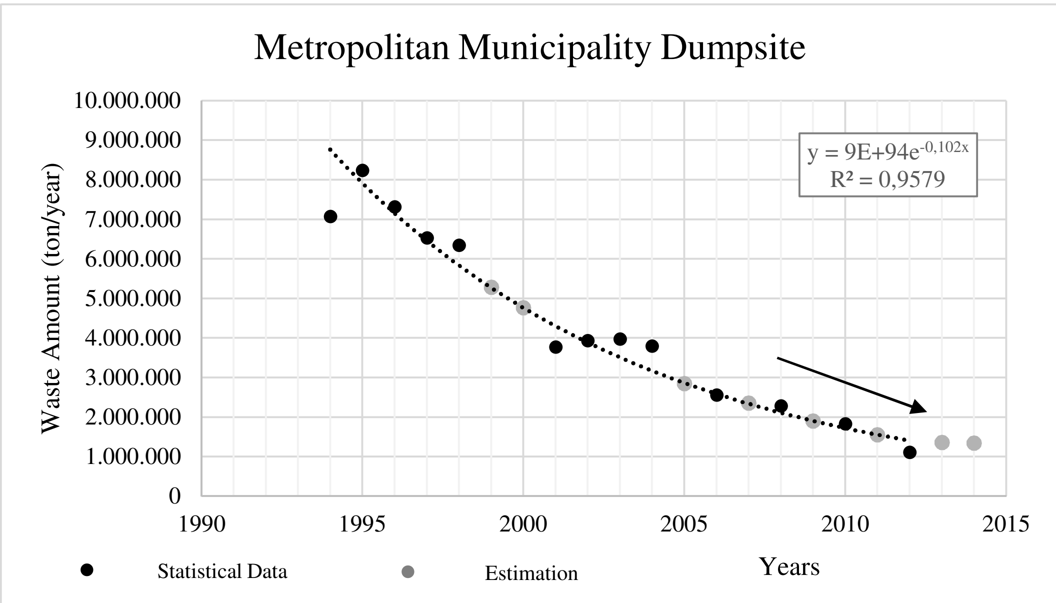

Figure 5.1 : Waste disposal amounts in metropoitan municipality dumpsites.

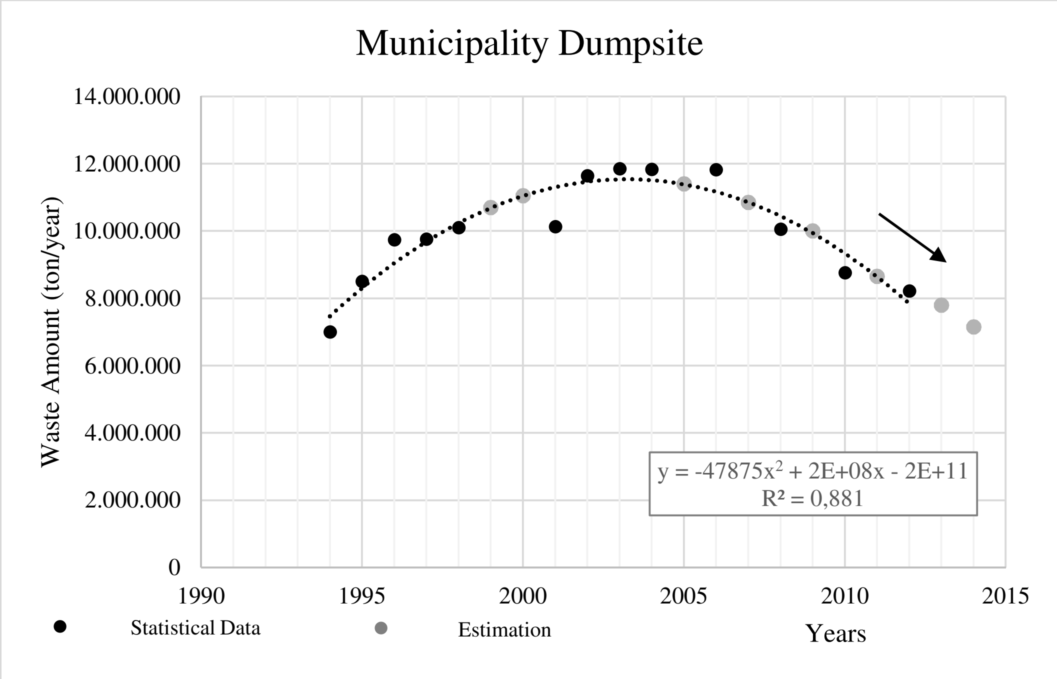

Figure 5.2 : Waste disposal amounts in municipality dumpsites.

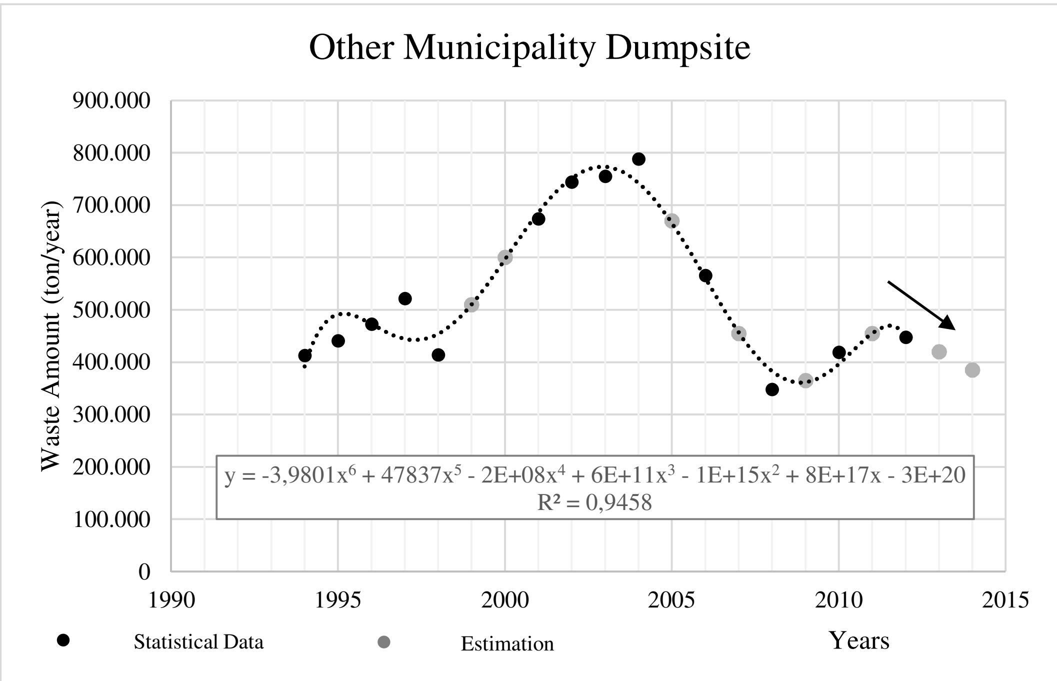

Figure 5.3 : Waste disposal amounts in other municipality dumpsites.

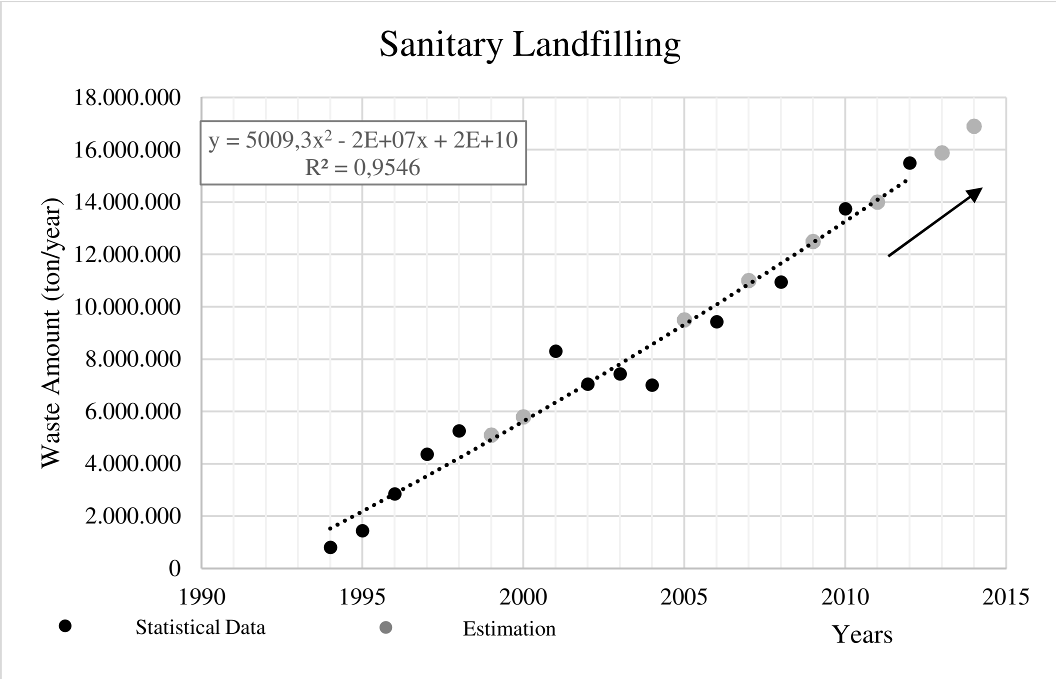

Figure 5.4 : Waste disposal amounts in sanitary landfilling.

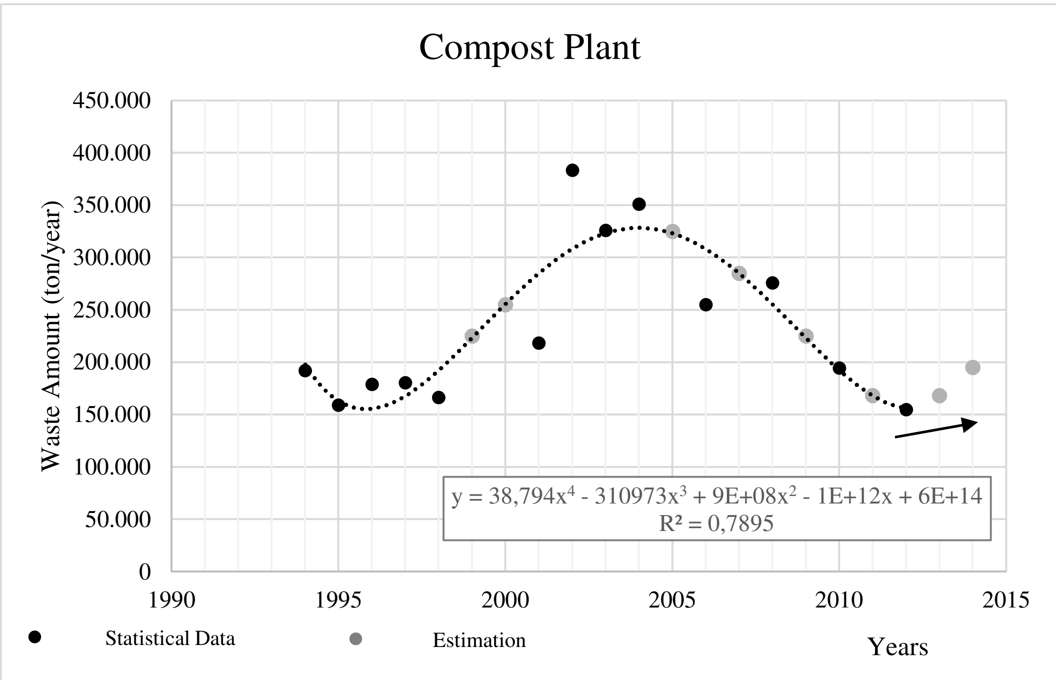

Figure 5.5 : Waste disposal amounts in compost plants.

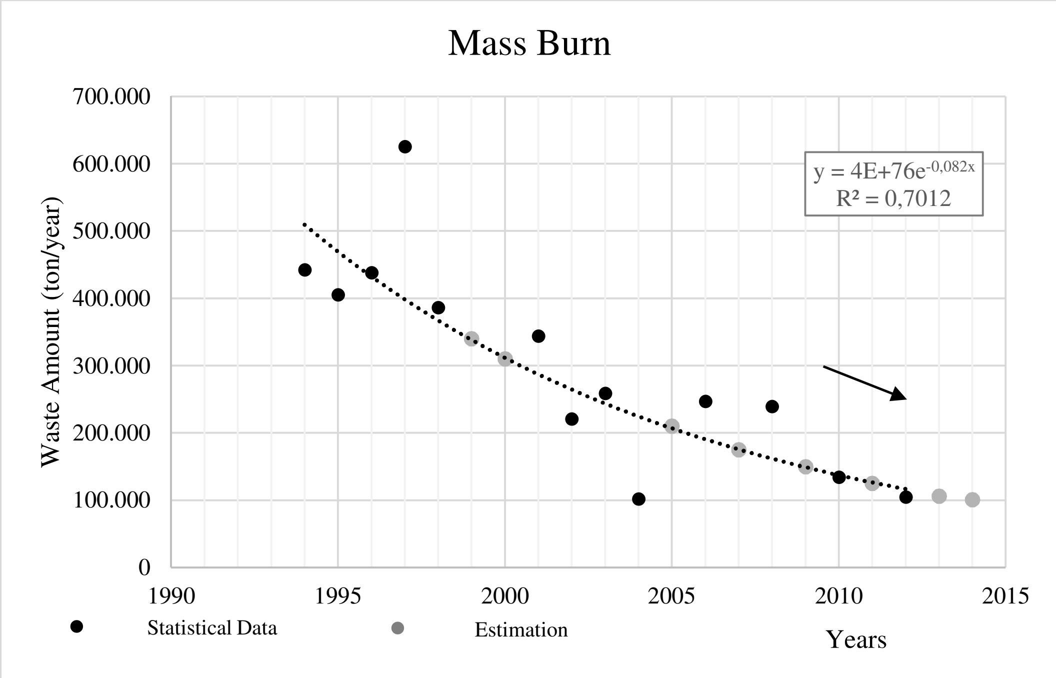

Figure 5.6 : Waste disposal amounts by mass burning.

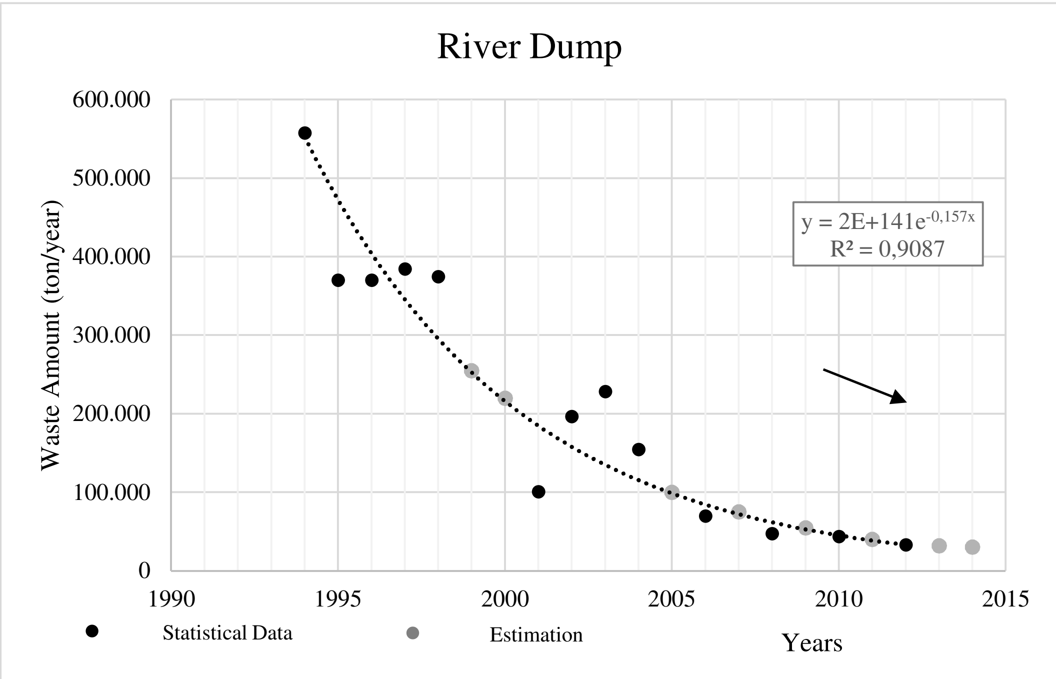

Figure 5.7 : Waste disposal amounts by river dumping.

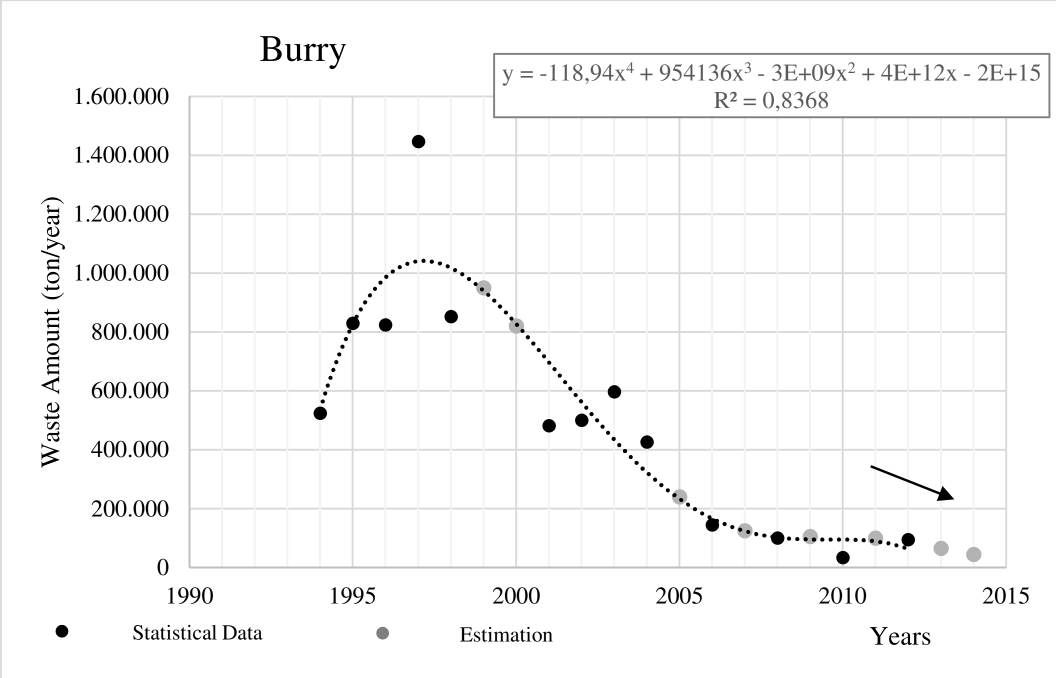

Figure 5.8 : Waste disposal amounts by burrying.

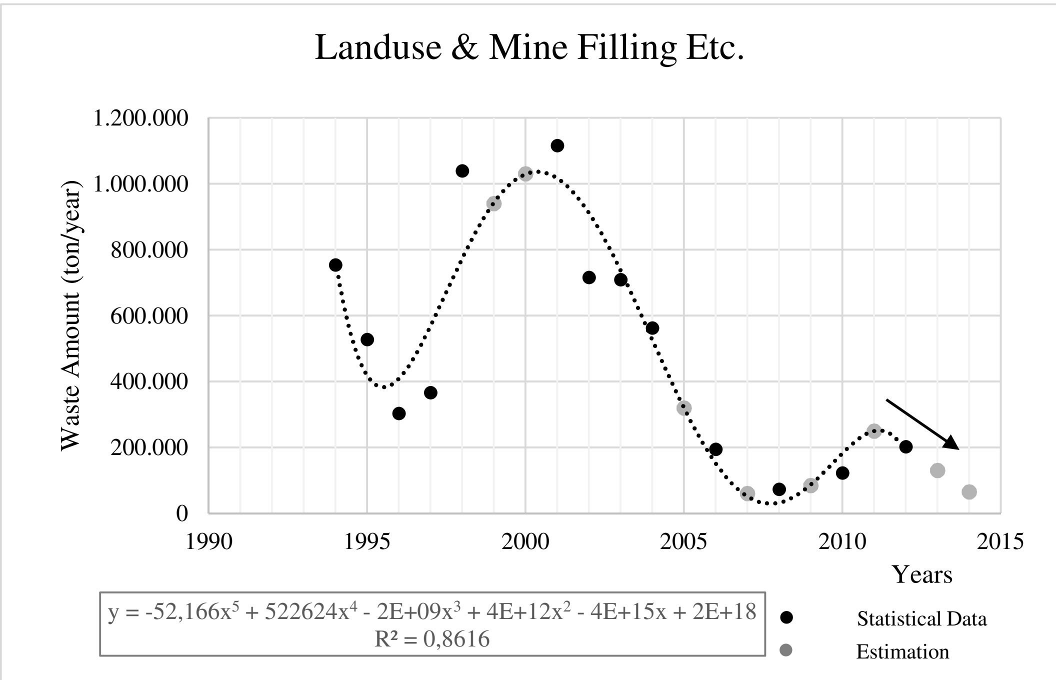

Figure 5.9 : Waste disposal amounts by landuse & mine filling etc.

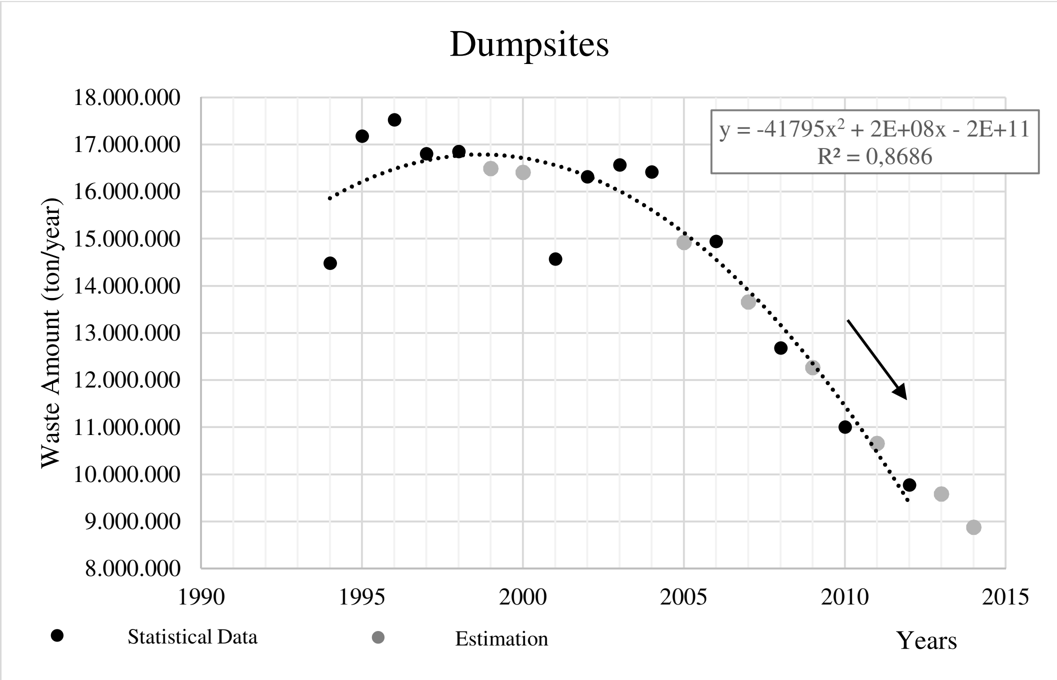

Figure 5.10 : Waste disposal amounts in dumpsites.

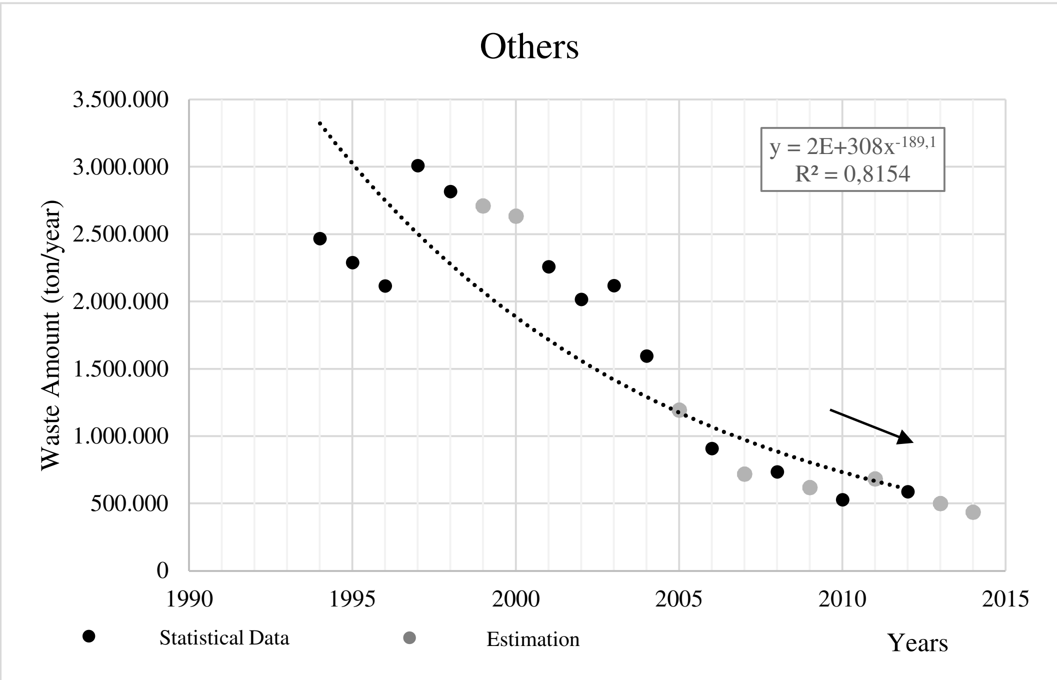

Figure 5.11 : Waste disposal amounts by other methods.

By using the same method, populations for different years were taken from TUIK and all missing data is created by using the graph trend as in Figure 5.12 (TUIK, 2015).

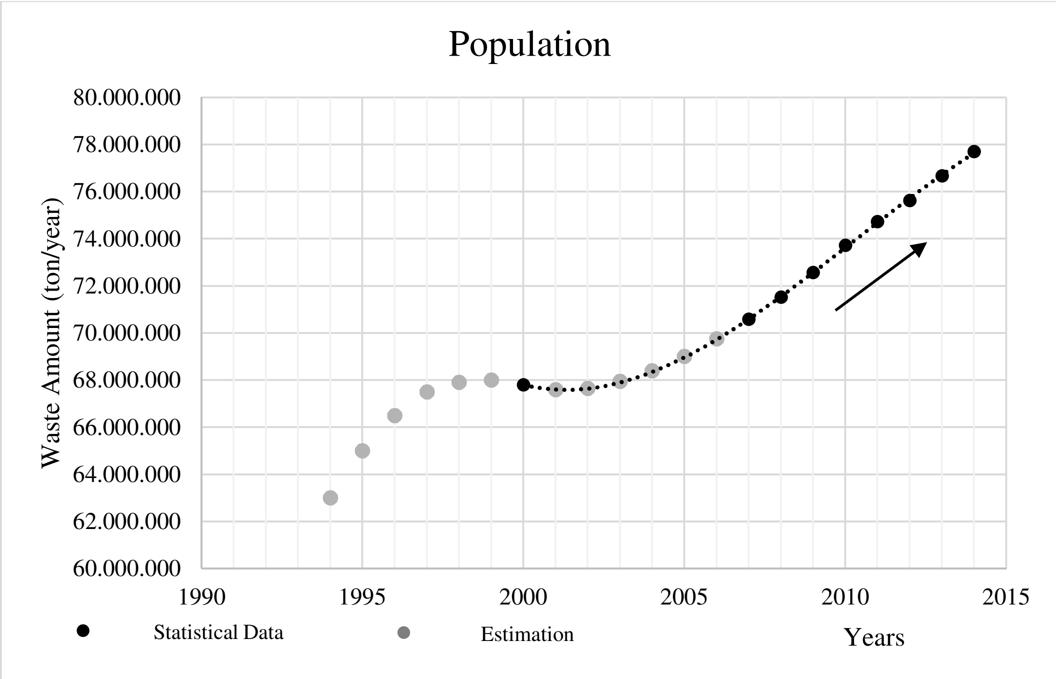

Figure 5.12 : Population of Turkey between 1994 – 2014.

The amount of municipal solid waste disposal by using different activities is given in Table 5.1. In this table, it can be clearly seen that sanitary landfilling is increasing by the decrease of dumpsiting activities. Both dumpsiting the waste and sanitary landfilling are mostly anaerobic environments. There will be landfill gas production in dumpsites too. Therefore, in order to see meaningful results, dumpsites and sanitary landfilling activities were taken into consideration together when calculating the landfill gas amounts. For that purpose, dumping and sanitary landfilling of waste were called as "landfilling of waste" and the places will be called "landfills" in Section 4 and 5. Especially in the last 10 years, it's clearly seen in the Table 5.1 that landfilling is approximately the only disposal method for municipal solid waste in Turkey. It's important to note that "Total" row in Table 5.1 shows only the disposal amounts not the waste generation amounts in Turkey.

In Table 5.2, waste disposal amounts and population of Turkey is seen together. By using the data in the table, daily waste disposal amounts per person were calculated in order to crosscheck the statistical data in TUIK and derivated data. The calculated amounts differ between 0.88 - 1.12 as an example below **(5.1)**. It's reported that yearly average municipal solid waste generation amount per person per day is 1.12 kg/cap/day in 2012 (TUIK, 2015). When 0.96 is divided by 1.12 it will show us the official (reported) waste disposal service given as 86% which is logical.

$$\text{Daily Waste Disposal per Cap(2003)} = \frac{20{,}225{,}098 \cdot 1000}{63{,}000{,}000 \cdot 365} = 0{,}88 \qquad \textbf{(5.1)}$$

Table 5.1 : Main disposal activities between 1994 – 2014.

Estimations	**Years**	**Others**	**Dumpsites**	**Sanitary Landfilling**	**Dumpsites & Landfilling Total**	**Total**
	Unit	(ton/year)	(ton/year)	(ton/year)	(ton/year)	(ton/year)
	1994	2,468,444	14,479,173	809,037	15,288,210	20,225,098
	1995	2,290,792	17,174,923	1,443,962	18,618,885	23,200,469
	1996	2,116,486	17,519,538	2,847,032	20,366,570	24,599,542
	1997	3,011,128	16,805,075	4,363,796	21,168,871	27,191,127
	1998	2,818,845	16,852,813	5,257,905	22,110,718	27,748,408
*	1999	2,710,000	16,490,000	5,100,000	21,590,000	27,010,000
*	2000	2,635,000	16,410,000	5,800,000	22,210,000	27,480,000
	2001	2,259,664	14,569,840	8,304,192	22,874,032	27,393,360
	2002	2,016,149	16,310,023	7,046,961	23,356,984	27,389,282
	2003	2,119,295	16,566,485	7,431,760	23,998,245	28,236,835
	2004	1,596,231	16,415,768	7,001,523	23,417,291	26,609,753
*	2005	1,195,000	14,920,000	9,500,000	24,420,000	26,810,000
	2006	910,494	14,941,154	9,428,323	24,369,477	26,190,465
*	2007	720,000	13,655,000	11,000,000	24,655,000	26,095,000
	2008	736,284	12,677,142	10,947,437	23,624,579	25,097,147
*	2009	620,000	12,265,000	12,500,000	24,765,000	26,005,000
	2010	528,668	11,001,153	13,746,876	24,748,029	25,805,365
*	2011	683,000	10,655,000	14,000,000	24,655,000	26,021,000
	2012	589,410	9,770,967	15,484,196	25,255,163	26,433,983
*	2013	501,000	9,580,000	15,880,000	25,460,000	26,462,000
*	2014	436,500	8,875,000	16,900,000	25,775,000	26,648,000

* Estimations on waste amounts regarding TUIK data for other years.

Table 5.2 : Waste disposal versus population between 1994.

Estimations	Years	Total	Population	Daily Waste Disposal per Capita
	Unit	(ton/year)	(persons)	(kg/cap/day)
**	1994	20,225,098	63,000,000	0.88
**	1995	23,200,469	65,000,000	0.98
**	1996	24,599,542	66,500,000	1.01
**	1997	27,191,127	67,500,000	1.10
**	1998	27,748,408	67,900,000	1.12
**	1999	27,010,000	68,000,000	1.09
	2000	27,480,000	67,803,927	1.11
**	2001	27,393,360	67,600,000	1.11
**	2002	27,389,282	67,650,000	1.11
**	2003	28,236,835	67,950,000	1.14
**	2004	26,609,753	68,400,000	1.07
**	2005	26,810,000	69,000,000	1.06
**	2006	26,190,465	69,750,000	1.03
	2007	26,095,000	70,586,256	1.01
	2008	25,097,147	71,517,100	0.96
	2009	26,005,000	72,561,312	0.98
	2010	25,805,365	73,722,988	0.96
	2011	26,021,000	74,724,269	0.95
	2012	26,433,983	75,627,384	0.96
	2013	26,462,000	76,667,864	0.95
	2014	26,648,000	77,695,904	0.94

** Estimations on populations regarding TUIK data for other years.

For the calculation of future waste disposal in landfill, the data of yearly landfilled waste per person for the last 15 years were extended till 2040 and the extended values are multiplied with the population projections reported by TUIK (TUIK, 2015). Also yearly total waste disposal amounts were calculated till 2040 by using the same approach. The results are shown in the following graphs (Figure 5.13 & 5.14).

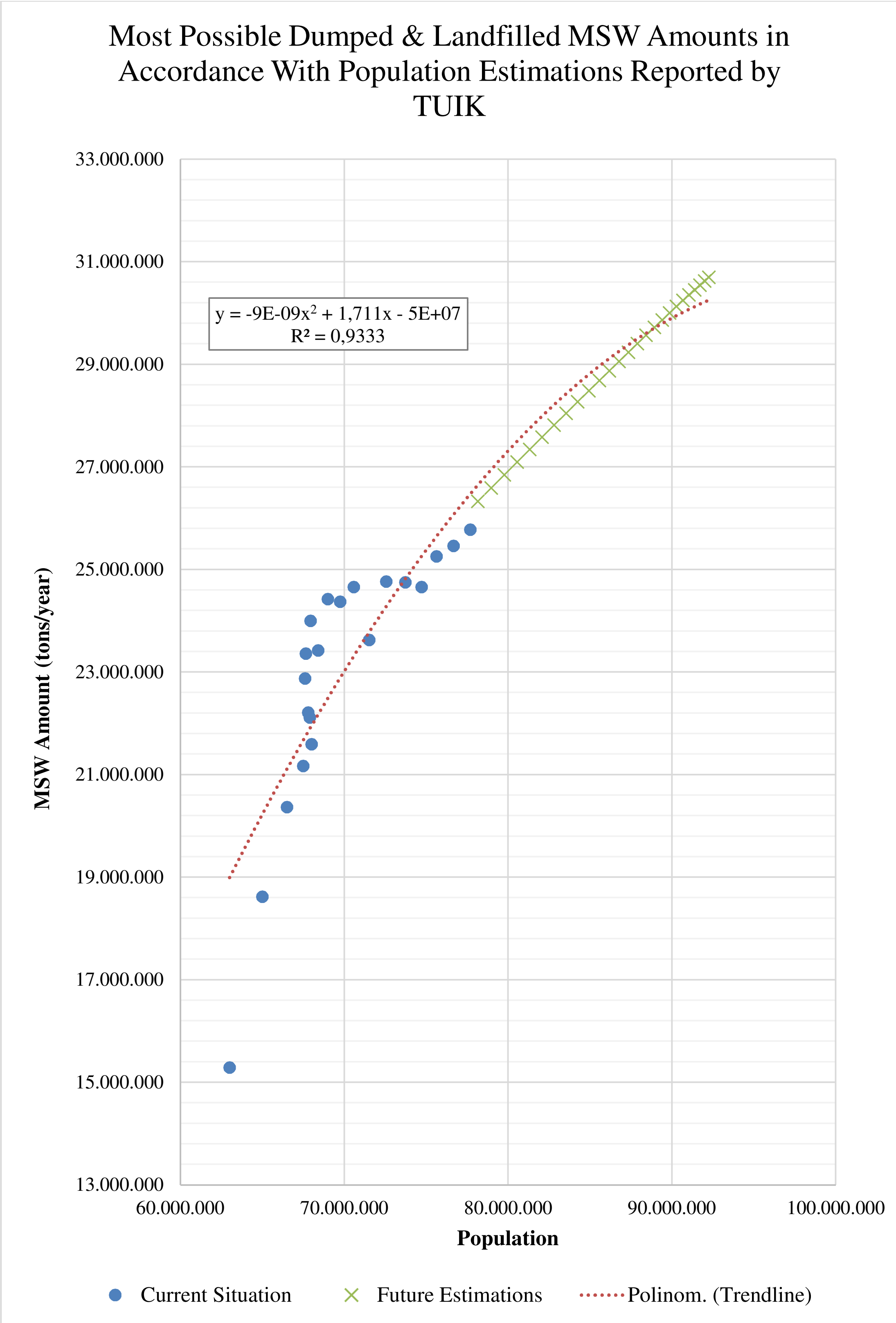

Figure 5.13 : Most possible dumped & landfilled MSW amounts in accordance with population estimations reported by TUIK.

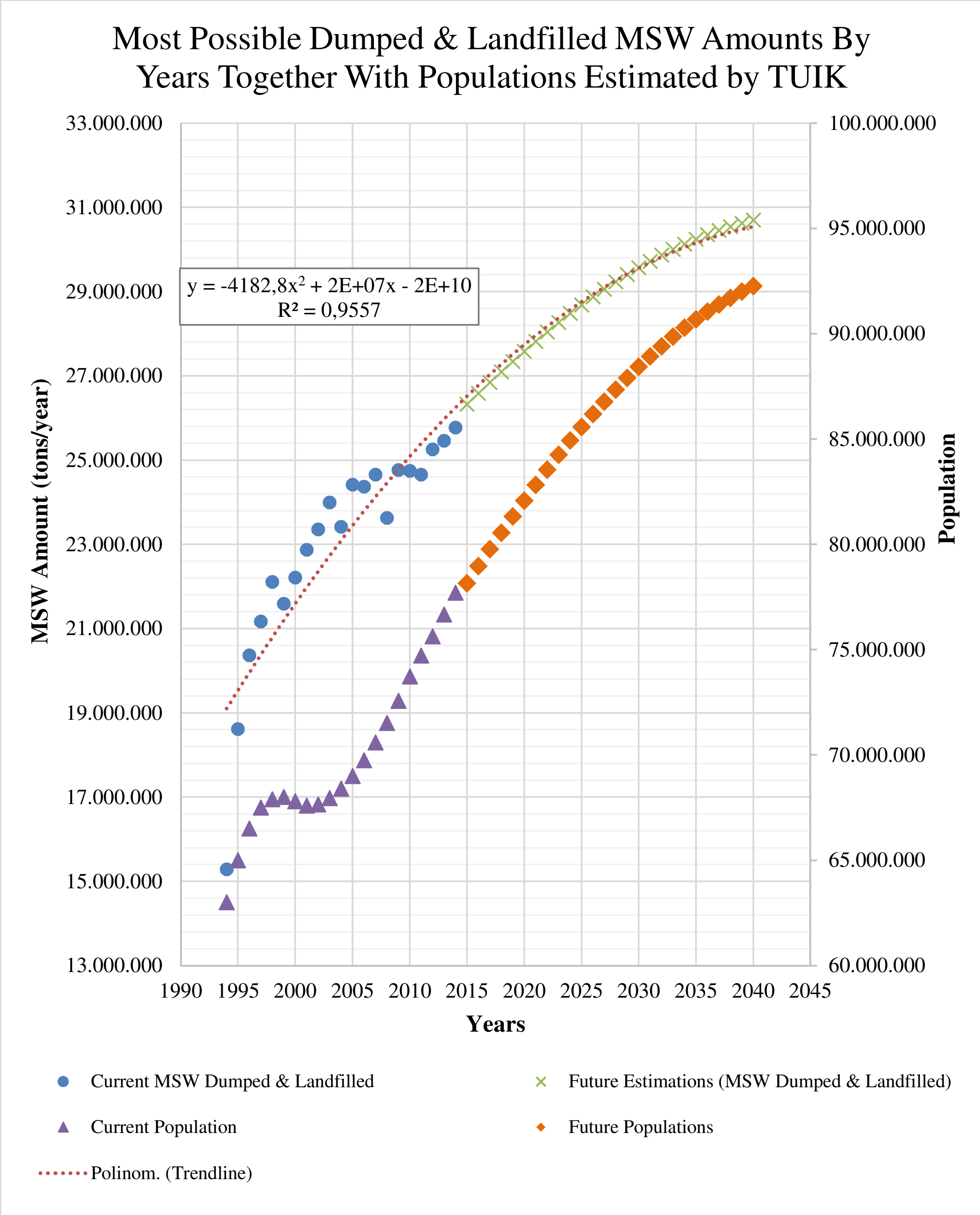

Figure 5.14: Most possible dumped & landfilled MSW amounts by years with population estimations reported by TUIK.

The graph given in the Figure 5.14 shows the calculated future initial data for further calculations. It's clearly seen that the population is making an S-shape graph which is published by TUIK as mentioned above. On the other hand, the same graph shows the waste to be landfilled according to the future estimations done in this study. This graph also makes an S-shape trend line but it's decreasing more than the population which is also as it should be.

5.2 Determination of Detailed Waste Characteristics for Each Scenario

In order to determine the municipal solid waste characteristics and compositions, the results of Solid Waste Master Plan Final Report (KAAP) were used. According to the plan report, there are 11 different regions in Turkey in order to characterize MSW composition. The regions and populations are given in Table 5.3 and 5.4 (TUIK, 2015) (MIMKO, 2006). Waste characterizations were defined for the years between 2003 – 2023 (between 2003 – 2020 and 2010 – 2030 for some regions) year by year for each regions in KAAP. All the characterizations were extended between 2003 – 2040.

In order to see the effect of each region's characterization on Turkey's average solid waste characteristics, current populations for each region were summed up and weight of each region were calculated as an example below **(5.2)**.

$$\text{Weight (1A)} = \frac{14{,}377{,}018 + 4{,}113{,}072}{77{,}695{,}904} = 0.238 \qquad \textbf{(5.2)}$$

Where;

14,377,018 is 2015 population of Istanbul,

4,113,072 is 2015 population of Izmir

77,795,904 is 2015 population of Turkey.

Table 5.3 : Population and Population Weight for Different Regions (1/2).

Regions	1A	1B	1C	2A	2B	2C
Population	18,490,090	5,443,040	9,698,498	5,150,072	3,949,817	7,679,088
Weight	0.238	0.070	0.125	0.066	0.051	0.099
	İstanbul	Bursa	Balıkesir	Ankara	Antalya	Adana
	İzmir	Kocaeli	Bilecik		Mersin	Samsun
		Sakarya	Çanakkale			Eskişehir
			Edirne			Kayseri
			Kırklareli			Konya
			Tekirdağ			
			Yalova			
			Afyon			
			Aydın			
			Denizli			
			Kütahya			
			Manisa			
			Muğla			
			Uşak			

Table 5.4 : Population and Population Weight for Different Regions (2/2).

Regions	2D	2E	3A	3B	3C
Population	6.327.805	6.779.146	1.889.466	2.398.368	9.890.514
Weight	0,081	0,087	0,024	0,031	0,127
	Amasya	Burdur	Gaziantep	Erzurum	Ağrı
	Artvin	Hatay		Diyarbakır	Ardahan
	Bartın	Isparta			Bingöl
	Bayburt	K.Maraş			Bitlis
	Bolu	Osmaniye			Elazığ
	Çorum	Aksaray			Erzincan
	Düzce	Çankırı			Hakkari
	Giresun	Karaman			Iğdır
	Gümüşhane	Kırıkkale			Kars
	Karabük	Kırşehir			Malatya
	Kastamonu	Nevşehir			Muş
	Ordu	Niğde			Tunceli
	Rize	Sivas			Van
	Sinop	Yozgat			Şırnak
	Tokat				Adıyaman
	Trabzon				atman
	Zonguldak				Kilis
					Mardin
					Siirt
					Şanlıurfa

Turkish weighted average waste characterization is calculated between 2003 – 2040 as in example **(5.3)** and results are given in App. B.

$$\begin{aligned}\text{Cardboard \% (2003)} & \\ &= (7.60 \cdot 0.24) + (9.50 \cdot 0.07) + (6.99 \cdot 0.12) \\ &+ (8.90 \cdot 0.07) + (8.70 \cdot 0.05) + (8.10 \cdot 0.10) \\ &+ (6.70 \cdot 0.08) + (6.53 \cdot 0.09) + (7.00 \cdot 0.02) \\ &+ (7.80 \cdot 0.02) + (6.20 \cdot 0.13) = 7.50\end{aligned} \quad \textbf{(5.3)}$$

Percentage and the amount of biodegradable materials are the key data for this study. By using the calculated waste disposal in landfills and the compositions of waste between the years 2003 – 2040, tonnages for different waste material were calculated (App. B). The "biodegradable waste" line in Table B.1, B.2 and B.3 indicates the sum of cardboard, high volume cardboard, kitchen waste, garden (yard) waste, other combustibles, other high volume combustibles and paper. Likewise, recyclable materials are sum of cardboard, high volume cardboard, glass, metal, high volume metal, paper and plastics. Package materials are similar with recyclable waste but, some portion of recyclable waste is packaging waste (MIMKO, 2006).

After the determination of waste characteristics between 2003 – 2040 according to the data taken from KAAP, variable conversion was done to have the suitable data for the model input. Characteristics (percentages of each material within mixed MSW going to landfill) and tonnages were calculated for each scenario.

5.2.1 Waste characteristics in scenario 1

According to the variable conversion done, waste characteristics for the Scenario 1 are given in the tables below. Also the tonnages are given in App C.

Table 5.5 : Characteristics of Turkish MSW as model input for scenario 1 (1/8) (2003 – 2007).

Waste Composition	2003	2004	2005	2006	2007
Food waste	34.4%	33.7%	33.1%	32.4%	31.8%
Paper & Cardboard	19.3%	19.6%	19.8%	20.1%	20.4%
Garden Waste (Green Waste)	0.8%	0.8%	0.8%	0.8%	0.8%
Wood Waste	1.6%	1.6%	1.6%	1.6%	1.6%
Ruber, Leather, Bones, Straw	2.1%	2.1%	2.2%	2.2%	2.2%
Textiles	3.2%	3.2%	3.2%	3.3%	3.3%
Other Organics	2.4%	2.4%	2.4%	2.4%	2.4%
Metals	2.8%	2.8%	2.8%	2.8%	2.8%
Construction & Demolition Waste	8.8%	9.0%	9.1%	9.3%	9.4%
Glass & Ceramics	3.3%	3.3%	3.3%	3.4%	3.4%
Plastics	9.2%	9.3%	9.4%	9.5%	9.6%
Other Inorganic Waste	12.3%	12.3%	12.4%	12.4%	12.4%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	63.7%	63.4%	63.1%	62.8%	62.5%

Table 5.6 : Characteristics of Turkish MSW as model input for scenario 1 (2/8) (2008 – 2012).

Waste Composition	2008	2009	2010	2011	2012
Foodwaste	31.2%	30.5%	30.0%	29.4%	28.7%
Paper & Cardboard	20.6%	20.9%	21.1%	21.4%	21.6%
Garden Waste (Green Waste)	0.8%	0.8%	0.8%	0.8%	0.8%
Wood Waste	1.6%	1.6%	1.6%	1.6%	1.6%
Ruber, Leather, Bones, Straw	2.2%	2.2%	2.3%	2.3%	2.3%
Textiles	3.3%	3.4%	3.4%	3.4%	3.4%
Other Organics	2.5%	2.5%	2.5%	2.5%	2.5%
Metals	2.8%	2.8%	2.9%	2.9%	2.9%
Construction & Demolition Waste	9.5%	9.7%	9.8%	10.0%	10.2%
Glass & Ceramics	3.4%	3.4%	3.4%	3.5%	3.5%
Plastics	9.7%	9.8%	9.8%	9.9%	10.0%
Other Inorganic Waste	12.4%	12.5%	12.4%	12.5%	12.5%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	62.1%	61.8%	61.6%	61.3%	61.0%

Table 5.7 : Characteristics of Turkish MSW as model input for scenario 1 (3/8) (2013 – 2017).

Waste Composition	2013	2014	2015	2016	2017
Foodwaste	28.1%	27.5%	26.9%	26.3%	25.7%
Paper & Cardboard	21.9%	22.1%	22.4%	22.5%	22.9%
Garden Waste (Green Waste)	0.8%	0.8%	0.8%	0.8%	0.8%
Wood Waste	1.6%	1.6%	1.6%	1.6%	1.6%
Ruber, Leather, Bones, Straw	2.3%	2.3%	2.4%	2.4%	2.4%
Textiles	3.5%	3.5%	3.5%	3.6%	3.6%
Other Organics	2.5%	2.5%	2.6%	2.6%	2.6%
Metals	2.9%	2.9%	2.9%	2.9%	2.9%
Construction & Demolition Waste	10.3%	10.4%	10.6%	10.8%	11.0%
Glass & Ceramics	3.5%	3.5%	3.5%	3.5%	3.5%
Plastics	10.1%	10.2%	10.3%	10.4%	10.5%
Other Inorganic Waste	12.5%	12.5%	12.5%	12.6%	12.6%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	60.7%	60.4%	60.1%	59.7%	59.5%

Table 5.8 : Characteristics of Turkish MSW as model input for scenario 1 (4/8) (2018 – 2022).

Waste Composition	2018	2019	2020	2021	2022
Foodwaste	25.1%	24.5%	23.9%	23.3%	22.8%
Paper & Cardboard	23.1%	23.4%	23.7%	23.9%	24.2%
Garden Waste (Green Waste)	0.8%	0.8%	0.8%	0.8%	0.8%
Wood Waste	1.6%	1.6%	1.6%	1.6%	1.6%
Ruber, Leather, Bones, Straw	2.4%	2.4%	2.5%	2.5%	2.5%
Textiles	3.6%	3.7%	3.7%	3.7%	3.8%
Other Organics	2.6%	2.6%	2.6%	2.6%	2.6%
Metals	3.0%	3.0%	3.0%	3.0%	3.0%
Construction & Demolition Waste	11.1%	11.3%	11.5%	11.7%	11.9%
Glass & Ceramics	3.5%	3.6%	3.6%	3.6%	3.6%
Plastics	10.5%	10.6%	10.6%	10.8%	10.8%
Other Inorganic Waste	12.6%	12.6%	12.5%	12.6%	12.5%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	59.3%	59.0%	58.8%	58.5%	58.2%

Table 5.9 : Characteristics of Turkish MSW as model input for scenario 1 (5/8) (2023 – 2027).

Waste Composition	2023	2024	2025	2026	2027
Foodwaste	22.3%	21.5%	20.9%	20.3%	19.8%
Paper & Cardboard	24.4%	24.7%	24.9%	25.2%	25.4%
Garden Waste (Green Waste)	0.8%	0.8%	0.8%	0.8%	0.8%
Wood Waste	1.6%	1.6%	1.6%	1.6%	1.6%
Ruber, Leather, Bones, Straw	2.5%	2.5%	2.6%	2.6%	2.6%
Textiles	3.8%	3.8%	3.8%	3.9%	3.9%
Other Organics	2.7%	2.7%	2.7%	2.7%	2.7%
Metals	3.0%	3.0%	3.1%	3.1%	3.1%
Construction & Demolition Waste	12.0%	12.1%	12.2%	12.4%	12.6%
Glass & Ceramics	3.6%	3.6%	3.6%	3.6%	3.7%
Plastics	10.9%	11.0%	11.1%	11.2%	11.3%
Other Inorganic Waste	12.5%	12.6%	12.6%	12.6%	12.6%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	58.1%	57.6%	57.3%	57.1%	56.8%

Table 5.10 : Characteristics of Turkish MSW as model input for scenario 1 (6/8) (2028 – 2032).

Waste Composition	2028	2029	2030	2031	2032
Foodwaste	19.2%	18.6%	18.1%	17.3%	16.7%
Paper & Cardboard	25.7%	25.9%	26.2%	26.4%	26.7%
Garden Waste (Green Waste)	0.8%	0.8%	0.8%	0.8%	0.8%
Wood Waste	1.6%	1.6%	1.6%	1.6%	1.6%
Ruber, Leather, Bones, Straw	2.6%	2.6%	2.7%	2.7%	2.7%
Textiles	3.9%	4.0%	4.0%	4.0%	4.1%
Other Organics	2.7%	2.7%	2.8%	2.8%	2.8%
Metals	3.1%	3.1%	3.1%	3.1%	3.1%
Construction & Demolition Waste	12.7%	12.9%	13.0%	13.2%	13.4%
Glass & Ceramics	3.7%	3.7%	3.7%	3.7%	3.7%
Plastics	11.4%	11.5%	11.5%	11.6%	11.7%
Other Inorganic Waste	12.6%	12.6%	12.6%	12.6%	12.6%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	56.5%	56.3%	56.0%	55.6%	55.4%

Table 5.11 : Characteristics of Turkish MSW as model input for scenario 1 (7/8) (2033 – 2037).

Waste Composition	2033	2034	2035	2036	2037
Foodwaste	16.1%	15.5%	14.9%	14.3%	13.7%
Paper & Cardboard	26.9%	27.2%	27.5%	27.7%	28.0%
Garden Waste (Green Waste)	0.8%	0.8%	0.8%	0.8%	0.8%
Wood Waste	1.6%	1.6%	1.6%	1.6%	1.6%
Ruber, Leather, Bones, Straw	2.7%	2.7%	2.8%	2.8%	2.8%
Textiles	4.1%	4.1%	4.2%	4.2%	4.2%
Other Organics	2.8%	2.8%	2.8%	2.8%	2.9%
Metals	3.2%	3.2%	3.2%	3.2%	3.2%
Construction & Demolition Waste	13.5%	13.7%	13.8%	14.0%	14.2%
Glass & Ceramics	3.7%	3.8%	3.8%	3.8%	3.8%
Plastics	11.8%	11.9%	12.0%	12.1%	12.1%
Other Inorganic Waste	12.7%	12.7%	12.7%	12.7%	12.7%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	55.1%	54.8%	54.5%	54.2%	53.9%

Table 5.12 : Characteristics of Turkish MSW as model input for scenario 1 (8/8) (2038 – 2040).

Waste Composition	2038	2039	2040
Foodwaste	13.1%	12.5%	11.9%
Paper & Cardboard	28.2%	28.5%	28.7%
Garden Waste (Green Waste)	0.8%	0.8%	0.8%
Wood Waste	1.6%	1.6%	1.6%
Ruber, Leather, Bones, Straw	2.8%	2.9%	2.9%
Textiles	4.2%	4.3%	4.3%
Other Organics	2.9%	2.9%	2.9%
Metals	3.2%	3.2%	3.2%
Construction & Demolition Waste	14.3%	14.5%	14.6%
Glass & Ceramics	3.8%	3.8%	3.8%
Plastics	12.2%	12.3%	12.4%
Other Inorganic Waste	12.7%	12.7%	12.7%
Total	**100%**	**100%**	**100%**
Biodegradable Waste	53.7%	53.4%	53.1%

5.2.2 Waste characteristics in scenario 2

According to the variable conversion done, waste characteristics for the Scenario 2 are given in the tables below. Also the tonnages are given in App D.

Table 5.13 : Characteristics of Turkish MSW as model input for scenario 2 (1/8) (2003 – 2007).

Waste Composition	2003	2004	2005	2006	2007
Foodwaste	34.4%	33.7%	33.1%	32.4%	31.8%
Paper & Cardboard	19.3%	19.6%	19.8%	20.1%	20.3%
Garden Waste (Green Waste)	0.8%	0.8%	0.8%	0.8%	0.8%
Wood Waste	1.6%	1.6%	1.6%	1.6%	1.6%
Ruber, Leather, Bones, Straw	2.1%	2.1%	2.2%	2.2%	2.2%
Textiles	3.2%	3.2%	3.2%	3.3%	3.3%
Other Organics	2.4%	2.4%	2.4%	2.4%	2.4%
Metals	2.8%	2.8%	2.8%	2.8%	2.8%
Construction & Demolition Waste	8.8%	9.0%	9.1%	9.3%	9.4%
Glass & Ceramics	3.3%	3.3%	3.3%	3.4%	3.4%
Plastics	9.2%	9.3%	9.4%	9.5%	9.6%
Other Inorganic Waste	12.3%	12.3%	12.4%	12.4%	12.4%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	63.7%	63.3%	63.0%	62.7%	62.4%

Table 5.14 : Characteristics of Turkish MSW as model input for scenario 2 (2/8) (2008 – 2012).

Waste Composition	2008	2009	2010	2011	2012
Foodwaste	31.2%	30.5%	30.0%	29.6%	28.8%
Paper & Cardboard	20.6%	20.9%	21.1%	20.8%	20.2%
Garden Waste (Green Waste)	0.8%	0.8%	0.8%	0.8%	0.8%
Wood Waste	1.6%	1.6%	1.6%	1.6%	1.5%
Ruber, Leather, Bones, Straw	2.2%	2.2%	2.3%	2.2%	2.2%
Textiles	3.3%	3.4%	3.4%	3.3%	3.2%
Other Organics	2.5%	2.5%	2.5%	2.5%	2.4%
Metals	2.8%	2.8%	2.9%	2.9%	3.1%
Construction & Demolition Waste	9.5%	9.7%	9.8%	10.1%	10.7%
Glass & Ceramics	3.4%	3.4%	3.4%	3.5%	3.7%
Plastics	9.7%	9.8%	9.8%	10.1%	10.5%
Other Inorganic Waste	12.4%	12.5%	12.4%	12.7%	13.1%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	62.1%	61.8%	61.6%	60.7%	59.1%

Table 5.15 : Characteristics of Turkish MSW as model input for scenario 2 (3/8) (2013 – 2017).

Waste Composition	2013	2014	2015	2016	2017
Foodwaste	28.2%	27.5%	26.7%	25.0%	23.2%
Paper & Cardboard	19.8%	19.3%	18.7%	17.5%	16.3%
Garden Waste (Green Waste)	0.7%	0.7%	0.7%	0.7%	0.6%
Wood Waste	1.5%	1.5%	1.4%	1.3%	1.2%
Ruber, Leather, Bones, Straw	2.1%	2.1%	2.0%	1.9%	1.7%
Textiles	3.2%	3.1%	3.0%	2.8%	2.6%
Other Organics	2.3%	2.3%	2.2%	2.1%	1.9%
Metals	3.1%	3.2%	3.3%	3.6%	3.8%
Construction & Demolition Waste	11.0%	11.5%	12.1%	13.1%	14.2%
Glass & Ceramics	3.8%	3.9%	4.0%	4.3%	4.6%
Plastics	10.9%	11.2%	11.7%	12.5%	13.5%
Other Inorganic Waste	13.4%	13.8%	14.2%	15.2%	16.3%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	57.8%	56.4%	54.7%	51.3%	47.6%

Table 5.16 : Characteristics of Turkish MSW as model input for scenario 2 (4/8) (2018 – 2022).

Waste Composition	2018	2019	2020	2021	2022
Foodwaste	21.1%	20.4%	19.7%	19.0%	18.2%
Paper & Cardboard	14.8%	14.3%	13.8%	13.3%	12.8%
Garden Waste (Green Waste)	0.6%	0.5%	0.5%	0.5%	0.5%
Wood Waste	1.1%	1.1%	1.0%	1.0%	1.0%
Ruber, Leather, Bones, Straw	1.6%	1.5%	1.5%	1.4%	1.4%
Textiles	2.4%	2.3%	2.2%	2.1%	2.1%
Other Organics	1.8%	1.7%	1.6%	1.6%	1.5%
Metals	4.2%	4.2%	4.3%	4.4%	4.5%
Construction & Demolition Waste	15.5%	16.0%	16.6%	17.2%	17.8%
Glass & Ceramics	4.9%	5.0%	5.1%	5.2%	5.4%
Plastics	14.6%	15.0%	15.4%	15.8%	16.2%
Other Inorganic Waste	17.5%	17.8%	18.1%	18.4%	18.8%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	43.4%	41.9%	40.5%	38.9%	37.4%

Table 5.17 : Characteristics of Turkish MSW as model input for scenario 2 (5/8) (2023 – 2027).

Waste Composition	2023	2024	2025	2026	2027
Foodwaste	17.5%	16.7%	15.9%	15.8%	15.6%
Paper & Cardboard	12.3%	11.7%	11.1%	11.1%	11.0%
Garden Waste (Green Waste)	0.5%	0.4%	0.4%	0.4%	0.4%
Wood Waste	0.9%	0.9%	0.8%	0.8%	0.8%
Ruber, Leather, Bones, Straw	1.3%	1.3%	1.2%	1.2%	1.2%
Textiles	2.0%	1.9%	1.8%	1.8%	1.8%
Other Organics	1.4%	1.4%	1.3%	1.3%	1.3%
Metals	4.6%	4.7%	4.8%	4.8%	4.9%
Construction & Demolition Waste	18.3%	18.8%	19.4%	19.6%	19.8%
Glass & Ceramics	5.5%	5.6%	5.7%	5.8%	5.8%
Plastics	16.6%	17.1%	17.6%	17.7%	17.8%
Other Inorganic Waste	19.1%	19.5%	19.9%	19.8%	19.8%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	35.9%	34.2%	32.6%	32.3%	32.0%

Table 5.18 : Characteristics of Turkish MSW as model input for scenario 2 (6/8) (2028 – 2032).

Waste Composition	2028	2029	2030	2031	2032
Foodwaste	15.5%	15.4%	15.2%	15.1%	15.0%
Paper & Cardboard	10.9%	10.8%	10.7%	10.6%	10.5%
Garden Waste (Green Waste)	0.4%	0.4%	0.4%	0.4%	0.4%
Wood Waste	0.8%	0.8%	0.8%	0.8%	0.8%
Ruber, Leather, Bones, Straw	1.2%	1.2%	1.1%	1.1%	1.1%
Textiles	1.7%	1.7%	1.7%	1.7%	1.7%
Other Organics	1.3%	1.3%	1.3%	1.3%	1.2%
Metals	4.9%	4.9%	4.9%	4.9%	4.9%
Construction & Demolition Waste	20.0%	20.2%	20.4%	20.6%	20.8%
Glass & Ceramics	5.8%	5.8%	5.8%	5.8%	5.8%
Plastics	17.9%	17.9%	18.0%	18.1%	18.2%
Other Inorganic Waste	19.8%	19.7%	19.7%	19.7%	19.6%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	31.8%	31.5%	31.3%	31.0%	30.7%

Table 5.19 : Characteristics of Turkish MSW as model input for scenario 2 (7/8) (2033 – 2037).

Waste Composition	2033	2034	2035	2036	2037
Foodwaste	14.9%	14.8%	14.7%	14.6%	14.5%
Paper & Cardboard	10.4%	10.4%	10.3%	10.2%	10.2%
Garden Waste (Green Waste)	0.4%	0.4%	0.4%	0.4%	0.4%
Wood Waste	0.8%	0.8%	0.8%	0.8%	0.8%
Ruber, Leather, Bones, Straw	1.1%	1.1%	1.1%	1.1%	1.1%
Textiles	1.7%	1.7%	1.7%	1.6%	1.6%
Other Organics	1.2%	1.2%	1.2%	1.2%	1.2%
Metals	4.9%	4.9%	4.9%	4.9%	4.9%
Construction & Demolition Waste	20.9%	21.1%	21.3%	21.5%	21.6%
Glass & Ceramics	5.8%	5.8%	5.8%	5.8%	5.8%
Plastics	18.3%	18.3%	18.4%	18.5%	18.6%
Other Inorganic Waste	19.6%	19.6%	19.5%	19.5%	19.4%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	30.5%	30.3%	30.1%	29.9%	29.7%

Table 5.20 : Characteristics of Turkish MSW as model input for scenario 2 (8/8) (2038 – 2040).

Waste Composition	2038	2039	2040
Foodwaste	14.4%	14.3%	14.2%
Paper & Cardboard	10.1%	10.0%	10.0%
Garden Waste (Green Waste)	0.4%	0.4%	0.4%
Wood Waste	0.8%	0.8%	0.7%
Ruber, Leather, Bones, Straw	1.1%	1.1%	1.1%
Textiles	1.6%	1.6%	1.6%
Other Organics	1.2%	1.2%	1.2%
Metals	4.9%	4.9%	4.9%
Construction & Demolition Waste	21.8%	22.0%	22.1%
Glass & Ceramics	5.8%	5.8%	5.8%
Plastics	18.6%	18.7%	18.8%
Other Inorganic Waste	19.4%	19.3%	19.2%
Total	**100%**	**100%**	**100%**
Biodegradable Waste	29.5%	29.3%	29.1%

5.2.3 Waste characteristics in scenario 3

According to the variable conversion done, waste characteristics for the Scenario 3 are given in the tables below. Also the tonnages are given in App E.

Table 5.21 : Characteristics of Turkish MSW as model input for scenario 3 (1/8) (2003 – 2007).

Waste Composition	2003	2004	2005	2006	2007
Foodwaste	34.4%	33.7%	33.1%	32.4%	31.8%
Paper & Cardboard	19.3%	19.6%	19.8%	20.1%	20.3%
Garden Waste (Green Waste)	0.8%	0.8%	0.8%	0.8%	0.8%
Wood Waste	1.6%	1.6%	1.6%	1.6%	1.6%
Ruber, Leather, Bones, Straw	2.1%	2.1%	2.2%	2.2%	2.2%
Textiles	3.2%	3.2%	3.2%	3.3%	3.3%
Other Organics	2.4%	2.4%	2.4%	2.4%	2.4%
Metals	2.8%	2.8%	2.8%	2.8%	2.8%
Construction & Demolition Waste	8.8%	9.0%	9.1%	9.3%	9.4%
Glass & Ceramics	3.3%	3.3%	3.3%	3.4%	3.4%
Plastics	9.2%	9.3%	9.4%	9.5%	9.6%
Other Inorganic Waste	12.3%	12.3%	12.4%	12.4%	12.4%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	63.7%	63.3%	63.0%	62.7%	62.4%

Table 5.22 : Characteristics of Turkish MSW as model input for scenario 3 (2/8) (2008 – 20012).

Waste Composition	2008	2009	2010	2011	2012
Foodwaste	31.2%	30.5%	30.0%	29.8%	29.2%
Paper & Cardboard	20.6%	20.9%	21.1%	20.9%	20.5%
Garden Waste (Green Waste)	0.8%	0.8%	0.8%	0.8%	0.8%
Wood Waste	1.6%	1.6%	1.6%	1.6%	1.5%
Ruber, Leather, Bones, Straw	2.2%	2.2%	2.3%	2.2%	2.2%
Textiles	3.3%	3.4%	3.4%	3.4%	3.3%
Other Organics	2.5%	2.5%	2.5%	2.5%	2.4%
Metals	2.8%	2.8%	2.9%	2.9%	3.0%
Construction & Demolition Waste	9.5%	9.7%	9.8%	10.0%	10.4%
Glass & Ceramics	3.4%	3.4%	3.4%	3.5%	3.6%
Plastics	9.7%	9.8%	9.8%	10.0%	10.3%
Other Inorganic Waste	12.4%	12.5%	12.4%	12.5%	12.8%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	62.1%	61.8%	61.6%	61.1%	59.9%

Table 5.23 : Characteristics of Turkish MSW as model input for scenario 3 (3/8) (2013 – 2017).

Waste Composition	2013	2014	2015	2016	2017
Foodwaste	28.8%	28.4%	27.8%	27.4%	27.0%
Paper & Cardboard	20.2%	19.9%	19.5%	19.2%	18.9%
Garden Waste (Green Waste)	0.8%	0.7%	0.7%	0.7%	0.7%
Wood Waste	1.5%	1.5%	1.5%	1.4%	1.4%
Ruber, Leather, Bones, Straw	2.2%	2.1%	2.1%	2.1%	2.0%
Textiles	3.3%	3.2%	3.1%	3.1%	3.0%
Other Organics	2.4%	2.4%	2.3%	2.3%	2.2%
Metals	3.0%	3.1%	3.2%	3.2%	3.3%
Construction & Demolition Waste	10.7%	11.0%	11.4%	11.8%	12.1%
Glass & Ceramics	3.6%	3.7%	3.8%	3.8%	3.9%
Plastics	10.5%	10.8%	11.1%	11.3%	11.5%
Other Inorganic Waste	13.0%	13.2%	13.5%	13.7%	13.9%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	59.1%	58.2%	57.1%	56.1%	55.3%

Table 5.24 : Characteristics of Turkish MSW as model input for scenario 3 (4/8) (2018 – 2022).

Waste Composition	2018	2019	2020	2021	2022
Foodwaste	26.5%	26.1%	25.7%	24.1%	22.3%
Paper & Cardboard	18.6%	18.3%	18.0%	16.9%	15.6%
Garden Waste (Green Waste)	0.7%	0.7%	0.7%	0.6%	0.6%
Wood Waste	1.4%	1.4%	1.4%	1.3%	1.2%
Ruber, Leather, Bones, Straw	2.0%	2.0%	1.9%	1.8%	1.7%
Textiles	3.0%	2.9%	2.9%	2.7%	2.5%
Other Organics	2.2%	2.2%	2.1%	2.0%	1.8%
Metals	3.3%	3.4%	3.4%	3.6%	3.9%
Construction & Demolition Waste	12.4%	12.8%	13.2%	14.2%	15.4%
Glass & Ceramics	4.0%	4.0%	4.1%	4.3%	4.6%
Plastics	11.8%	12.0%	12.2%	13.1%	14.1%
Other Inorganic Waste	14.0%	14.2%	14.4%	15.3%	16.3%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	54.4%	53.6%	52.7%	49.4%	45.7%

Table 5.25 : Characteristics of Turkish MSW as model input for scenario 3 (5/8) (2023 – 2027).

Waste Composition	2023	2024	2025	2026	2027
Foodwaste	20.3%	19.6%	18.9%	18.2%	17.5%
Paper & Cardboard	14.2%	13.7%	13.2%	12.8%	12.2%
Garden Waste (Green Waste)	0.5%	0.5%	0.5%	0.5%	0.5%
Wood Waste	1.1%	1.0%	1.0%	1.0%	0.9%
Ruber, Leather, Bones, Straw	1.5%	1.5%	1.4%	1.4%	1.3%
Textiles	2.3%	2.2%	2.1%	2.1%	2.0%
Other Organics	1.7%	1.6%	1.6%	1.5%	1.4%
Metals	4.2%	4.3%	4.4%	4.5%	4.6%
Construction & Demolition Waste	16.7%	17.1%	17.6%	18.1%	18.7%
Glass & Ceramics	5.0%	5.1%	5.2%	5.3%	5.4%
Plastics	15.1%	15.6%	16.0%	16.4%	16.8%
Other Inorganic Waste	17.4%	17.8%	18.1%	18.4%	18.7%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	41.6%	40.1%	38.7%	37.3%	35.8%

Table 5.26 : Characteristics of Turkish MSW as model input for scenario 3 (6/8) (2028 – 2032).

Waste Composition	2028	2029	2030	2031	2032
Foodwaste	16.7%	16.0%	15.2%	15.1%	15.0%
Paper & Cardboard	11.7%	11.2%	10.7%	10.6%	10.5%
Garden Waste (Green Waste)	0.4%	0.4%	0.4%	0.4%	0.4%
Wood Waste	0.9%	0.8%	0.8%	0.8%	0.8%
Ruber, Leather, Bones, Straw	1.3%	1.2%	1.1%	1.1%	1.1%
Textiles	1.9%	1.8%	1.7%	1.7%	1.7%
Other Organics	1.4%	1.3%	1.3%	1.3%	1.2%
Metals	4.7%	4.8%	4.9%	4.9%	4.9%
Construction & Demolition Waste	19.2%	19.8%	20.4%	20.6%	20.8%
Glass & Ceramics	5.5%	5.7%	5.8%	5.8%	5.8%
Plastics	17.2%	17.6%	18.0%	18.1%	18.2%
Other Inorganic Waste	19.0%	19.4%	19.7%	19.7%	19.6%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	34.3%	32.8%	31.3%	31.0%	30.7%

Table 5.27 : Characteristics of Turkish MSW as model input for scenario 3 (7/8) (2033 – 2037).

Waste Composition	2033	2034	2035	2036	2037
Foodwaste	14.9%	14.8%	14.7%	14.6%	14.5%
Paper & Cardboard	10.4%	10.4%	10.3%	10.2%	10.2%
Garden Waste (Green Waste)	0.4%	0.4%	0.4%	0.4%	0.4%
Wood Waste	0.8%	0.8%	0.8%	0.8%	0.8%
Ruber, Leather, Bones, Straw	1.1%	1.1%	1.1%	1.1%	1.1%
Textiles	1.7%	1.7%	1.7%	1.6%	1.6%
Other Organics	1.2%	1.2%	1.2%	1.2%	1.2%
Metals	4.9%	4.9%	4.9%	4.9%	4.9%
Construction & Demolition Waste	20.9%	21.1%	21.3%	21.5%	21.6%
Glass & Ceramics	5.8%	5.8%	5.8%	5.8%	5.8%
Plastics	18.3%	18.3%	18.4%	18.5%	18.6%
Other Inorganic Waste	19.6%	19.6%	19.5%	19.5%	19.4%
Total	**100%**	**100%**	**100%**	**100%**	**100%**
Biodegradable Waste	30.5%	30.3%	30.1%	29.9%	29.7%

Table 5.28 : Characteristics of Turkish MSW as model input for scenario 3 (8/8) (2038 – 2040).

Waste Composition	2038	2039	2040
Foodwaste	14.4%	14.3%	14.2%
Paper & Cardboard	10.1%	10.0%	10.0%
Garden Waste (Green Waste)	0.4%	0.4%	0.4%
Wood Waste	0.8%	0.8%	0.7%
Ruber, Leather, Bones, Straw	1.1%	1.1%	1.1%
Textiles	1.6%	1.6%	1.6%
Other Organics	1.2%	1.2%	1.2%
Metals	4.9%	4.9%	4.9%
Construction & Demolition Waste	21.8%	22.0%	22.1%
Glass & Ceramics	5.8%	5.8%	5.8%
Plastics	18.6%	18.7%	18.8%
Other Inorganic Waste	19.4%	19.3%	19.2%
Total	**100%**	**100%**	**100%**
Biodegradable Waste	29.5%	29.3%	29.1%

5.3 LFG Model Outputs

LFG generation output tables were formed for 100 years and it's assumed that all waste landfilling will be stopped in 2040 in order to check the trend of curve to see if there is some errors or not. Output tables for Scenario 1, Scenario 2 and Scenario 3 are given in below between years 2003 – 2040. Also comparison graphs are given in Figure 5.15 and 5.16.

Also in Figure 5.17, the potential distribution of recoverable electricity energy till 2040 is given. In order to form this graph, some assumptions were done as below.

When all the average considerations were entered to the model about LFG recovery, the result comes out 73% can be recoverable which is logical.

It's also assumed that methane content of LFG is 50% and gross heat rate of 10,800 Btus per kW-hr (hhv), equivalent to 11.28 MJ per kW-hr. In other words, it's assumed 1 MWh electricity can be generated by use of 604 m^3/h landfill gas.

Table 5.29 : Total MSW amount to be landfilled and LFG generation for scenario 1 (2003 – 2040).

Year	Disposal (tonnes/year)	MSW In-Place (tonnes)	LFG Generation (m^3/hr)	LFG Generation (MJ/hr)	Max. Power Plant Cap. (MW)
2003	23,998,245	23,998,245	0	0	0
2004	23,417,291	47,415,536	21,686	408,444	26
2005	24,420,000	71,835,536	40,491	762,614	49
2006	24,369,477	96,205,013	58,199	1,096,135	70
2007	24,655,000	120,860,013	74,034	1,394,375	89
2008	23,624,579	144,484,592	88,538	1,667,552	107
2009	24,765,000	169,249,592	100,730	1,897,175	122
2010	24,748,029	193,997,621	112,822	2,124,931	136
2011	24,655,000	218,652,621	123,814	2,331,960	150
2012	25,255,163	243,907,784	133,770	2,519,478	162
2013	25,460,000	269,367,784	143,429	2,701,381	173
2014	25,775,000	295,142,784	152,498	2,872,193	184
2015	26,323,970	321,466,754	161,142	3,035,004	195
2016	26,585,024	348,051,778	169,610	3,194,495	205
2017	26,841,257	374,893,035	177,711	3,347,071	215
2018	27,092,141	401,985,176	185,481	3,493,413	224
2019	27,337,739	429,322,915	192,958	3,634,242	233
2020	27,578,013	456,900,928	200,171	3,770,097	242
2021	27,812,745	484,713,673	207,152	3,901,564	250
2022	28,041,983	512,755,656	213,915	4,028,945	258
2023	28,265,340	541,020,996	220,500	4,152,980	266
2024	28,482,396	569,503,392	226,881	4,273,162	274
2025	28,680,519	598,183,911	233,102	4,390,330	282
2026	28,871,953	627,055,864	239,167	4,504,547	289
2027	29,056,444	656,112,308	245,080	4,615,918	296
2028	29,233,783	685,346,091	250,861	4,724,802	303
2029	29,403,635	714,749,726	256,516	4,831,302	310
2030	29,565,308	744,315,035	262,056	4,935,652	317
2031	29,718,429	774,033,464	267,467	5,037,573	323
2032	29,863,006	803,896,470	272,767	5,137,386	329
2033	29,998,706	833,895,176	277,958	5,235,159	336
2034	30,125,562	864,020,738	283,044	5,330,945	342
2035	30,243,321	894,264,059	288,026	5,424,787	348
2036	30,351,637	924,615,696	292,908	5,516,719	354
2037	30,450,593	955,066,290	297,688	5,606,761	360
2038	30,540,503	985,606,792	302,370	5,694,932	365
2039	30,621,298	1,016,228,090	306,953	5,781,249	371
2040	30,692,977	1,046,921,067	311,438	5,865,726	376

Table 5.30 : Total MSW amount to be landfilled and LFG generation for scenario 2 (2003 – 2040).

Year	Disposal	MSW In-Place	LFG Generation		Max. Power Plant Cap.
	(tonnes/year)	(tonnes)	(m^3/hr)	(MJ/hr)	(MW)
2003	23,998,245	23,998,245	0	0	0
2004	23,417,291	47,415,536	21,672	408,186	26
2005	24,420,000	71,835,536	40,463	762,102	49
2006	24,369,477	96,205,013	58,158	1,095,367	70
2007	24,655,000	120,860,013	73,983	1,393,415	89
2008	23,624,579	144,484,592	88,481	1,666,482	107
2009	24,765,000	169,249,592	100,671	1,896,077	122
2010	24,748,029	193,997,621	112,767	2,123,891	136
2011	24,273,687	218,271,308	123,651	2,328,888	149
2012	24,076,838	242,348,146	132,907	2,503,207	161
2013	23,712,054	266,060,200	141,030	2,656,208	170
2014	23,396,075	289,456,275	147,970	2,786,918	179
2015	23,176,761	312,633,037	153,845	2,897,572	186
2016	21,975,289	334,608,326	158,523	2,985,677	191
2017	20,733,405	355,341,731	161,258	3,037,182	195
2018	19,491,143	374,832,873	162,166	3,054,297	196
2019	19,296,291	394,129,164	161,937	3,049,985	196
2020	19,093,348	413,222,512	161,538	3,042,470	195
2021	18,909,840	432,132,353	160,959	3,031,561	194
2022	18,719,915	450,852,268	160,222	3,017,671	194
2023	18,505,110	469,357,377	159,331	3,000,892	192
2024	18,348,472	487,705,849	158,257	2,980,656	191
2025	18,146,772	505,852,621	157,060	2,958,119	190
2026	18,305,493	524,158,114	155,884	2,935,971	188
2027	18,469,774	542,627,888	154,974	2,918,826	187
2028	18,621,522	561,249,410	154,295	2,906,048	186
2029	18,774,009	580,023,419	153,805	2,896,820	186
2030	18,916,522	598,939,941	153,478	2,890,664	185
2031	19,091,917	618,031,859	153,278	2,886,895	185
2032	19,240,128	637,271,987	153,213	2,885,657	185
2033	19,385,173	656,657,160	153,245	2,886,268	185
2034	19,526,992	676,184,152	153,360	2,888,436	185
2035	19,665,395	695,849,546	153,545	2,891,912	185
2036	19,800,146	715,649,692	153,787	2,896,481	186
2037	19,931,205	735,580,897	154,078	2,901,956	186
2038	20,058,637	755,639,534	154,408	2,908,177	187
2039	20,182,335	775,821,869	154,771	2,915,006	187
2040	20,302,219	796,124,088	155,159	2,922,325	187

Table 5.31 : Total MSW amount to be landfilled and LFG generation for scenario 3 (2003 – 2040).

Year	Disposal	MSW In-Place	LFG Generation		Max. Power Plant Cap.
	(tonnes/year)	(tonnes)	(m^3/hr)	(MJ/hr)	(MW)
2003	23,998,245	23,998,245	0	0	0
2004	23,417,291	47,415,536	21,672	408,186	26
2005	24,420,000	71,835,536	40,463	762,102	49
2006	24,369,477	96,205,013	58,158	1,095,367	70
2007	24,655,000	120,860,013	73,983	1,393,415	89
2008	23,624,579	144,484,592	88,481	1,666,482	107
2009	24,765,000	169,249,592	100,671	1,896,077	122
2010	24,748,029	193,997,621	112,767	2,123,891	136
2011	24,530,315	218,527,936	123,741	2,330,585	149
2012	24,590,095	243,118,031	133,400	2,512,507	161
2013	24,481,939	267,599,970	142,213	2,678,493	172
2014	24,422,589	292,022,559	150,103	2,827,085	181
2015	24,459,903	316,482,462	157,164	2,960,088	190
2016	24,410,437	340,892,900	163,605	3,081,400	198
2017	24,320,559	365,213,459	169,432	3,191,132	205
2018	24,230,303	389,443,762	174,670	3,289,798	211
2019	24,141,043	413,584,805	179,378	3,378,468	217
2020	24,043,693	437,628,497	183,610	3,458,165	222
2021	22,813,770	460,442,268	186,987	3,521,783	226
2022	21,577,431	482,019,698	188,606	3,552,261	228
2023	20,316,211	502,335,910	188,592	3,552,010	228
2024	20,159,573	522,495,483	187,513	3,531,685	226
2025	19,957,874	542,453,357	186,368	3,510,109	225
2026	19,754,374	562,207,731	185,112	3,486,464	224
2027	19,556,435	581,764,166	183,742	3,460,653	222
2028	19,345,962	601,110,128	182,262	3,432,786	220
2029	19,136,229	620,246,358	180,663	3,402,663	218
2030	18,916,522	639,162,880	178,947	3,370,344	216
2031	19,091,917	658,254,797	177,261	3,338,602	214
2032	19,240,128	677,494,925	175,884	3,312,652	212
2033	19,385,173	696,880,098	174,752	3,291,331	211
2034	19,526,992	716,407,090	173,829	3,273,960	210
2035	19,665,395	736,072,485	173,086	3,259,962	209
2036	19,800,146	755,872,631	172,496	3,248,845	208
2037	19,931,205	775,803,836	172,036	3,240,184	208
2038	20,058,637	795,862,473	171,687	3,233,616	207
2039	20,182,335	816,044,807	171,433	3,228,831	207
2040	20,302,219	836,347,027	171,260	3,225,562	207

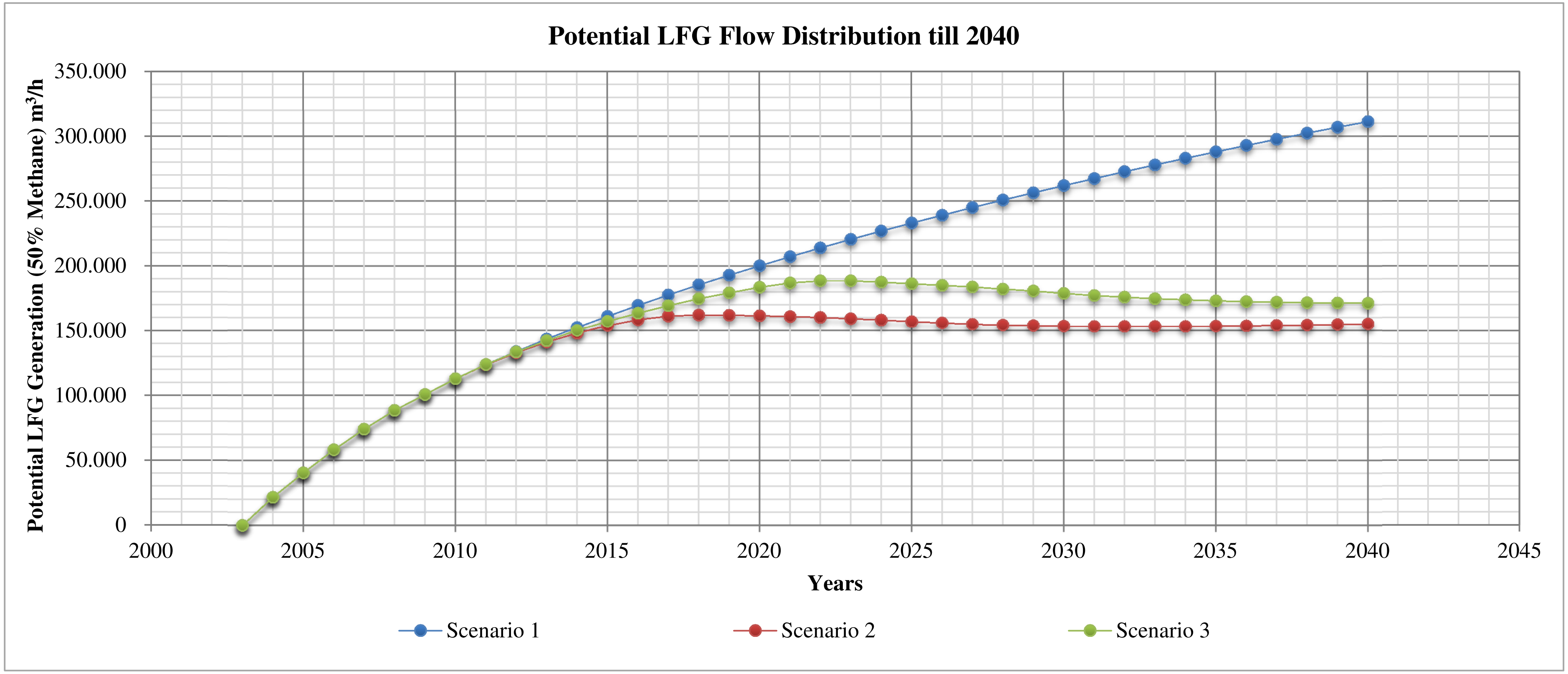

Figure 5.15 : Potential LFG flow distibution till 2040 for 3 scenarios.

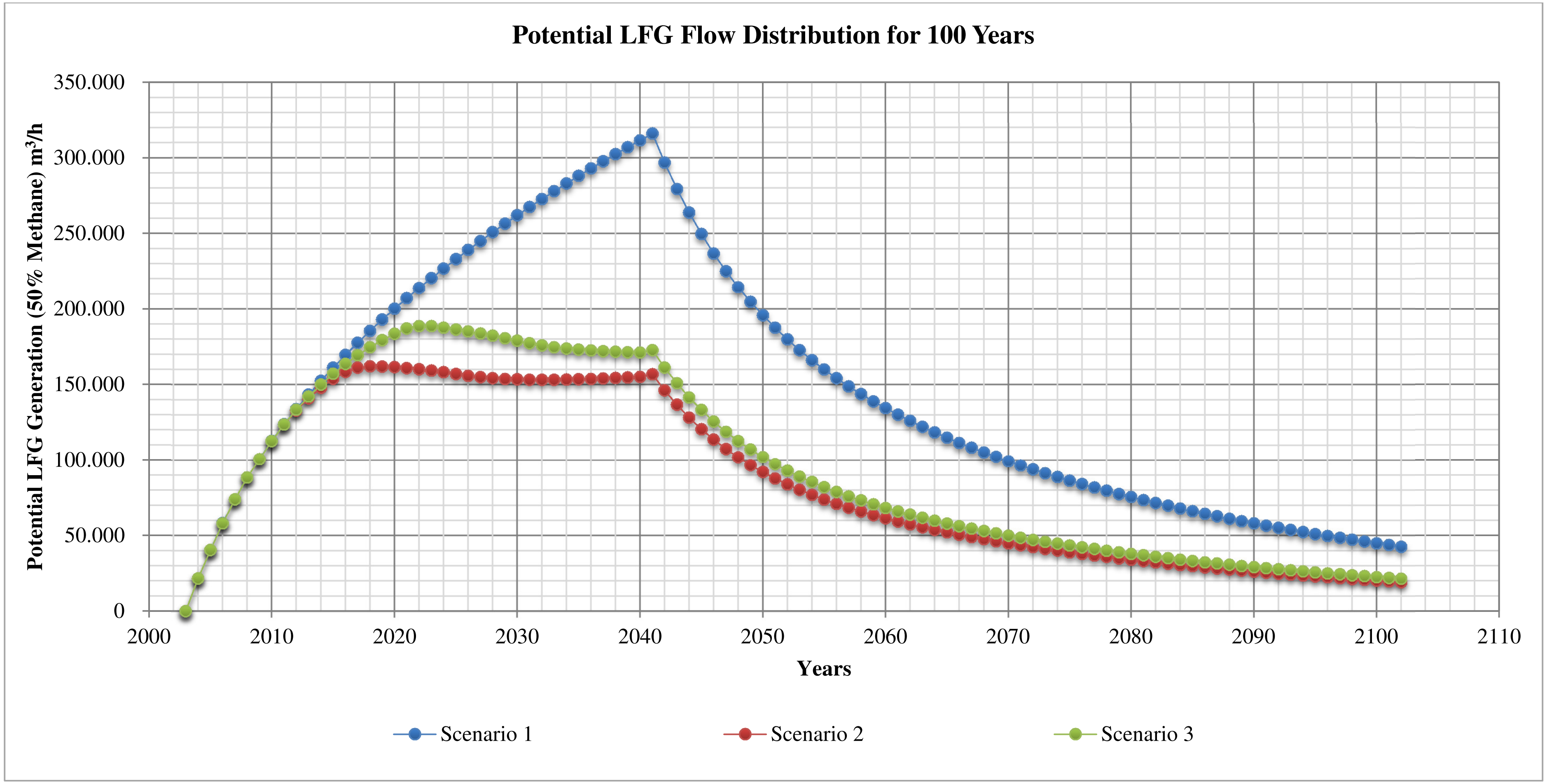

Figure 5.16 : Potential LFG flow distributions for 100 years if landfillin stops at 2040.

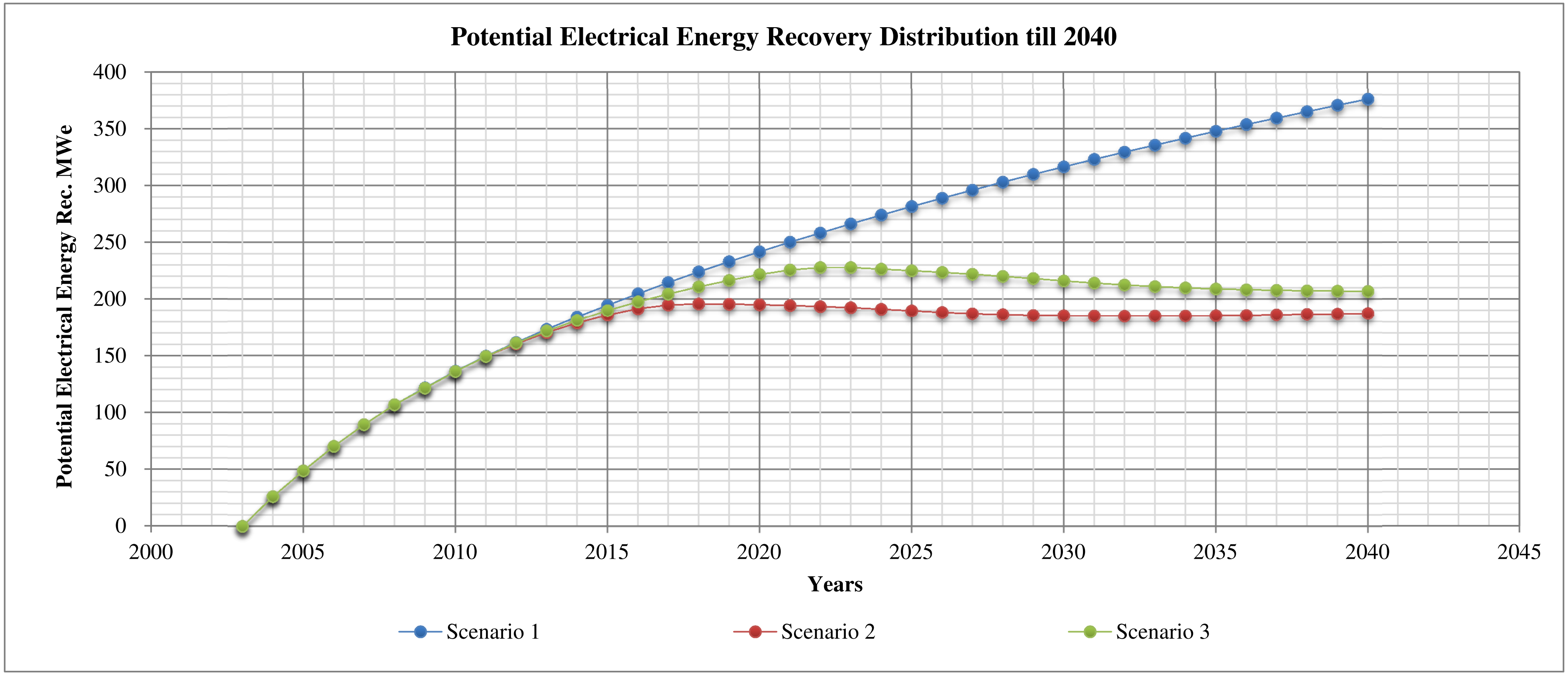

Figure 5.17 : Potential electricity energy recovery distibution till 2040.

6. CONCLUSIONS AND RECOMMENDATIONS

In this thesis, first, the LFG management of Turkey was examined, then the effects of biodegradable waste diversion on Turkey's LFG potential was determined.

The installed LFGTE plant capacity of Turkey is approximately 180 MWe in 2015. Most of the plants use 80% of their installed capacities in whole year and keeps reserve capacity. Therefore, actual electricity from LFGTE plants in Turkey is approximately 144 MWh. According to the model results, Turkey's LFGTE generation potential in 2016 is 205 MW. This means that around 70% of total LFGTE generation potential of Turkey is being used at the end of 2015.

According to the results of the study, if the diversion of biodegradable materials comes true as it's stated in the regulations, the LFG production potential of Turkey may decrease up to it's 50% in 2040. In other words, the LFG production potential will be 155,000 m^3/h less than the situation where no biodegradable MSW diversion done. According to the outputs of the model, 73% of LFG can be collected from sites which may differ from site to site. It's calculated that the maximum potential electricity generation in LFGTE plants will be 376 MWh in 2040 if there is no biodegradable diversion. Thus, if the Scenario 1 takes place, 113,550 m^3/h less LFG will be recovered in LFGTE facilities in comparison to Scenario 2, which means that there will be approximately 190 MWh decrease in electricity generation potential up to 187 MWh by using LFG in internal combustion engines only in 2040.

Even if 5 years of lag seen on the application like in Scenario 3, there will be approximately 30,000 m^3/h more LFG production potential in 2023 in comparison with as it is in Scenario 2, which means that 21,900 m^3/h more LFG can be collected or 36 MWh more electricity can be generated. In other words, if 5 years of lag seen on the application, LFGTE generation potential of Turkey increases 15 % in 2023. It should be kept in mind that 36 MW plant can serve electricity energy for one million persons' living purposes.

This study shedding light on the potential LFG amount of Turkey till 2040, reveals the electricity generation potential based on LFG, as a 70% foreign-dependent country in energy sector. If there won't be any change on the application of these regulation provisions, energy generation based on LFG potential will be reduced by half in 2040 which is an important challenge. However, this diversion may born some critical opportunities if diverted organics will be handled correctly.

It's crucial to recover readily biodegradable organic matters in MSW such as food waste in anaerobic digesters whether it may be a co-digestion process together with some other organics from different sources like agro industries. Anaerobic digesters are more efficient plants than LFGTE facilities when electricity generation is taken into consideration if designed and operated aright. There can be much more electricity generation with same amount of organic matter in anaerobic digesters in comparison with in landfills. At that point, the importance of source-separated waste collection increases in order to have noncontaminated biodegradable waste. Another important point to be thought on will be the final disposal or recovery of the residues of biogas plants.

Biodegradable materials can also recovered in order to produce biodiesel or bioethanol. At present, gasoline products shall include at least 3% (based on volume) bioethanol, produced by domestic agricultural products (EMRA, 2012). Also a draft annunciation on blending biodiesel into diesel products has published which includes a statement on blending 0.1% biodiesel into diesel products. It may be possible to evaluate diverted biodegradable materials in that field.

Currently, landfill gas to electricity plants are the only LFG recovery plants in Turkey. Due to the characterization change in landfilled MSW, some other recovery alternatives may become much more feasible. For instance, LFG may be fed into the natural gas grid after reaching specific standards with some purification or conditioning processes.

As a brief conclusion, diversion of biodegradables will cause dramatic decrease in Turkey's cumulative landfill gas potential in future, which will especially influence the further investments on LFG recovery projects. Therefore, alternative biodegradable material recovery technologies should be developed in order to fill the gap which will occur with the decrease on LFG.

APPENDICES

APPENDIX A

Table A.1 : Current waste disposal activities (1/3) (TUIK, 2015).

Years	Metropolitan Municipality Dumpsite	Municipality Dumpsite	Other Municipality Dumpsite	Sanitary Landfilling	Compost Plant
(unit)	(ton/year)	(ton/year)	(ton/year)	(ton/year)	(ton/year)
1994	7,066,231	7,000,408	412,534	809,037	192,086
1995	8,233,407	8,500,528	440,988	1,443,962	158,906
1996	7,309,679	9,737,033	472,826	2,847,032	178,839
1997	6,528,973	9,754,762	521,340	4,363,796	180,363
1998	6,344,736	10,094,098	413,979	5,257,905	166,265
2001	3,770,586	10,125,442	673,812	8,304,192	218,077
2002	3,929,354	11,636,724	743,945	7,046,961	383,120
2003	3,967,816	11,843,832	754,837	7,431,760	325,944
2004	3,795,643	11,832,021	788,104	7,001,523	350,744
2006	2,553,398	11,822,158	565,598	9,428,323	254,929
2008	2,276,540	10,052,659	347,943	10,947,437	275,737
2010	1,827,750	8,754,470	418,933	13,746,876	194,452
2012	1,106,706	8,216,626	447,635	15,484,196	154,652

Table A.2 : Current waste disposal activities (2/3) (TUIK, 2015).

Years	Incineration Plant	Mass Burn	River Dump	Burry	Land use & Mine Filling Etc,
(unit)	(ton/year)	(ton/year)	(ton/year)	(ton/year)	(ton/year)
1994	0	442,149	557,574	523,378	753,257
1995	265	405,030	370,398	828,862	527,331
1996	2,503	437,902	370,349	823,622	303,271
1997	8,556	625,144	384,404	1,446,852	365,809
1998	0	386,134	374,912	852,390	1,039,144
2001	0	343,591	100,935	481,683	1,115,378
2002	0	220,549	196,827	499,891	715,762
2003	0	258,527	228,487	597,042	709,295
2004	0	101,623	154,735	426,474	562,655
2006	0	246,548	69,828	144,459	194,730
2008	0	239,291	47,685	100,486	73,085
2010	0	133,876	43,965	34,295	122,080
2012	0	104,751	33,409	94,315	202,283

Table A.3 : Current waste disposal activities (3/3) (TUIK, 2015).

Years	Others	Dumpsites	Sanitary Landfilling	Dumpsites & Landfilling Total	Total
(unit)	(ton/year)	(ton/year)	(ton/year)	(ton/year)	(ton/year)
1994	2,468,444	14,479,173	809,037	15,288,210	20,225,098
1995	2,290,792	17,174,923	1,443,962	18,618,885	23,200,469
1996	2,116,486	17,519,538	2,847,032	20,366,570	24,599,542
1997	3,011,128	16,805,075	4,363,796	21,168,871	27,191,127
1998	2,818,845	16,852,813	5,257,905	22,110,718	27,748,408
2001	2,259,664	14,569,840	8,304,192	22,874,032	27,393,360
2002	2,016,149	16,310,023	7,046,961	23,356,984	27,389,282
2003	2,119,295	16,566,485	7,431,760	23,998,245	28,236,835
2004	1,596,231	16,415,768	7,001,523	23,417,291	26,609,753
2006	910,494	14,941,154	9,428,323	24,369,477	26,190,465
2008	736,284	12,677,142	10,947,437	23,624,579	25,097,147
2010	528,668	11,001,153	13,746,876	24,748,029	25,805,365
2012	589,410	9,770,967	15,484,196	25,255,163	26,433,983

APPENDIX B

Table B.1 : Turkey weighted average waste compositions between 2003 – 2015 (1/3).

Waste Composition (%)	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Cardboard	7.50	7.57	7.71	7.79	7.91	7.99	8.10	8.19	8.30	8.40	8.50	8.60	8.70
High Volume Cardboard	0.32	0.31	0.31	0.31	0.30	0.30	0.30	0.30	0.30	0.30	0.29	0.29	0.29
Concrete / Tile / Debris	9.31	9.44	9.59	9.75	9.91	10.05	10.20	10.34	10.50	10.70	10.82	10.99	11.17
Kitchen Waste	34.38	33.73	33.10	32.45	31.80	31.17	30.53	30.02	29.37	28.74	28.09	27.50	26.87
Garden (Yard) Waste	1.97	1.97	1.97	1.98	1.98	1.98	1.98	1.97	1.97	1.97	1.98	2.00	1.98
Glass	2.82	2.86	2.86	2.88	2.91	2.91	2.93	2.92	2.94	2.95	2.96	2.96	2.96
Hazardous Waste	0.30	0.30	0.30	0.30	0.30	0.29	0.29	0.29	0.29	0.29	0.28	0.28	0.28
Metal	2.46	2.46	2.51	2.52	2.53	2.55	2.55	2.57	2.61	2.63	2.63	2.63	2.66
High Volume Metal	0.30	0.30	0.30	0.30	0.30	0.29	0.29	0.29	0.29	0.29	0.28	0.28	0.28
Other Combustibles	7.02	7.10	7.18	7.24	7.32	7.41	7.46	7.53	7.63	7.65	7.74	7.81	7.86
Other High Volume Combustibles	1.02	1.01	1.01	1.03	1.01	1.00	1.00	1.01	0.98	0.98	0.98	0.98	0.98
Other High Volume Non-Comb.	1.16	1.15	1.15	1.17	1.15	1.14	1.14	1.15	1.12	1.12	1.12	1.12	1.12
Other Non-Combustibles	10.34	10.39	10.42	10.43	10.46	10.50	10.53	10.49	10.56	10.57	10.60	10.62	10.62
Paper	11.52	11.69	11.83	11.97	12.15	12.30	12.47	12.58	12.75	12.91	13.07	13.20	13.37
Plastic	9.17	9.27	9.36	9.46	9.56	9.65	9.76	9.83	9.91	10.00	10.10	10.20	10.27
EEEW	0.49	0.50	0.50	0.49	0.50	0.51	0.50	0.50	0.48	0.48	0.48	0.49	0.49
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Biodegradable Waste	63.7	63.4	63.1	62.8	62.5	62.1	61.8	61.6	61.3	61.0	60.7	60.4	60.1
Recyclable Materials	34.0	34.4	34.8	35.2	35.6	36.0	36.4	36.7	37.1	37.5	37.8	38.2	38.5
Package Materials	17.7	17.9	18.1	18.2	18.5	18.6	18.9	19.0	19.2	19.4	19.6	19.8	20.0
Others	12.0	12.0	12.1	12.1	12.1	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.3

Table B.2 : Turkey weighted average waste compositions between 2016 – 2028 (2/3).

Waste Composition (%)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Cardboard	8.77	8.91	9.01	9.11	9.23	9.34	9.43	9.53	9.61	9.72	9.82	9.91	10.01
High Volume Cardboard	0.28	0.28	0.28	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.26	0.26	0.26
Concrete / Tile / Debris	11.41	11.58	11.72	11.90	12.10	12.29	12.48	12.62	12.73	12.89	13.06	13.24	13.40
Kitchen Waste	26.27	25.65	25.10	24.52	23.92	23.33	22.77	22.25	21.49	20.91	20.33	19.75	19.18
Garden (Yard) Waste	1.96	1.96	1.99	2.01	2.03	2.04	2.01	2.05	2.03	2.03	2.03	2.03	2.03
Glass	2.95	2.96	2.96	2.96	2.95	2.94	2.95	2.95	2.99	2.99	2.99	2.99	3.00
Hazardous Waste	0.28	0.28	0.28	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.26	0.26	0.26
Metal	2.66	2.67	2.71	2.71	2.70	2.73	2.74	2.76	2.77	2.80	2.82	2.82	2.83
High Volume Metal	0.28	0.28	0.28	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.26	0.26	0.26
Other Combustibles	7.95	8.02	8.07	8.15	8.20	8.26	8.34	8.40	8.48	8.55	8.63	8.67	8.74
Other High Volume Combustibles	0.98	0.97	0.96	0.96	0.96	0.95	0.93	0.92	0.94	0.92	0.91	0.91	0.90
Other High Volume Non-Comb.	1.12	1.11	1.09	1.09	1.08	1.08	1.05	1.05	1.06	1.04	1.03	1.03	1.03
Other Non-Combustibles	10.69	10.68	10.68	10.68	10.68	10.69	10.69	10.68	10.75	10.76	10.76	10.79	10.79
Paper	13.49	13.70	13.85	14.01	14.17	14.33	14.48	14.64	14.78	14.94	15.09	15.23	15.39
Plastic	10.37	10.46	10.53	10.61	10.63	10.76	10.83	10.88	11.03	11.11	11.20	11.28	11.37
EEEW	0.50	0.50	0.51	0.52	0.51	0.51	0.53	0.52	0.51	0.51	0.51	0.51	0.52
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Biodegradable Waste	59.7	59.5	59.3	59.0	58.8	58.5	58.2	58.1	57.6	57.3	57.1	56.8	56.5
Recyclable Materials	38.8	39.2	39.6	39.9	40.3	40.6	40.9	41.3	41.7	42.1	42.4	42.8	43.1
Package Materials	20.1	20.3	20.5	20.7	20.9	21.0	21.2	21.4	21.6	21.8	22.0	22.1	22.3
Others	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.4	12.4	12.4	12.4

Table B.3 : Turkey weighted average waste compositions between 2029 – 2040 (3/3).

Waste Composition (%)	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Cardboard	10.11	10.21	10.32	10.43	10.53	10.63	10.73	10.83	10.93	11.03	11.13	11.24
High Volume Cardboard	0.26	0.26	0.25	0.25	0.25	0.25	0.24	0.24	0.24	0.24	0.24	0.23
Concrete / Tile / Debris	13.55	13.73	13.90	14.07	14.23	14.40	14.57	14.74	14.90	15.07	15.24	15.40
Kitchen Waste	18.62	18.06	17.32	16.71	16.11	15.51	14.90	14.30	13.70	13.09	12.49	11.89
Garden (Yard) Waste	2.03	2.04	2.04	2.04	2.05	2.05	2.05	2.06	2.06	2.06	2.06	2.07
Glass	3.01	3.01	3.02	3.02	3.03	3.03	3.04	3.04	3.05	3.05	3.06	3.06
Hazardous Waste	0.26	0.26	0.25	0.25	0.25	0.25	0.25	0.24	0.24	0.24	0.24	0.24
Metal	2.85	2.86	2.88	2.90	2.91	2.92	2.94	2.95	2.97	2.98	3.00	3.01
High Volume Metal	0.26	0.26	0.25	0.25	0.25	0.25	0.24	0.24	0.24	0.24	0.24	0.23
Other Combustibles	8.82	8.88	8.96	9.02	9.09	9.16	9.23	9.30	9.37	9.43	9.50	9.57
Other High Volume Combustibles	0.89	0.89	0.89	0.89	0.88	0.88	0.87	0.87	0.87	0.86	0.86	0.85
Other High Volume Non-Comb.	1.02	1.02	1.01	1.01	1.00	1.00	0.99	0.99	0.98	0.97	0.97	0.96
Other Non-Combustibles	10.80	10.79	10.85	10.87	10.88	10.90	10.92	10.93	10.95	10.96	10.98	10.99
Paper	15.52	15.69	15.86	16.01	16.17	16.32	16.48	16.63	16.79	16.94	17.10	17.25
Plastic	11.46	11.53	11.63	11.71	11.80	11.89	11.97	12.06	12.14	12.23	12.32	12.40
EEEW	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.53	0.53	0.53	0.53	0.53
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Biodegradable Waste	56.3	56.0	55.6	55.4	55.1	54.8	54.5	54.2	53.9	53.7	53.4	53.1
Recyclable Materials	43.5	43.8	44.2	44.6	44.9	45.3	45.7	46.0	46.4	46.7	47.1	47.5
Package Materials	22.5	22.7	22.9	23.1	23.2	23.4	23.6	23.8	24.0	24.2	24.4	24.5
Others	12.4	12.4	12.4	12.4	12.4	12.5	12.5	12.5	12.5	12.5	12.5	12.5

APPENDIX C

Table C.1 : Solid waste tonnages for each material as model input for scenario 1 (1/5) (2003 – 2010).

(tonnes/year)	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Foodwaste	8,245,648	7,894,370	8,075,765	7,900,518	7,834,272	7,359,757	7,559,266	7,430,628
Paper & Cardboard	4,635,711	4,580,148	4,842,108	4,888,113	5,016,240	4,861,286	5,166,449	5,213,396
Garden Waste (Green Waste)	188,682	184,396	192,552	192,434	194,767	187,180	196,548	194,959
Wood Waste	380,588	370,967	387,007	389,367	391,492	375,142	393,546	392,217
Ruber, Leather, Bones, Straw	504,901	498,596	525,608	528,971	541,278	524,709	553,894	558,937
Textiles	757,352	747,894	788,413	793,456	811,918	787,063	830,840	838,406
Other Organics	567,099	557,057	585,276	591,883	600,078	578,816	609,664	615,451
Metals	661,899	646,936	685,134	687,182	697,026	670,667	705,051	709,581
Construction & Demolition Waste	2,121,140	2,099,199	2,222,716	2,256,326	2,318,553	2,253,969	2,399,474	2,431,702
Glass & Ceramics	787,418	778,905	814,717	820,329	838,494	806,719	851,444	851,853
Plastics	2,199,207	2,169,480	2,284,444	2,303,284	2,354,685	2,279,894	2,415,410	2,433,878
Other Inorganic Waste	2,948,599	2,889,344	3,016,261	3,017,613	3,056,196	2,939,377	3,083,413	3,077,020
Total	**23,998,245**	**23,417,291**	**24,420,000**	**24,369,477**	**24,655,000**	**23,624,579**	**24,765,000**	**24,748,029**
Biodegradable Waste	15,279,981	14,833,428	15,396,728	15,284,742	15,390,046	14,673,952	15,310,207	15,243,995

Table C.2 : Solid waste tonnages for each material as model input for scenario 1 (2/5) (2011 – 2018).

(tonnes/year)	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Foodwaste	7,240,016	7,258,791	7,156,311	7,090,905	7,080,407	6,985,526	6,883,561	6,798,746
Paper & Cardboard	5,263,710	5,458,655	5,568,417	5,695,322	5,892,679	5,996,257	6,144,951	6,269,209
Garden Waste (Green Waste)	194,176	198,947	201,502	206,419	208,402	208,766	210,398	215,181
Wood Waste	388,297	397,838	402,532	411,133	416,315	417,168	420,228	427,114
Ruber, Leather, Bones, Straw	564,091	579,735	591,897	604,157	621,465	634,520	645,663	655,813
Textiles	846,136	869,602	887,846	906,236	932,197	951,780	968,494	983,719
Other Organics	615,625	632,238	643,665	655,720	673,456	684,795	694,999	703,024
Metals	715,889	738,689	741,849	750,915	773,549	781,774	791,516	810,136
Construction & Demolition Waste	2,459,979	2,566,458	2,618,201	2,693,266	2,796,037	2,882,804	2,951,895	3,015,392
Glass & Ceramics	853,473	879,070	891,486	904,648	926,653	937,224	948,812	960,246
Plastics	2,442,899	2,526,896	2,574,278	2,629,818	2,706,000	2,757,483	2,806,374	2,851,227
Other Inorganic Waste	3,070,709	3,148,244	3,182,015	3,226,461	3,296,811	3,346,928	3,374,367	3,402,334
Total	**24,655,000**	**25,255,163**	**25,460,000**	**25,775,000**	**26,323,970**	**26,585,024**	**26,841,257**	**27,092,141**
Biodegradable Waste	15,112,051	15,395,806	15,452,170	15,569,892	15,824,919	15,878,811	15,968,294	16,052,806

Table C.3 : Solid waste tonnages for each material as model input for scenario 1 (3/5) (2019 – 2026).

(tonnes/year)	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**
Foodwaste	6,699,794	6,598,370	6,485,505	6,383,004	6,286,192	6,122,707	5,999,283	5,870,834
Paper & Cardboard	6,391,334	6,529,090	6,653,226	6,780,315	6,904,249	7,027,120	7,152,950	7,270,518
Garden Waste (Green Waste)	219,682	223,510	226,862	225,613	231,559	230,893	232,550	234,101
Wood Waste	434,520	440,969	446,460	442,558	451,158	453,588	454,112	456,843
Ruber, Leather, Bones, Straw	668,463	678,461	689,025	701,189	711,615	725,169	735,956	747,568
Textiles	1,002,694	1,017,691	1,033,537	1,051,783	1,067,422	1,087,753	1,103,934	1,121,352
Other Organics	714,549	723,940	733,437	740,533	748,741	765,180	771,227	781,510
Metals	813,877	818,290	832,277	844,065	854,562	864,864	878,260	887,737
Construction & Demolition Waste	3,089,551	3,172,076	3,244,444	3,323,327	3,387,759	3,446,089	3,512,820	3,583,219
Glass & Ceramics	971,225	982,049	988,792	1,002,374	1,012,342	1,032,304	1,042,554	1,052,616
Plastics	2,899,211	2,933,164	2,990,478	3,034,860	3,074,641	3,141,023	3,188,905	3,235,689
Other Inorganic Waste	3,432,840	3,460,402	3,488,704	3,512,363	3,535,100	3,585,706	3,607,969	3,629,968
Total	**27,337,739**	**27,578,013**	**27,812,745**	**28,041,983**	**28,265,340**	**28,482,396**	**28,680,519**	**28,871,953**
Biodegradable Waste	16,131,035	16,212,031	16,268,051	16,324,994	16,400,936	16,412,410	16,450,012	16,482,725

Table C.4 : Solid waste tonnages for each material as model input for scenario 1 (4/5) (2027 – 2034).

(tonnes/year)	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Foodwaste	5,743,189	5,610,620	5,476,994	5,340,769	5,148,561	4,993,484	4,835,222	4,673,940
Paper & Cardboard	7,383,450	7,504,372	7,614,107	7,734,244	7,858,884	7,973,226	8,085,918	8,196,900
Garden Waste (Green Waste)	235,628	238,058	239,402	240,659	242,730	244,273	245,746	247,151
Wood Waste	459,522	462,010	464,314	466,446	470,430	472,686	474,802	476,777
Ruber, Leather, Bones, Straw	756,608	766,825	777,977	787,424	798,801	808,817	818,651	828,297
Textiles	1,134,912	1,150,237	1,166,966	1,181,137	1,198,202	1,213,226	1,227,976	1,242,446
Other Organics	789,626	796,405	806,131	814,374	825,170	833,430	841,483	849,324
Metals	895,907	903,660	914,912	922,135	931,101	939,441	947,537	955,389
Construction & Demolition Waste	3,656,110	3,723,107	3,784,897	3,855,120	3,926,087	3,992,675	4,058,524	4,123,596
Glass & Ceramics	1,062,727	1,072,103	1,083,343	1,092,330	1,104,021	1,113,440	1,122,566	1,131,397
Plastics	3,278,840	3,324,283	3,369,021	3,409,125	3,456,895	3,499,564	3,541,437	3,582,494
Other Inorganic Waste	3,659,925	3,682,103	3,705,570	3,721,547	3,757,547	3,778,743	3,798,844	3,817,850
Total	**29,056,444**	**29,233,783**	**29,403,635**	**29,565,308**	**29,718,429**	**29,863,006**	**29,998,706**	**30,125,562**
Biodegradable Waste	16,502,936	16,528,526	16,545,891	16,565,051	16,542,777	16,539,143	16,529,798	16,514,835

Table C.5 : Solid waste tonnages for each material as model input for scenario 1 (5/5) (2035 – 2040).

(tonnes/year)	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Foodwaste	4,509,761	4,342,799	4,173,236	4,001,284	3,827,097	3,650,840
Paper & Cardboard	8,306,034	8,413,156	8,518,216	8,621,231	8,722,113	8,820,792
Garden Waste (Green Waste)	248,483	249,741	250,925	252,036	253,074	254,039
Wood Waste	478,608	480,290	481,823	483,213	484,458	485,559
Ruber, Leather, Bones, Straw	837,744	846,976	855,990	864,789	873,365	881,713
Textiles	1,256,616	1,270,464	1,283,985	1,297,183	1,310,047	1,322,569
Other Organics	856,945	864,330	871,478	878,395	885,074	891,511
Metals	962,982	970,305	977,355	984,138	990,651	996,887
Construction & Demolition Waste	4,187,816	4,251,090	4,313,385	4,374,703	4,434,989	4,494,200
Glass & Ceramics	1,139,920	1,148,118	1,155,990	1,163,544	1,170,775	1,177,677
Plastics	3,622,683	3,661,938	3,700,245	3,737,618	3,774,024	3,809,440
Other Inorganic Waste	3,835,728	3,852,430	3,867,965	3,882,369	3,895,632	3,907,749
Total	**30,243,321**	**30,351,637**	**30,450,593**	**30,540,503**	**30,621,298**	**30,692,977**
Biodegradable Waste	16,494,192	16,467,756	16,435,654	16,398,131	16,355,228	16,307,022

APPENDIX D

Table D.1 : Solid waste tonnages for each material as model input for scenario 2 (1/5) (2003 – 2010).

(tonnes/year)	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Foodwaste	8,245,648	7,894,370	8,075,765	7,900,518	7,834,272	7,359,757	7,559,266	7,430,628
Paper & Cardboard	4,635,711	4,580,148	4,842,108	4,888,113	5,016,240	4,861,286	5,166,449	5,213,396
Garden Waste (Green Waste)	188,682	184,396	192,552	192,434	194,767	187,180	196,548	194,959
Wood Waste	380,588	370,967	387,007	389,367	391,492	375,142	393,546	392,217
Ruber, Leather, Bones, Straw	504,901	498,596	525,608	528,971	541,278	524,709	553,894	558,937
Textiles	757,352	747,894	788,413	793,456	811,918	787,063	830,840	838,406
Other Organics	567,099	557,057	585,276	591,883	600,078	578,816	609,664	615,451
Metals	661,899	646,936	685,134	687,182	697,026	670,667	705,051	709,581
Construction & Demolition Waste	2,121,140	2,099,199	2,222,716	2,256,326	2,318,553	2,253,969	2,399,474	2,431,702
Glass & Ceramics	787,418	778,905	814,717	820,329	838,494	806,719	851,444	851,853
Plastics	2,199,207	2,169,480	2,284,444	2,303,284	2,354,685	2,279,894	2,415,410	2,433,878
Other Inorganic Waste	2,948,599	2,889,344	3,016,261	3,017,613	3,056,196	2,939,377	3,083,413	3,077,020
Total	**23,998,245**	**23,417,291**	**24,420,000**	**24,369,477**	**24,655,000**	**23,624,579**	**24,765,000**	**24,748,029**
Biodegradable Waste	15,279,981	14,833,428	15,396,728	15,284,742	15,390,046	14,673,952	15,310,207	15,243,995

Table D.2 : Solid waste tonnages for each material as model input for scenario 2 (2/5) (2011 – 2018).

(tonnes/year)	2011	2012	2013	2014	2015	2016	2017	2018
Foodwaste	7,180,443	6,930,258	6,680,073	6,429,888	6,179,702	5,493,069	4,806,435	4,119,802
Paper & Cardboard	5,037,864	4,862,332	4,686,800	4,511,268	4,335,736	3,853,987	3,372,239	2,890,491
Garden Waste (Green Waste)	188,394	181,830	175,266	168,702	162,138	144,122	126,107	108,092
Wood Waste	379,012	365,806	352,600	339,395	326,189	289,946	253,702	217,459
Ruber, Leather, Bones, Straw	540,118	521,299	502,480	483,661	464,842	413,193	361,544	309,895
Textiles	810,178	781,949	753,720	725,492	697,263	619,789	542,316	464,842
Other Organics	594,729	574,007	553,285	532,563	511,841	454,970	398,099	341,228
Metals	715,889	738,689	741,849	750,915	773,549	781,774	791,516	810,136
Construction & Demolition Waste	2,459,979	2,566,458	2,618,201	2,693,266	2,796,037	2,882,804	2,951,895	3,015,392
Glass & Ceramics	853,473	879,070	891,486	904,648	926,653	937,224	948,812	960,246
Plastics	2,442,899	2,526,896	2,574,278	2,629,818	2,706,000	2,757,483	2,806,374	2,851,227
Other Inorganic Waste	3,070,709	3,148,244	3,182,015	3,226,461	3,296,811	3,346,928	3,374,367	3,402,334
Total	**24,273,687**	**24,076,838**	**23,712,054**	**23,396,075**	**23,176,761**	**21,975,289**	**20,733,405**	**19,491,143**
Biodegradable Waste	14,730,738	14,217,481	13,704,224	13,190,968	12,677,711	11,269,076	9,860,442	8,451,807

Table D.3 : Solid waste tonnages for each material as model input for scenario 2 (3/5) (2019 – 2026).

(tonnes/year)	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**
Foodwaste	3,943,239	3,766,676	3,590,113	3,413,550	3,236,987	3,060,424	2,883,861	2,883,861
Paper & Cardboard	2,766,612	2,642,734	2,518,856	2,394,978	2,271,100	2,147,222	2,023,343	2,023,343
Garden Waste (Green Waste)	103,459	98,827	94,194	89,562	84,929	80,297	75,664	75,664
Wood Waste	208,139	198,820	189,500	180,180	170,861	161,541	152,221	152,221
Ruber, Leather, Bones, Straw	296,613	283,332	270,051	256,770	243,489	230,207	216,926	216,926
Textiles	444,920	424,998	405,077	385,155	365,233	345,311	325,389	325,389
Other Organics	326,604	311,979	297,355	282,731	268,107	253,483	238,859	238,859
Metals	813,877	818,290	832,277	844,065	854,562	864,864	878,260	887,737
Construction & Demolition Waste	3,089,551	3,172,076	3,244,444	3,323,327	3,387,759	3,446,089	3,512,820	3,583,219
Glass & Ceramics	971,225	982,049	988,792	1,002,374	1,012,342	1,032,304	1,042,554	1,052,616
Plastics	2,899,211	2,933,164	2,990,478	3,034,860	3,074,641	3,141,023	3,188,905	3,235,689
Other Inorganic Waste	3,432,840	3,460,402	3,488,704	3,512,363	3,535,100	3,585,706	3,607,969	3,629,968
Total	**19,296,291**	**19,093,348**	**18,909,840**	**18,719,915**	**18,505,110**	**18,348,472**	**18,146,772**	**18,305,493**
Biodegradable Waste	8,089,587	7,727,367	7,365,146	7,002,926	6,640,706	6,278,485	5,916,265	5,916,265

Table D.4 : Solid waste tonnages for each material as model input for scenario 2 (4/5) (2027 – 2034).

(tonnes/year)	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Foodwaste	2,883,861	2,883,861	2,883,861	2,883,861	2,883,861	2,883,861	2,883,861	2,883,861
Paper & Cardboard	2,023,343	2,023,343	2,023,343	2,023,343	2,023,343	2,023,343	2,023,343	2,023,343
Garden Waste (Green Waste)	75,664	75,664	75,664	75,664	75,664	75,664	75,664	75,664
Wood Waste	152,221	152,221	152,221	152,221	152,221	152,221	152,221	152,221
Ruber, Leather, Bones, Straw	216,926	216,926	216,926	216,926	216,926	216,926	216,926	216,926
Textiles	325,389	325,389	325,389	325,389	325,389	325,389	325,389	325,389
Other Organics	238,859	238,859	238,859	238,859	238,859	238,859	238,859	238,859
Metals	895,907	903,660	914,912	922,135	931,101	939,441	947,537	955,389
Construction & Demolition Waste	3,656,110	3,723,107	3,784,897	3,855,120	3,926,087	3,992,675	4,058,524	4,123,596
Glass & Ceramics	1,062,727	1,072,103	1,083,343	1,092,330	1,104,021	1,113,440	1,122,566	1,131,397
Plastics	3,278,840	3,324,283	3,369,021	3,409,125	3,456,895	3,499,564	3,541,437	3,582,494
Other Inorganic Waste	3,659,925	3,682,103	3,705,570	3,721,547	3,757,547	3,778,743	3,798,844	3,817,850
Total	**18,469,774**	**18,621,522**	**18,774,009**	**18,916,522**	**19,091,917**	**19,240,128**	**19,385,173**	**19,526,992**
Biodegradable Waste	5,916,265	5,916,265	5,916,265	5,916,265	5,916,265	5,916,265	5,916,265	5,916,265

Table D.5 : Solid waste tonnages for each material as model input for scenario 2 (5/5) (2035 – 2040).

(tonnes/year)	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Foodwaste	2,883,861	2,883,861	2,883,861	2,883,861	2,883,861	2,883,861
Paper & Cardboard	2,023,343	2,023,343	2,023,343	2,023,343	2,023,343	2,023,343
Garden Waste (Green Waste)	75,664	75,664	75,664	75,664	75,664	75,664
Wood Waste	152,221	152,221	152,221	152,221	152,221	152,221
Ruber, Leather, Bones, Straw	216,926	216,926	216,926	216,926	216,926	216,926
Textiles	325,389	325,389	325,389	325,389	325,389	325,389
Other Organics	238,859	238,859	238,859	238,859	238,859	238,859
Metals	962,982	970,305	977,355	984,138	990,651	996,887
Construction & Demolition Waste	4,187,816	4,251,090	4,313,385	4,374,703	4,434,989	4,494,200
Glass & Ceramics	1,139,920	1,148,118	1,155,990	1,163,544	1,170,775	1,177,677
Plastics	3,622,683	3,661,938	3,700,245	3,737,618	3,774,024	3,809,440
Other Inorganic Waste	3,835,728	3,852,430	3,867,965	3,882,369	3,895,632	3,907,749
Total	**19,665,395**	**19,800,146**	**19,931,205**	**20,058,637**	**20,182,335**	**20,302,219**
Biodegradable Waste	5,916,265	5,916,265	5,916,265	5,916,265	5,916,265	5,916,265

APPENDIX E

Table E.1 : Solid waste tonnages for each material as model input for scenario 3 (1/5) (2003 – 2010).

(tonnes/year)	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Foodwaste	8,245,648	7,894,370	8,075,765	7,900,518	7,834,272	7,359,757	7,559,266	7,430,628
Paper & Cardboard	4,635,711	4,580,148	4,842,108	4,888,113	5,016,240	4,861,286	5,166,449	5,213,396
Garden Waste (Green Waste)	188,682	184,396	192,552	192,434	194,767	187,180	196,548	194,959
Wood Waste	380,588	370,967	387,007	389,367	391,492	375,142	393,546	392,217
Ruber, Leather, Bones, Straw	504,901	498,596	525,608	528,971	541,278	524,709	553,894	558,937
Textiles	757,352	747,894	788,413	793,456	811,918	787,063	830,840	838,406
Other Organics	567,099	557,057	585,276	591,883	600,078	578,816	609,664	615,451
Metals	661,899	646,936	685,134	687,182	697,026	670,667	705,051	709,581
Construction & Demolition Waste	2,121,140	2,099,199	2,222,716	2,256,326	2,318,553	2,253,969	2,399,474	2,431,702
Glass & Ceramics	787,418	778,905	814,717	820,329	838,494	806,719	851,444	851,853
Plastics	2,199,207	2,169,480	2,284,444	2,303,284	2,354,685	2,279,894	2,415,410	2,433,878
Other Inorganic Waste	2,948,599	2,889,344	3,016,261	3,017,613	3,056,196	2,939,377	3,083,413	3,077,020
Total	**23,998,245**	**23,417,291**	**24,420,000**	**24,369,477**	**24,655,000**	**23,624,579**	**24,765,000**	**24,748,029**
Biodegradable Waste	15,279,981	14,833,428	15,396,728	15,284,742	15,390,046	14,673,952	15,310,207	15,243,995

Table E.2 : Solid waste tonnages for each material as model input for scenario 3 (2/5) (2011 – 2018).

(tonnes/year)	2011	2012	2013	2014	2015	2016	2017	2018
Foodwaste	7,305,535	7,180,443	7,055,350	6,930,258	6,805,165	6,680,073	6,554,980	6,429,888
Paper & Cardboard	5,125,630	5,037,864	4,950,098	4,862,332	4,774,566	4,686,800	4,599,034	4,511,268
Garden Waste (Green Waste)	191,676	188,394	185,112	181,830	178,548	175,266	171,984	168,702
Wood Waste	385,615	379,012	372,409	365,806	359,203	352,600	345,997	339,395
Ruber, Leather, Bones, Straw	549,528	540,118	530,709	521,299	511,890	502,480	493,071	483,661
Textiles	824,292	810,178	796,063	781,949	767,835	753,720	739,606	725,492
Other Organics	605,090	594,729	584,368	574,007	563,646	553,285	542,924	532,563
Metals	715,889	738,689	741,849	750,915	773,549	781,774	791,516	810,136
Construction & Demolition Waste	2,459,979	2,566,458	2,618,201	2,693,266	2,796,037	2,882,804	2,951,895	3,015,392
Glass & Ceramics	853,473	879,070	891,486	904,648	926,653	937,224	948,812	960,246
Plastics	2,442,899	2,526,896	2,574,278	2,629,818	2,706,000	2,757,483	2,806,374	2,851,227
Other Inorganic Waste	3,070,709	3,148,244	3,182,015	3,226,461	3,296,811	3,346,928	3,374,367	3,402,334
Total	**24,530,315**	**24,590,095**	**24,481,939**	**24,422,589**	**24,459,903**	**24,410,437**	**24,320,559**	**24,230,303**
Biodegradable Waste	14,987,366	14,730,738	14,474,110	14,217,481	13,960,853	13,704,224	13,447,596	13,190,968

Table E.3 : Solid waste tonnages for each material as model input for scenario 3 (3/5) (2019 – 2026).

(tonnes/year)	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**
Foodwaste	6,304,795	6,179,702	5,493,069	4,806,435	4,119,802	3,943,239	3,766,676	3,590,113
Paper & Cardboard	4,423,502	4,335,736	3,853,987	3,372,239	2,890,491	2,766,612	2,642,734	2,518,856
Garden Waste (Green Waste)	165,420	162,138	144,122	126,107	108,092	103,459	98,827	94,194
Wood Waste	332,792	326,189	289,946	253,702	217,459	208,139	198,820	189,500
Ruber, Leather, Bones, Straw	474,251	464,842	413,193	361,544	309,895	296,613	283,332	270,051
Textiles	711,377	697,263	619,789	542,316	464,842	444,920	424,998	405,077
Other Organics	522,202	511,841	454,970	398,099	341,228	326,604	311,979	297,355
Metals	813,877	818,290	832,277	844,065	854,562	864,864	878,260	887,737
Construction & Demolition Waste	3,089,551	3,172,076	3,244,444	3,323,327	3,387,759	3,446,089	3,512,820	3,583,219
Glass & Ceramics	971,225	982,049	988,792	1,002,374	1,012,342	1,032,304	1,042,554	1,052,616
Plastics	2,899,211	2,933,164	2,990,478	3,034,860	3,074,641	3,141,023	3,188,905	3,235,689
Other Inorganic Waste	3,432,840	3,460,402	3,488,704	3,512,363	3,535,100	3,585,706	3,607,969	3,629,968
Total	**24,141,043**	**24,043,693**	**22,813,770**	**21,577,431**	**20,316,211**	**20,159,573**	**19,957,874**	**19,754,374**
Biodegradable Waste	12,934,339	12,677,711	11,269,076	9,860,442	8,451,807	8,089,587	7,727,367	7,365,146

Table E.4 : Solid waste tonnages for each material as model input for scenario 3 (4/5) (2027 – 2034).

(tonnes/year)	2027	2028	2029	2030	2031	2032	2033	2034
Foodwaste	3,413,550	3,236,987	3,060,424	2,883,861	2,883,861	2,883,861	2,883,861	2,883,861
Paper & Cardboard	2,394,978	2,271,100	2,147,222	2,023,343	2,023,343	2,023,343	2,023,343	2,023,343
Garden Waste (Green Waste)	89,562	84,929	80,297	75,664	75,664	75,664	75,664	75,664
Wood Waste	180,180	170,861	161,541	152,221	152,221	152,221	152,221	152,221
Ruber, Leather, Bones, Straw	256,770	243,489	230,207	216,926	216,926	216,926	216,926	216,926
Textiles	385,155	365,233	345,311	325,389	325,389	325,389	325,389	325,389
Other Organics	282,731	268,107	253,483	238,859	238,859	238,859	238,859	238,859
Metals	895,907	903,660	914,912	922,135	931,101	939,441	947,537	955,389
Construction & Demolition Waste	3,656,110	3,723,107	3,784,897	3,855,120	3,926,087	3,992,675	4,058,524	4,123,596
Glass & Ceramics	1,062,727	1,072,103	1,083,343	1,092,330	1,104,021	1,113,440	1,122,566	1,131,397
Plastics	3,278,840	3,324,283	3,369,021	3,409,125	3,456,895	3,499,564	3,541,437	3,582,494
Other Inorganic Waste	3,659,925	3,682,103	3,705,570	3,721,547	3,757,547	3,778,743	3,798,844	3,817,850
Total	**19,556,435**	**19,345,962**	**19,136,229**	**18,916,522**	**19,091,917**	**19,240,128**	**19,385,173**	**19,526,992**
Biodegradable Waste	7,002,926	6,640,706	6,278,485	5,916,265	5,916,265	5,916,265	5,916,265	5,916,265

Table E.5 : Solid waste tonnages for each material as model input for scenario 3 (5/5) (2035 – 2040).

(tonnes/year)	2035	2036	2037	2038	2039	2040
Foodwaste	2,883,861	2,883,861	2,883,861	2,883,861	2,883,861	2,883,861
Paper & Cardboard	2,023,343	2,023,343	2,023,343	2,023,343	2,023,343	2,023,343
Garden Waste (Green Waste)	75,664	75,664	75,664	75,664	75,664	75,664
Wood Waste	152,221	152,221	152,221	152,221	152,221	152,221
Ruber, Leather, Bones, Straw	216,926	216,926	216,926	216,926	216,926	216,926
Textiles	325,389	325,389	325,389	325,389	325,389	325,389
Other Organics	238,859	238,859	238,859	238,859	238,859	238,859
Metals	962,982	970,305	977,355	984,138	990,651	996,887
Construction & Demolition Waste	4,187,816	4,251,090	4,313,385	4,374,703	4,434,989	4,494,200
Glass & Ceramics	1,139,920	1,148,118	1,155,990	1,163,544	1,170,775	1,177,677
Plastics	3,622,683	3,661,938	3,700,245	3,737,618	3,774,024	3,809,440
Other Inorganic Waste	3,835,728	3,852,430	3,867,965	3,882,369	3,895,632	3,907,749
Total	**19,665,395**	**19,800,146**	**19,931,205**	**20,058,637**	**20,182,335**	**20,302,219**
Biodegradable Waste	5,916,265	5,916,265	5,916,265	5,916,265	5,916,265	5,916,265

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