


## A STUDY ON ENERGY PRODUCTION AND GHG MITIGATION POTENTIAL FROM MUNICIPAL SOLID WASTE OF EDİRNE

Betül ÖZER\*

Department of Energy Systems Engineering, Technology Faculty, Kırklareli University, Turkey, betulozer@klu.edu.tr

 <https://orcid.org/0000-0001-7540-5457>

Received: 25.06.2018, Accepted: 03.10.2018

Research Article

\*Corresponding author

DOI: 10.22531/muglajsci.447895

### Abstract

*Solid waste originated problems are one of the major environmental problems in Turkey. The Ministry of Environment and Urban Planning in The Republic of Turkey foresees a solution with the Regional Solid Waste Disposal Facilities over the associations that will be formed by more than one municipality. In this context, Edirne Solid Waste Management Association (EDİKAB) was established in order to realize waste management at regional level. In this study, the application example of EDİKAB solid waste disposal plant is evaluated. The amount of waste to be collected for the years 2020 and 2045 in the region is calculated as 94,665 tons/year and 274,497 tons/year, respectively. Solid wastes to be disposed of are classified as packing wastes to be recovered, organic wastes to be composted and wastes to be landfilled. Packaging waste will be collected separately, classified and baled in sorting plant. Landfill gas production is calculated 3.8 million m<sup>3</sup>/year and 15 million m<sup>3</sup>/year for 2020 and 2045, respectively. EDİKAB case study represents up to 90% of GHG emission reduction can be achievable in case of converting LFG into electricity, by producing 7288; 13384 and 28673 MWh cumulative electricity from 2016 to 2020, 2030 and 2045, respectively.*

**Keywords:** Municipal solid waste (MSW), bioenergy, landfill gas, waste to energy, Edirne, GHG mitigation

## EDİRNE’NİN EVSEL KATI ATIKTAN ENERJİ ÜRETİMİ VE SERA GAZI AZALTIM POTANSİYELİ ÜZERİNE BİR ÇALIŞMA

### Öz

*Katı atıkların sebep olduğu problemler Türkiye için önemli çevre sorunları arasında gelmektedir. T.C. Çevre ve Şehircilik Bakanlığı birden fazla belediyelerin oluşturacağı birlikler üzerinden Bölgesel Katı Atık Bertaraf Tesisleri ile çözüm öngörmektedir. Bu kapsamda atık yönetiminin bölgesel düzeyde gerçekleştirilmesi amacıyla Edirne Katı Atık Yönetim Birliği (EDİKAB) kurulmuştur. Bu çalışmada EDİKAB katı atık bertaraf tesisi uygulama örneği anlatılacaktır. Bölgede 2020 ve 2045 yılları için toplanacak atık miktarı sırasıyla 94,665 ton/yıl ve 274,497 ton/yıl olarak hesaplanmıştır. Bertaraf edilecek katı atıklar; geri kazanılacak ambalaj atıkları, kompost olarak değerlendirilecek organik atıklar ve düzenli depolanacak atıklar olarak sınıflandırılmıştır. Ambalaj atıkları ayrı toplanıp ambalaj atıkları ayrıştırma tesisinde sınıflanarak balyalanacaktır. 2020 yılı için 3.8 milyon m<sup>3</sup>/yıl ve 2045 yılı için 15 milyon m<sup>3</sup>/yıl depo gazı oluşacağı hesaplanmıştır. EDİKAB örneği, düzenli depolama ile elde edilecek gazın 2016 yılından itibaren 2020, 2030 ve 2045 yıllarına kadar kümülatif olarak sırasıyla 7288, 13384 ve 28673 MWh elektriğe dönüştürülmesi ile sera gazı emisyonlarında %90’a varan azaltma sağlanabileceğini göstermektedir.*

**Anahtar Kelimeler:** Evsel katı atık, biyoenerji, depo gazı, atıktan enerji üretimi, Edirne, sera gazı azaltımı

### Cite

Özer, B., (2018). "A study on energy production and GHG mitigation potential from municipal solid waste of Edirne", *Mugla Journal of Science and Technology*, 4(2), 182-190.

### 1. Introduction

Municipal solid waste (MSW) can be defined as the waste come from households, institutions such as schools and hospitals; and commercial sources consisting of everyday items such as recyclable wastes (newspaper and magazines, cans, bottles, corrugated cardboard, etc.), food scraps, appliances, hazardous wastes (batteries, light bulbs, paint boxes, etc.) domestic qualified industrial solid waste [1]. Once generated, MSW must be collected and managed via regular disposal methods.

Solid waste management can be defined as to make the waste harmless to the environment and to human health by temporarily storing where they are generated, collecting, transporting and by processing them for gaining material and energy to contribute to the economy.

Common management methods of disposal of solid wastes, include recovery for recycling, biological treatment (composting), combustion (with the resulting

energy used to generate electricity or steam in some cases), gasification, and pyrolysis or sanitary landfill.

The wastes that may be reused or recycled or converted to energy cause loss of materials or energy in case they are disposed in landfill areas. [2]. Four main strategies for Integrated Waste Management System (IWMS) are envisaged to be applied with priority order: waste minimization, material recycling (packaging waste, composting), energy recovery, regular storage, and thermal conversion (combustion, gasification, biomethane energy).

Recycling is the process of returning to production of recyclable materials in municipal solid waste via separation. Recycling of biodegradable packaging waste (such as paper and cardboard) instead of irregular or regular storage disposal method, plays an important role in the reduction of greenhouse gas emission in the waste sector. In parallel with the increase in the gross domestic product (GDP) the ratio of packaging waste in the waste stream is increasing. Accordingly, recovery of paper and cardboard at source at high rates ( $\geq 60\%$ ) will further increase the sustainability and the reduction of greenhouse gas emissions in the waste sector. Municipal solid wastes (MSW) constitute  $\sim 30\%$  by weight and  $\sim 50\%$  by volume of packaging wastes. A sustainable waste management system requires recovery of the packaging wastes via collecting separately at the source before being mixed with other wastes within the framework of an organized binary dual collection [1]. Recycling increases the service life of waste storage facilities. As a result of effective recycling, the efficiencies of composting, biomethanization and incineration plants as well as the product and ash qualities, increase. Waste management plans are designed to reduce the transmission of bio-wastes to the storage areas and to improve the efficiency of recovery of binary collection system [3].

Thermal recycling (waste incineration, gasification, pyrolysis) of solid waste is the main disposal option due to the great difficulties in selecting landfill sites in the European Union (EU). Landfill is soil-based waste disposal method and can be defined as it uses engineering principles for sanitary disposal of solid waste by confining it to the smallest area via reducing the volume [4]. Regular storage facilities (landfill sites), when designed especially to be operated by a bioreactor, the methane gas can be recovered energy with higher speed. There is no integrated waste management options, which can be applied without regular storage system. Landfill gas (LFG) produced via MSW treatment activities is a significant source of greenhouse gases (GHGs), including mostly methane. Therefore, all treatment activities of MSW can also be turned into an opportunity for reducing GHGs and energy sustainability that is known as "waste-to-energy" (WTE) [5]. In recent years, incentives for energy production from gas produced by anaerobic treatment of organic wastes has accelerated the return of such wastes to a great extent. During the process of methane production in MSW

plants, LFG is collected, treated and then used for power production purposes. A typical sanitary landfill diagram is given with Fig. 1.

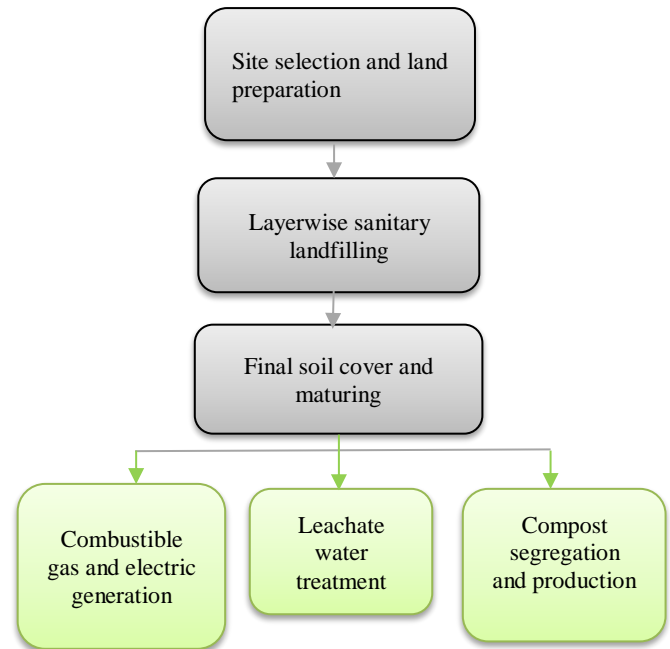


Figure 1. Flow diagram of a typical MSW plant based on sanitary landfill modified from Tozlu et.al. [5]

Incineration and landfilling methods are the most preferred technologies all over the world today due to their high energy production potentials even if there are high technology new methods are invented.

According to the current legislation in Turkey solid wastes management system must be implemented by all the municipalities. Currently, the most of municipal wastes are disposed of by regular storage method. Municipal waste delivered to landfill sites is 61.2% whereas waste delivered to municipality's dumping site 29%. According to TurkStat data, the amount of MSW collected in Turkey, as of the year 2016 is 31.584 thousand ton, 93% of the country's population, while 99% of the municipals' population benefits from waste collection services [6].

In Turkey within the scope of the legislation related to wastes below regulations are available:

- Regulation on the Regular Storage of Wastes (RRSW),
- Packaging Waste (PW) Control Regulation,
- Regulation on Waste Incineration,
- Waste Management Regulation

The most important innovation brought by the RRSW is that, in line with the EU Regular Storage Directive, the limitation of the amount of biodegradable waste to be admitted to the regular storage facility, as the comparison year for biodegradation waste reduction, instead of 1995 in the EU, RRSW 2005 is taken as basis and the reduction percentages are exactly the same.

According to the Packaging Waste Control Regulation in order to protecting of natural resources and reduce the

amount of waste to be stored, prevention of packaging waste generation, in cases where production is inevitable, reusing, recycling and recovery are essential. Additionally giving directly or indirectly, to the receiving environment in a manner that will harm the environment; and storage on landfills of packaging waste are prohibited [7].

According to data from Eurostat, municipal wastes are treated in various methods in the EU 28 in 2014. 28% are recycled, 16% are composted, 27% are incinerated and 28% are landfilled. Furthermore, among the EU countries disposal methods differ significantly, e.g. Netherlands, Germany, Denmark, Belgium, Austria, and Sweden have a share of landfilled waste below 4% [8, 9].

According to 2016 values, there were 134 sanitary landfills, 6 incineration plants, 1516 waste recovery facilities, 7 compost, and 35 co-incineration plants in Turkey. The WTE techniques applied in Turkey by 2016 is summarized in Fig. 2 [6].

MSW management, especially by the way of landfill disposal contribute to the GHG emission reduction via the replacement of fossil fuels with biogas and sustainable energy supply [10, 11]

The way of solid waste disposal in landfills may supply energy from landfill biogas utilization. In this case the organic content of the waste is important to compare the benefits of composting and LFG utilization. [12].

The number of the cities those have MSW generated biogas power plants both in Turkey and in the World are increasing due to the sustainable energy concerns.

MSW originated biogas power plants take the first place among the licensed biomass power plants in Turkey. One of the examples is in Malatya, there is a 1.2 MW power plant producing electricity from MSW that is being carried out to meet the electricity needs of 15,000 people ([13]

Turkey foresees a solution with the Regional Solid Waste Disposal Facilities over the associations that will be formed by more than one municipality. In this context, Edirne Solid Waste Management Union (EDİKAB), in which Edirne Central District, Havsa, Lalapaşa and Süloğlu District Municipalities are involved, was established in order to realize waste management at regional level.

This study comprises the municipal solid waste disposal application of The Center, Havsa, Lalapaşa and Süloğlu counties those are all in (EDİKAB), recent MSW management in EDİKAB region is displayed with the current WTE technology applied, giving some concluding remarks.

## 2. Materials and Methods

### 2.1. EDİKAB Region and MSW Generation

All counties in Edirne had own unsanitary landfill area. There are two other landfill facilities in Edirne Region. GÜNEKAB has already constructed whereas OREKAB Sanitary Landfill Area is under Construction. EDİKAB is

in the north-west side of Turkey in Marmara Region. The map of the region is given with Fig.3.

Total area of the facility that will give service for all urban and rural solid waste of the counties in the Union is 163,873 m<sup>2</sup> (16.4 ha). The facility is 1.5 km away from the nearest town. 11.3 ha is reserved for landfill lots including saddles and 2.0 ha for compost and treatment plant, with fixed facilities (including security and weighbridge, administrative building, wheel washing unit, workshop building, balancing leachate basin, packaging waste sorting facility), 2.5 ha of the area is reserved for roads and the sanitary protection band, and the remaining 0.6 ha is unavailable area which cannot be used as lot of the landfill because of the land's shape. 8 meters width protection band is created around the facility for fire protection. The main units of the facility can be mentioned as below:

1. Landfill area
2. Leachate water basin and treatment system
3. Fresh water storage pond
4. Battery and dangerous waste storage area
5. Pilot compost plant,
6. Packaging waste collection and sorting plant
7. Reserve area for medical waste treatment building
8. Anaerobic reactors
9. Electric energy generation plant

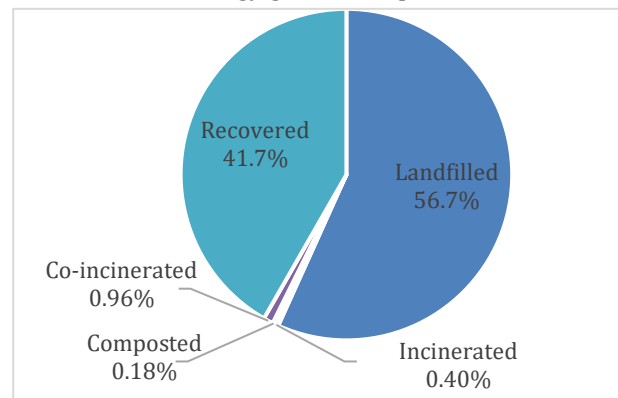


Figure 2. WTE Technics in Turkey by 2016 [6]

The total life time of the plant is projected as 30 years with 3 lots. The operation of the facility is under the responsibility of the Union and it will continue over the next 30 years. Due to minimisation of the leachate water every lot was separated into 2 cells. The plant will be the first dried fermentation applied process in Turkey. The leachate treatment plant was also designed and will be constructed according to rainfall statistics and waste data.

Population projections has been made until 2045 using various methodologies including arithmetic, geometric, exponential, İller Bank and UNDP (United Nations Development Programme) methodologies. Finally İller Bank Method is decided to be used since it is the most appropriate and used method, the results are given with Fig. 4. The population is projected approximately

300,000 in 2045. According to the projections the rural population of all districts in EDİKAB Region will have a decreasing trend. However, urban and overall population increasing as given with Figure 3. The urban population is increasing also due to migration from the rural area. The projections are consistent with the statistical data those indicate the urban populations in The Center and Havsa counties have upward trend, whereas Lalapaşa and Süloğlu have downward trend.

The amount of solid waste produced and collected by waste vehicles, extremely important in terms of establishing a solid waste management plan. The determination of the quantity plays an important role in the determination of the route of the collection vehicles, in the selection of the collection equipment, in the design of the material recovery facilities and in the determination of the disposal methods [1].



Figure 3. Project area

Characterization studies of EDİKAB municipalities in summer and winter seasons for 2008 were made and the results are given in Table 1. Waste generation was calculated as 1.30 kg/capita-day for summer and 1.37 kg/capita-day for winter in 2008 and 2011, respectively according to the actual solid waste generation and population values.

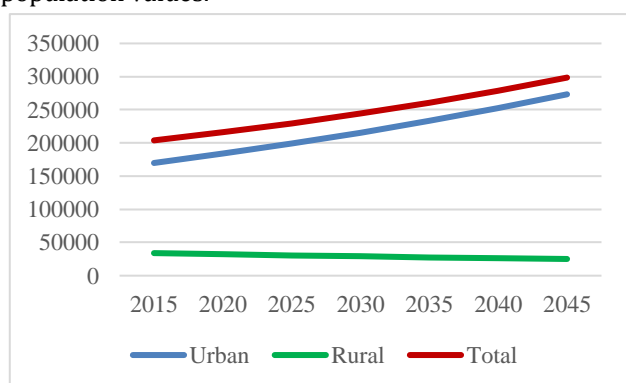


Figure 4. Population trend by İller Bank method [14]

The amount of the solid waste is larger in winter since it contains ash in higher ratio. In the various studies the unit solid waste generation is in the range of 0.80-2.01 kg/capita-day for different cities of Turkey [14]. It has

been decided to use 1.2 kg/capita-day value which is in the range and the actual value taken from İstanbul solid waste disposal plant. The urban and rural annual waste generation until 2045 is calculated with gradually increasing assumption. For the rural population including towns and villages the amount of solid waste production is estimated to be 60% of the urban unit solid waste generation. Since collection of the waste at the scattered village houses is difficult (inefficient), maximum 60% of rural waste is assumed to be collected and transferred regularly to the landfill area after the first three years of the waste collection system.

97% of the MSW will be collected by the municipality, while 3% will be recycled by recycling companies. Separately collected packaging wastes will be classified and baled in PW Sorting facility. About 33% of the total MSW in EDİKAB is packaging waste those can be recyclable. However, in the first years, since some of the packaging waste cannot be separated by the binary collection at the source, it will be mixed with other domestic wastes and sent to the storage area. In this case, until the compost plant or refuse derived fuel (RDF) plant is constructed in the landfill area the amount of waste to be stored is calculated by taking the packaging waste ratio 15%. After the composting or RDF plant will be established at the end of 2018, 28% of packaging waste will be recycled, 35% of total organic waste (that is 42% those come from kitchen, park and gardens) will be converted to fuel for compost or cement plants.

## 2.2. Solid Waste Disposal Plants

### 2.2.1. Packaging waste collection separation facility

Packaging wastes should not be sent to the landfill area and 100% of them should be recovered. Packaging Waste Management plan has been implemented since 2010 in Edirne Central District. In addition to the existing licensed packaging waste collection and separation facility in the region, a second collection separation facility will be installed on the storage area. However, the amount of packaging waste originating from the low efficiency of separate collection that is impurities in household waste (unrecovered packaging waste) was taken into account in the storage capacity.

Table 1. Characterization of MSW in EDİKAB, % (2014)

Kitchen waste	38
Paper	8
Cardboard	2
Volumed cardboard	2
Plastic	14
Glass	5
Metal	2
Park, garden and agricultural waste	4
Combustible	9.5
Ash (dust, sand and stone)	14.5
Other	1

The amount of packaging waste in the province will be 50.000 tons/year (137 tons/day) in 2030. The unit

volume weight of the extractable garbage is assumed as 0.35 ton/m<sup>3</sup> and accordingly, the volume load of the waste is calculated as 400 m<sup>3</sup>/day. 150 m<sup>3</sup>/day of this waste will be recovered in the existing licensed packaging waste collection and separation facility, whereas the remaining 250 m<sup>3</sup>/day will be recovered via the facility to be installed by EDİKAB.

### 2.2.2. Biodegradable waste management and compost plant

According to the RRSW, regular storage obligation which is under the EU criteria was imposed and the amount of the biodegradable waste to be stored has been reduced by the ratios of 2005 values: 75% in 2015, 50% in 2018, and 35% in 2025. Biodegradable waste including paper, carton, volume carton, kitchen waste, park and garden waste correspond 54% of the total waste generated in the current situation of EDİKAB.

The urban population in the EDİKAB region is 141,000, whereas rural population 38,500 in 2005. The organic waste ratio was assumed 45% in 2005. Annual waste amount was calculated according to the Eq.1 as 21,600 ton/year.

$$WA_{total} = OR \times (WA_u + WA_r) \times 365 \quad (1)$$

WA<sub>total</sub>: ton/year

OR: organic waste ratio, %

WA<sub>u</sub>: daily urban waste amount, ton

WA<sub>r</sub>: daily rural waste amount, ton

$$WA_{u/r} = P \times UWG \quad (2)$$

P: population, capita

UWG: unit waste generation, kg/capita-day

UWG is assumed 0.8 kg/capita-day for urban area, whereas it is assumed 0.48 kg/capita-day for rural area that is 60% of the urban value.

Composting is a recycling process of organic waste such as kitchen and yard wastes including leaves and vegetable scraps via decomposition under the controlled conditions, which keeps the organic waste out of landfills where take up space and release methane, that is a significant greenhouse gas and transforms the organic waste into a productive *soil amendment* [15]. Waste those will be accepted to the composting plant are:

- Biodegradable waste from households and parks-gardens
- Waste from marketplace.

The compost that becomes ready for distribution is temporarily stored, whereas residual ultimate waste after composting process will send to the sanitary landfill area. After the composting or RDF plant is constructed the amount of recovered or recycled organic waste will significantly exceed the regulation value referred to in the Table 2. Composting plant capacity will be 1045 ton/year capacity.

Table 2. Amount of organic waste that can be stored according to Regulation on the Regular Storage of Wastes (RRSW)

Year	BW* rate to be stored	BW to be produced in EDİKAB	Amount of BW to be stored**	Amount of BW to be recycled/ converted ***
		(ton/year)		
2015	75%	41,268	16,200	5,400
2018	50%	47,025	10,800	10,800
2025	35%	61,872	7,560	14,040
(*) BW: Biodegradable Waste (**) Amount of biodegradable waste that can be stored according to the Regulation = amount of biodegradable waste in 2005 (21,600 tons / year) x Biodegradable waste rate that can be stored according to the Regulation (***) Amount of biodegradable waste to be recovered / converted according to the regulation = 21,600 tons/year - amount of biodegradable waste that can be stored.				

### 2.2.3. Landfill gas (LFG) generation and disposal

Landfill gas occurs via complex chemical, physical and biological conversion processes of organic substances in the solid waste in the storage area. The basic phases of biochemical decomposition are:

- hydrolysis
- acidogenesis
- methanogenesis

processes. The rate of decomposition is dependent on pH, temperature, moisture and organic content of the litter. It is very difficult to estimate the gas quantities especially in unopened storage areas with technical measurement methods. The typical composition of a landfill gas from municipal solid waste is given in Table 3.

Table.3: Typical composition of the Municipal Solid Waste (MSW)

Component	Volume, %
Methane (CH <sub>4</sub> )	40-60
Carbon dioxide (CO <sub>2</sub> )	20-40
Nitrogen (N)	2-20
Oxygen (O <sub>2</sub> )	<1
Hydrogen Sulphur (H <sub>2</sub> S)	40-100 ppm
Non-saturated hydrocarbons	<1
Complex organics	1000-2000 ppm

After the landfill of the MSW, initially an aerobic decomposition phase begins and methane generation occurs slowly. Then, typically within less than one year, as anaerobic conditions occur and methane-generation begins to increase [16]. At the beginning, the formation of excess CO<sub>2</sub> is the result of aerobic decomposition. After that, the decomposition continues anaerobically and the composition of the gas is quite stable after about 18 months. In the anaerobic treatment process compost and

liquid fertilizer are also produced with biogas with 50-55% CH<sub>4</sub> content. After the methane content of the biogas produced from the waste has been enriched, the use as vehicle fuel is another evolving application. The typical percentages of the LFG components are given in Table 4. The amount of methane gas to be produced for the projected years can be quantified by the Eq. (3). [14, 17].

$$Gt = (1.868 \times C_{ox} (0.014 \times T + 0.28)) \times (1 - 10^{-kt}) \quad (3)$$

Gt: cumulative LFG gas production with time t, m<sup>3</sup>/t MSW

1868: the gas production rate resulting from decomposition of organic waste (m<sup>3</sup> biogas kg<sup>-1</sup> C) (note that 22.4 L biogas mol<sup>-1</sup>)/(12 g C mol<sup>-1</sup>)=1.868 L biogas g<sup>-1</sup> C)

Co: organic carbon content in MSW, (kg C/ton waste, typical production rate is 170-220 kg C/ton MSW).

t: time, year

k: decomposition constant (rate), t<sup>-1</sup>

This way Co calculation is based on the carbon content of biodegradable organic waste. The temperature-dependent decomposition rate in °C is (0.014T+0.28)

According to general observations in the landfill areas, gas production begins about 2 and 6 months. It is assumed that there is a transition period of one year between the dates MSW begin to be stored and the gas production normally begins.

The landfill gas amount for the projected years is calculated basing on the following assumptions:

- Co is assumed 200 kg organic carbon/ton MSW
- T=26°C and k is 0.03 year<sup>-1</sup>

Table 4. Typical percentage ratios of LFG

Time after the supply of the dumpster, month	Volumetric Average,%		
	Nitrogen, N <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>
0-3	5,2	88	5
3-6	3,8	76	21
6-12	0,4	65	29
12-18	1,1	52	40
18-24	0,4	53	47
24-30	0,2	52	48
30-36	1,3	46	51
36-42	0,9	50	47
42-48	0,4	51	48

The laboratory scale landfill gas curve is given with Fig. 5. The LFG (landfill gas) that can be produced in Edirne from MSW is estimated 3.8 million m<sup>3</sup> and 7.3 million m<sup>3</sup> and 15 million m<sup>3</sup> in 2020, 2030 and 2045, respectively [14]. In EDİKAB, sanitary landfill has 1.65 MW installed power for electricity generation. The plant will be the first dried fermentation applied process in Turkey.

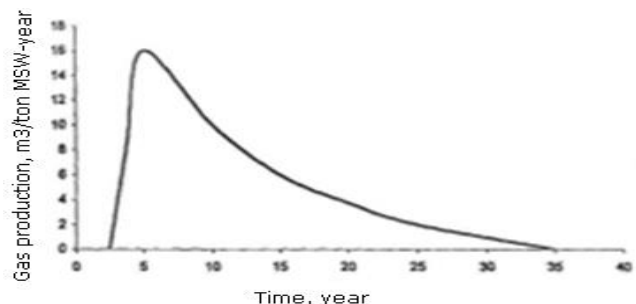


Figure 5. Typical landfill gas production curve at laboratory scale

Gas collection chimneys

Gas collection system will be built in the storage area with vertical wells. Gas chimneys will be installed 2-3 m above the laid waste on the floor of the storage area during operation.

Waste battery and hazardous waste storage area 16 m<sup>2</sup> reinforced concrete floor will be constructed for mobile battery storage placement. Over the area will be covered by corrosion resistant steel construction.

Collection and transportation of solid waste

If the amount of waste is small and the distance to the disposal area is not too far away, direct transportation of the waste is more economical. However, on a certain distance and when the waste is excessive, the solid waste transfer center is becoming more economical via transport with large tonnage vehicles. The waste quantities and the distances of the municipalities to the landfill area are given in Table 5. Havsa Municipality, which is the farthest, is 35 km and Süloğlu Municipality is 30 km away from the storage area. However, since these municipalities have a small amount of waste, they can transfer their wastes directly to the storage area. The waste of Edirne Center will be directly transferred to the landfill area with collection trucks since The Center is 8 km far away to the storage area and has the largest amount of waste. Consequently, it has been decided that there is no need for a transfer center for EDİKAB. Monitoring and Control Processes During Operation and After Shutdown will comply with the current regulations in the MSW Disposal Plant.

Considering the quantity and characteristics of the leachate, a membrane bioreactor (MBR) treatment system plant will be installed.

Table 5. MSW amount of the counties and the distances to the landfill site

	MSW Amount (2016) ton/day	Distance to the landfill area
Edirne Center	194.7	8
Havsa	13.5	35
Süloğlu	5.5	30
Lalapaşa	3.3	16

The medical wastes currently collected in the region are disposed at the Medical Waste Sterilization Facility. In the storage region, a special area that can be used for sterilization facility has been left for future landfill.

### 3. CO<sub>2</sub> emissions reduction potential

#### 3.1. Calculation of the CO<sub>2</sub> emissions from LFG

GHG emissions are calculated by using yearly based generation of CO<sub>2</sub> and CH<sub>4</sub> components of LFG given with Table 4 (those are 51% CO<sub>2</sub> and 48% CH<sub>4</sub> after the first 5 years values) for the years 2020, 2030 and 2045. 2016 is assumed as the first year of the gas collection.

Changes in the CO<sub>2</sub> emissions are compared by two scenarios. Scenario 1 can be defined as the worst case from the point of GHG emissions, in case of LFG is directly given to the atmosphere and emitting CH<sub>4</sub> and CO<sub>2</sub> where coal is the energy source for electricity production and emitting CO<sub>2</sub>. In Scenario 2, MSW-originated emissions are avoided and CO<sub>2</sub> emissions are occurring only from LFG-fired electricity generation which is offsetting coal-fired power. The possible greatest GHG reduction potential of Scenario 1 is calculated by subtracting the total CO<sub>2</sub> emissions of Scenario 2 from Scenario 1 (the largest GHG emission case).

For Scenario 1, the masses of CO<sub>2</sub> and CH<sub>4</sub> are calculated from the volumes of LFG obtained by Eq.3 and the fraction of the gasses given in Table 4 (Eq.4). The densities are assumed 0.7167 kg/m<sup>3</sup> and 1.9768 kg/m<sup>3</sup> for CH<sub>4</sub> and CO<sub>2</sub>, respectively [14].

“Carbon dioxide equivalent” (CO<sub>2</sub>e) term is used for expressing different GHGs in a common unit. Global warming potential (GWP), that is the amount of warming a gas causes over a given period of time (normally 100 years) of CH<sub>4</sub> is 28 [18]

The quantity of a GHG can be expressed as CO<sub>2</sub>e by multiplying the amount of the GHG by its GWP. Thus CO<sub>2</sub>e of CH<sub>4</sub> is calculated by multiplying the mass of CH<sub>4</sub> by 28.

$$CO_{2e} = \frac{(V_{CH_4} * d_{CH_4} * 28) + V_{CO_2} * d_{CO_2}}{1000} \quad (4)$$

CO<sub>2e</sub>: equivalent CO<sub>2</sub> emissions of CH<sub>4</sub> and CO<sub>2</sub>, ton/year

V: volume of the gas, m<sup>3</sup>/year

d: density of the gas, kg/m<sup>3</sup>

28: GWP of CH<sub>4</sub> [18]

Heating value of CH<sub>4</sub> is mentioned in the range of 35.8-37.78 MJ/Nm<sup>3</sup> in the literature [19-21]. By considering a calorific value of 36 MJ per cubic meter of CH<sub>4</sub> (36 MJ/m<sup>3</sup>) energy content of CH<sub>4</sub> (Energy content CH<sub>4</sub>) is accepted 10 kWh/m<sup>3</sup> CH<sub>4</sub> with a similar value used in Ref.[22].

The energy from CH<sub>4</sub> produced by LFG assumed to be converted to electricity with an efficiency (η) of 40% [23, 24]. The electricity that can be produced from biogas can be found with the Eq. 5.

$$E_{LFG} = V_{CH_4} * 10 * \eta \quad (5)$$

E<sub>LFG</sub>: electricity generation from LFG, kWh/year

10: Energy content of CH<sub>4</sub>, kWh/ m<sup>3</sup>CH<sub>4</sub>

η: conversion efficiency of LFG to electricity, 40%

The electricity generation by years are given with Fig. 6. The CO<sub>2</sub> emissions occurring in case of the electricity production from CH<sub>4</sub> can be calculated with the Eq.6.

$$LFG_{CO_2} = (E_{LFG} * 0.9)/1000 \quad (6)$$

LFG<sub>CO<sub>2</sub></sub>: CO<sub>2</sub> emissions from CH<sub>4</sub>-fired electricity generation ton/year

0.9: Emission factor of CH<sub>4</sub>, kg CO<sub>2</sub>/kWh [21]

To determine the amount of coal for electricity generation for Scenario 1 producing the same amount of electricity from CH<sub>4</sub> as generated in Scenario 2, the average efficiency of the conversion from coal to electricity of 33% was used in Eq. 7 [25-27].

$$CE_{CO_2} = \left( \frac{E_{LFG}}{0.33} * 1 \right) / 1000 \quad (7)$$

CE<sub>CO<sub>2</sub></sub>: CO<sub>2</sub> emissions from coal-fired electricity generation ton /year

0.33 is conversion efficiency of the coal to the electricity  
1 is emission factor of coal, kg CO<sub>2</sub>/kWh [23]

For Scenario 1 the total CO<sub>2</sub> emissions are the sum of the emissions obtained from Eq.4 and Eq.7. For Scenario 2 the CO<sub>2</sub> emissions are calculated from Eq.6 and all given with the Fig. 7. Cumulative CO<sub>2</sub> emissions from 2016 would be 62.5, 119.4 and 245.8 thousand tons in 2020, 2030 and 2045, respectively in Scenario 1, whereas 6.6, 12.5 and 26 thousand tons in 2020, 2030 and 2045, respectively in Scenario 2. The calculations indicate that 89.5% of GHG emission reduction can be achievable in case of converting LFG into electricity.

#### 4. Results and Conclusion

GHG emissions are compared by two scenarios for EDİKAB Region. In the first one that can be mentioned as the worst-case scenario (Scenario 1) GHG emissions including CH<sub>4</sub> and CO<sub>2</sub> is directly given to the atmosphere with the assumption of the municipal solid waste (MSW) of EDİKAB is not disposed by sanitary landfill method and the coal is the main energy source for electricity generation. In the Scenario 2, is the case of disposing MSW of EDİKAB by sanitary landfill method which avoids GHG and generates LFG. LFG-fired electricity generation is the only source of CO<sub>2</sub> emissions. The differences in Scenario 1 and Scenario 2 those mean reduced CO<sub>2</sub> emissions are summarized in the Fig. 8 for the years 2020, 2030 and 2045.

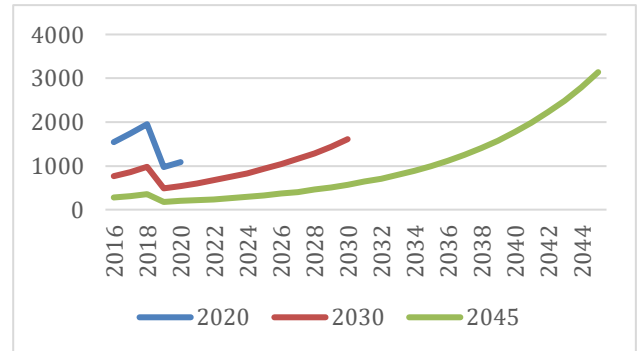


Figure 6. Electricity generation, MWh

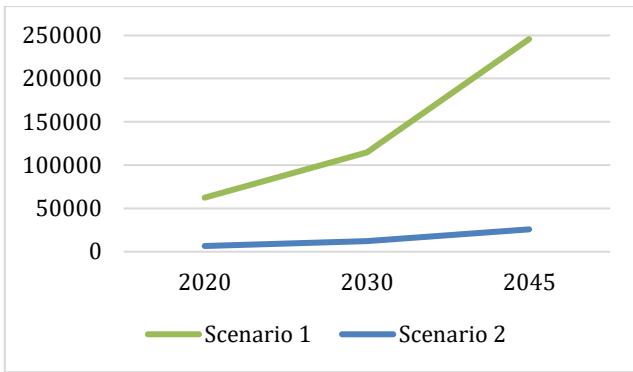


Figure 7. Cumulative CO<sub>2</sub> emissions by scenarios, ton

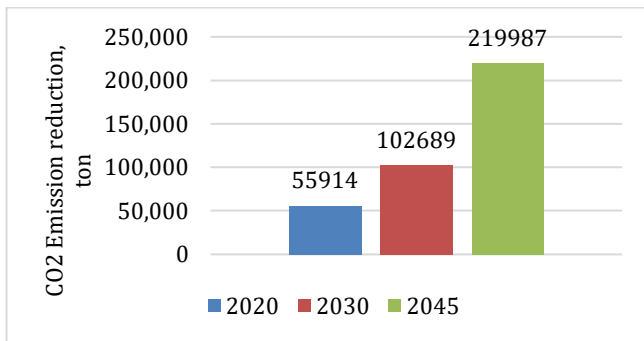


Figure 8. Cumulative reduced CO<sub>2</sub> emissions

One of the primary goals of Turkey in the waste management of the year 2023 is to reduce the amount of waste sent to the landfill area by increasing the amount of waste to be recycled, increasing the efficiency of the separate collection at the source. Besides, management of the MSW with the construction of the landfill areas to reduce the negative environmental impacts in regions where waste delivered to the dumping sites. The realization of the separate collection of the MSW at source will be economically beneficial via both composting and recycling. According to TurkStat data, the amount of municipal solid waste (MSW) collected in Turkey, as of the year 2016 is 31.584 thousand ton, 93% of the country's population, while 99% of the municipals' population benefits from waste collection services. Initially the rate of population served by municipal waste services in total population should be 100%, which is 93% in 2016. The key issues for the sanitary landfill facilities include the efficient design and efficient after-closure monitoring systems. Today's modern sanitary landfills where hazardous liquids and solid wastes are not accepted; including LFG and leachate control systems are completely different from the old open (wild) dumping areas. The storage ground should be completely impermeable and there should be an effective underground water quality monitoring system. In this sense, the EDİKAB example is suitable for principles and legislation of the sanitary landfill areas. Priority is given to the use of relatively-high energy content waste such as food waste from municipal wastes, wastes from food industry in biogas production. In EDİKAB regional planning, animal manure and agricultural waste with high energy potential should be considered.

EDİKAB case study represents up to 90% of GHG emission reduction can be achievable in case of converting LFG into electricity, by producing 7288; 13384 and 28673 MWh cumulative electricity in 2020, 2030 and 2045, respectively.

MSW segregation and utilization of waste should be implemented in the region and all over Turkey due to increase the recovery and composting of the MSW. The waste, that cannot be recycled or composted, will be sent to the landfill area. Incineration with energy recovery which is another commonly used disposal method in EU may also be considered for Turkey.

The main units including "Sorting Plant for Recyclable Materials, Leachate Treatment Unit, Compost Plant, Electric Energy Production from Landfill Gas and Anaerobic Reactors" makes the EDİKAB MSW Disposal Plant most self-financing Landfill Facility in the Thrace Region.

## 5. Acknowledgment

The author would like to thank Edirne Municipality, Mr Özgür Cengiz and Mimko Engineering Company for data supply and support to this study.

## 6. References

- [1]. Öztürk, İ., Arıkan, A. O., Altınbaş, M., Alp, K., & Güven, H. (2015). Solid Waste Conversion and Treatment Technologies (Handbook) in Turkish. Union of Municipalities of Turkey. <https://doi.org/10.1007/s13398-014-0173-7.2>
- [2]. Report on the Environment <https://www.epa.gov/roe/> Municipal Solid Waste
- [3]. The Ministry of Environment and Urbanization, Ulusal Atık Yönetimi ve Eylem Planı 2016-2023
- [4]. Barros RM, Filho GLT, da Silva TR. The electric energy potential of landfill biogas in Brazil. *Energy Policy* 2014;65: 150–64.
- [5]. Tozlu, A., Özahi, E., & Abuşoğlu, A. (2016). Waste to energy technologies for municipal solid waste management in Gaziantep. *Renewable and Sustainable Energy Reviews*, 54, 809-815. doi:10.1016/j.rser.2015.10.09
- [6]. TurkStat, waste statistics, [http://www.tuik.gov.tr/PreTablo.do?alt\\_id=1019](http://www.tuik.gov.tr/PreTablo.do?alt_id=1019)
- [7]. Packaging Waste Control Regulation, Official Gazette dated: 27.12.2017 Number: 30283
- [8]. Cucchiella, F., D'adamo, I., & Gastaldi, M. (2017). Sustainable waste management: Waste to energy plant as an alternative to landfill, *Energy Conversion and Management* 131, 18–31 <https://doi.org/10.1016/j.enconman.2016.11.012>
- [9]. Eurostat. Statistics database. Eurostat Luxembourg; 2016
- [10]. Midilli et al. 2006, Midilli, A., Dincer, I., Aya, M., 2006. Green energy strategies for sustainable development. *Energy Policy* 34, 3623–3633,
- [11]. , Barros et al. 2014. Barros, M.R., Filho, G.L.T., Silva, T. R. 2014. The electric energy potential of landfill biogas in Brazil, *Energy Policy* 65, 150–164).



- [12]. Barros (2013), Barros, R. M. 2013. The Treaty about Solid Waste: Management, Usage, and Sustainability. Rio de Janeiro, Interciência, Minas Gerais, Acta, 2013. 376p. ISBN 978-85-7193-295-1.
- [13]. Malatya İli'nde Oluşan Evsel Katı Atıklardaki Enerji Potansiyeli, Behçet, R., İlkılınc C., Oral F. 2014. ISEM, Adiyaman
- [14]. Mimko, 2014. EDİKAP, Solid Waste Disposal Facilities Application Project Report, in Turkish (Katı Atık Bertaraf Tesisleri Uygulama Projesi Raporu)
- [15]. EPA, <https://www.epa.gov/recycle/composting-home>,
- [16]. [https://www.epa.gov/sites/production/files/2016-07/documents/pdh\\_chapter1.pdf](https://www.epa.gov/sites/production/files/2016-07/documents/pdh_chapter1.pdf)
- [17]. Tabasaran, O. Rettenberger, G., 1987 Basis for the Planning of Biogas Extraction Manual German: Grundlagen zur Planung von Entgasungsanlagen Handbuch Müll und Abfall, Kennz. 4547, Lieferung 1/87, Erich Schmidt Verlag, Berlin.
- [18]. [https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5\\_Chapter08\\_FINAL.pdf](https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf)
- [19]. Şahinkaya, E., 2014.
- [20]. [http://aves.medeniyet.edu.tr/erkan.sahinkaya/dokumanlar/Anaerobic Treatment](http://aves.medeniyet.edu.tr/erkan.sahinkaya/dokumanlar/Anaerobic%20Treatment), in Turkish
- [21]. Sabuncu O, C. Technical, economical and environmental analysis of biogas production, in Turkish MSc. Thesis, Hacettepe University, 2010, Ankara, Turkey.
- [22]. Murphy, J.D., McKeogh, E., Kiely, G. Technical/economic/ environmental analysis of biogas utilisation, Applied Energy 2004;77: 407-427.
- [23]. Abdeshahian, P., Lim, J. S., Ho, W. S., Hashim, H., & Lee, C. T. Potential of biogas production from farm animal waste in Malaysia. Renewable and Sustainable Energy Reviews, 2016, 60: 714–723. <http://doi.org/10.1016/j.rser.2016.01.117>.
- [24]. Özer, B. 2017. Biogas energy opportunity of Ardahan city of Turkey, Energy 139 (2017) 1144-1152. <http://dx.doi.org/10.1016/j.energy.2017.07.052>.
- [25]. Szarka N, Scholwin F, Trommler M, Jacobi HF, Eichhorn M, Ortwein A, Thrän D. A novel role for bioenergy: A flexible, demand-oriented power supply. Energy 2013; 61:18–26. doi:10.1016/j.energy.2012.12.053
- [26]. Cuéllar, A. D.; Webber, M. E. Cow power: the energy and emissions benefits of converting manure to biogas. Environmental Research Letters, 2008; 3(3), 34002. <http://doi.org/10.1088/1748-9326/3/3/034002>.
- [27]. Virginia Energy Patterns and Trends available from <http://www.energy.vt.edu/vept/energyover/thermalconv.asp>
- [28]. Özer, B. 2012. The Scenario Analysis on CO<sub>2</sub> Emission Mitigation Potential in Turkish Electricity Sector, *PhD Thesis*, Institute of Science and Technology, İstanbul Technical University 2012., İstanbul, Turkey.