BİTLİS EREN ÜNİVERSİTESİ
FEN BİLİMLERİ DERGİSİ

ISSN: 2147-3129 / e-ISSN: 2147-3188

Article Type : Research Article
Received : June 13, 2025
Revised : October 26, 2025
Accepted : October 31, 2025
DOI : 10.17798/bitlisfen.1719185

Year : 2025
Volume : 14
Issue : 4
Pages : 2192-2213

PANORAMA OF 20 YEARS IN WASTE MANAGEMENT: TÜRKİYE'S CHANGING DISPOSAL METHODS AND THE BİTLİS EXAMPLE

Çiğdem ÖZER [1]

[1] *Bitlis Eren University, Chemistry Department, Bitlis, Türkiye, cozer@beu.edu.tr*

ABSTRACT

This study examines the transformation of municipal solid waste management in Türkiye between 2002 and 2022, using Bitlis province as a local case. Data from the Turkish Statistical Institute (TUIK) show that primitive practices such as open burning and discharge into water bodies have been almost entirely abandoned, replaced by sanitary landfilling and licensed company operations. Nevertheless, landfilling still accounted for 67% of total waste in 2022, posing environmental risks including leachate and methane emissions. Recycling rose from 5–7% in 2002 to 13% in 2022, though this remains far below the EU average of 45–50%. At the same time, per capita daily waste generation declined by 2.1% annually, reflecting the impact of prevention policies. Economic analysis indicates that disposal and transportation costs made up about 44.5% of Türkiye's environmental protection expenditures in 2022, equal to 0.65% of GDP. Statistical tests confirmed significant declines in high-risk methods such as burial and water discharge, while recycling and energy recovery showed no consistent upward trend. In Bitlis, uncontrolled dumping and open burning, once common in the early 2000s, have been replaced by sanitary landfilling and licensed disposal since the opening of a regional facility in 2018. Overall, findings reveal that Türkiye has made notable progress in reducing harmful disposal methods and expanding infrastructure. However, stronger investments in recycling, composting, and energy recovery are essential to mitigate climate impacts, strengthen the circular economy, and align with European Union waste management standards.

Keywords: Solid waste, Bitlis, Türkiye, Waste policy, The Mann-Kendall, Sen's slope.

1 INTRODUCTION

With the rapid increase in urbanization, diversification of consumption habits and widespread industrialization in the 21st century, solid waste management has emerged as a

License: CC BY-NC 4.0

critical environmental and economic problem on a global scale. In developing countries such as Türkiye, increasing population and irregular urbanization have caused serious increases in solid waste quantities; this situation has necessitated the re-evaluation of both the environmental and economic impacts of waste disposal methods [1], [2]. In Türkiye, municipal solid waste collected within city boundaries increased from approximately 25 million tons in 2002 to nearly 35 million tons in 2022 [3]. During the same period, while there was an increase in regular storage rates, it was observed that environmentally harmful methods such as open burning and uncontrolled dumping decreased [3], [4].

Solid waste management policies in Türkiye have been based on a disposal-based approach for many years, and landfills have been used as the primary method in this process [5]. However, in the following period, in line with the European Union harmonization process and environmental sustainability goals, there has been an increased tendency towards environmentally friendly disposal methods such as recycling, composting and energy recovery [6], [7]. Among the fundamental dynamics underlying this trend are the spread of circular economy principles [8], the adoption of zero waste policies [2] and the introduction of life cycle analysis in waste management [9]. The aim of solid waste disposal methods is not only to reduce the volume of waste but also the efficient use of economic resources and efforts to prevent possible damage to the environment. In this context, the changes in solid waste disposal methods in Türkiye in the two-decade period between 2002 and 2022 were not limited to technical transformation; they also had important repercussions at the environmental, economic and administrative levels [10], [11]. It is seen that methods such as recycling and composting provide long-term economic contributions to municipalities and create multidimensional effects in areas such as labor employment, raw material savings and energy production [9], [12]. In addition, applications such as planning waste transportation routes and selecting disposal facilities reveal the importance of effective use of geographic information systems and multi-criteria decision-making techniques in waste management [13], [14]. With the Zero Waste Project implemented in Türkiye (after 2017), serious steps have been taken to reduce waste production at its source, expand separation systems and support the recycling economy [2], [7]. In this process, public-private sector cooperation models, technical capacity building of local governments and use of European Union (EU) funds played an important role in the success of the transformation [10].

This study aims to examine the changes in solid waste disposal methods applied in Türkiye between 2002 and 2022 in terms of ecological and economic dimensions and to analyze

this change based on the environmental statistics of the Turkish Statistical Institute (TUIK). By monitoring the methodological changes in the mentioned period, suggestions have been developed in terms of sustainable waste management policies. In addition to literature-based evaluations, the transformation process of disposal methods over time will be addressed with a holistic approach through findings supported by graphical and statistical analyses. In particular, the changes in landfill, composting, incineration and recycling methods over the years, their environmental impacts and economic sustainability have been evaluated in the study. Supported by the Bitlis sample, it will be revealed to what extent Türkiye follows a waste management policy compatible with the circular economy and sustainable development goals.

2 MATERIAL AND METHOD

2.1 Research Method

This study examined the ecological and economic impacts of solid waste disposal methods implemented in Türkiye between 2002 and 2022 using a descriptive statistical approach combined with comparative assessment techniques. The research design primarily focused on quantitative data analysis based on official statistics provided by national and international institutions. Annual municipal waste data from the Turkish Statistical Institute constituted the core dataset, while complementary information from sources such as Eurostat, the OECD, and the European Environment Agency was also used to strengthen the comparative dimension of the analysis.

The methodology comprised several stages. First, the raw data were organized and normalized using Microsoft Excel to ensure comparability across years. Then, time-series analyses were conducted to identify long-term changes in disposal methods such as landfilling, recycling, composting, and incineration. Graphical tools and tabular summaries were used to clearly visualize trends. Comparative ratio analysis was used to assess the proportional distribution of different disposal methods over time, while per capita waste and cost indicators were calculated to demonstrate the economic impacts.

Nonparametric methods were used to test the statistical significance of the observed patterns. Integrating trend analysis with economic cost calculations provided a more holistic assessment of waste management performance. Overall, this multilayered methodological framework enabled a systematic examination of both ecological sustainability and economic efficiency aspects over a two-decade period.

2.2 Data Sources

The basic data set used in the study was obtained from environmental statistics published by TUIK: municipal waste statistics (2002–2022), solid waste disposal facilities statistics, annual data on recycling and landfill rates, per capita waste production and disposal costs of municipalities [3].

These data which were accessed through the official online data portal of TUIK [5] were downloaded on an annual basis and then organized in Excel, and then Microsoft Excel graphic tools were used for analysis. In addition, comparative data on Türkiye from institutions such as the European Environment Agency (EEA) [4], Eurostat [15] and OECD [16] were used as supporting sources.

2.3 Analysis Method

The following analysis techniques were applied to the data:

Time-Dependent Trend Analysis: The proportional change in disposal methods for the period 2002–2022 was presented graphically.

Comparative Ratio Analysis: The changes in regular storage, recycling, composting and other methods were compared over the years.

Waste and Cost Analysis Per Capita: Economic evaluation was made with data normalized by population.

International Comparison: Türkiye's disposal methods were compared with the European Union averages and Türkiye's situation was evaluated.

Statistical Analyses: The Mann-Kendall test is a nonparametric statistical test developed to test for the presence of monotonic trends in time series. Sen's slope is a nonparametric estimation method used to measure the magnitude of a trend in a time series. The Mann-Kendall test was applied to assess the statistical significance of the trend in the temporal change data of solid waste disposal methods across Türkiye and Bitlis, and Sen's slope analyses were applied to quantify the magnitude and direction of the trend. The combination of these methods increased the validity and reliability of the study [17].

The test used a Z-test statistic to determine trends. A positive Z value signifies an increasing trend, while a negative Z value signifies a decreasing trend. The equation 1 is used for the Z-test statistic applied in this study [17].

$$Z = S - 1/\sqrt{VAR(S)} \qquad if\ S > 0$$
$$Z = 0 \qquad if\ S = 0 \tag{1}$$
$$Z = S + 1/\sqrt{VAR(S)} \qquad if\ S < 0$$

where VAR(S) is a Variance of the Mann-Kendall and the S variance can be calculated using equation 2 [17].

$$\mathrm{VAR(S)} = \frac{1}{18\left[\mathrm{n(n\ -1)(2n\ +5)}\sum t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right]} \tag{2}$$

The formula for Sen's slope is shown in equation 3 [17].

$$Q = {}^{x_j\ -\ x_k}/_{j\ -\ k} \tag{3}$$

where Q is the estimated value of Sen's slope, while xj and xk are the data values at times j and k.

2.4 Limitations

The limitations of this study include the lack of micro-scale data for some years, and the comparability problems created by methodological changes in the TUIK data sets. In addition, the fact that the study is based only on official institution data limits its capacity to reflect the differences in the practices of local governments in detail.

3 RESULTS AND DISCUSSION

3.1 Time-Dependent Trend Analysis

According to TUIK data, there have been significant changes in municipal waste management in Türkiye between 2002 and 2022. The analysis was based on three basic disposal methods:

The amount of waste sent to waste treatment facilities (recycling, composting, incineration); As seen in Figure 1a, the amount of waste sent to facilities increased by 250%, from 7 430 thousand tons in 2002 to 26 017 thousand tons in 2022. The largest increase occurred in the 2010-2016 period (13 941 thousand tons to 22 430 thousand tons). This period can be associated with investments in waste management infrastructure during the EU harmonization

process. [3]. The rate of increase has slowed down after 2018, suggesting that investments have reached saturation.

Municipal landfills: Landfills decreased from 16 310 thousand tons in 2002 to 4 093 thousand tons in 2022 (75% decrease). The decrease is especially noticeable after 2010. This can be explained by the impact of EU policies such as the "landfill tax" [15].

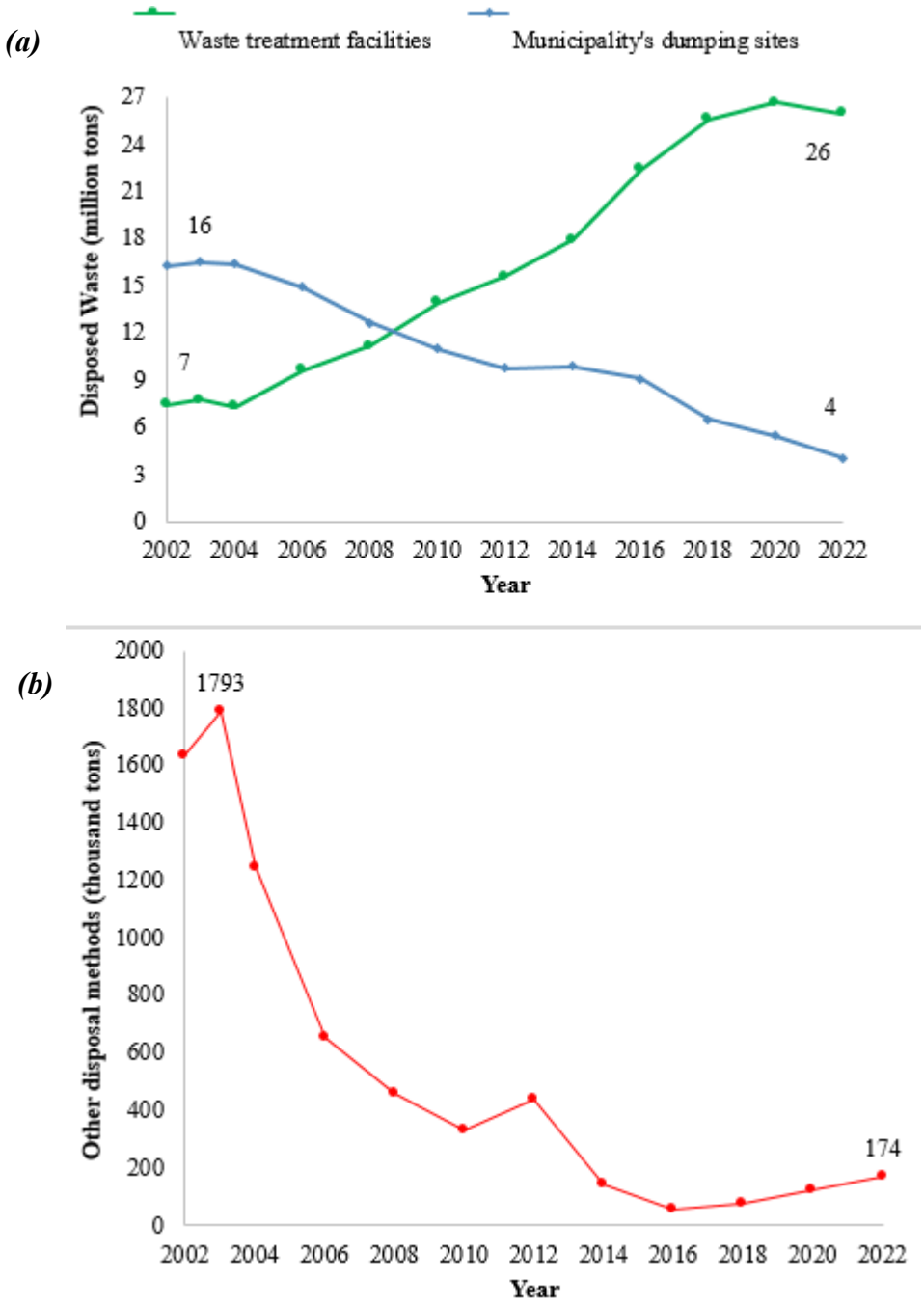


Figure 1. Temporal changes in disposal methods in Türkiye, (a) Waste treatment facilities, (b) Municipality's dumping sites.

Other methods (open burning, dumping into streams, etc.); Environmentally harmful methods such as open burning and dumping into streams, which were 1 634 thousand tons in 2002, decreased to 174 thousand tons in 2022 (89% decrease). The most dramatic decrease was seen between 2005-2014 (656 thousand tons to 141 thousand tons). This was associated with the strengthening of control mechanisms by local governments [18]. It is thought that the slight increase observed between 2020 and 2022 (124 thousand tons to 174 thousand tons) may be due to disruptions in waste collection services in rural areas (Figure 1b).

3.2 Comparative Ratio Analysis

The changes in solid waste disposal in Türkiye during this period are a telling indicator of policy and infrastructure developments aimed at environmental sustainability. The increase in the rate of landfilling and the decrease in environmentally risky disposal methods are noteworthy (Figure 2). A decrease in the graphs presented using the comparative ratio method indicates a decrease in the amount of waste disposed of using that method. The purpose of this study is to reveal the relative distribution and trends among preferred disposal methods rather than capacity analysis. The data in Figure 2a (other disposal methods) show that in 2002, wild disposal methods (burning, burying, discharge to surface waters and other methods) had an important place. For example, while “discharge to surface waters” was 11% (69 828 tons/year) and “open burning” was approximately 38% (246 548 tons/year) in 2006, a significant decrease was observed in these methods after 2014; as of 2020, discharge to surface waters almost completely ended and the open burning rate fell below 15% (19 024 tons/year). This change shows that traditional methods are being abandoned with infrastructure investments and increased environmental awareness [19], [20]. The “other disposal methods” in the TUIK data, under the heading “other disposal methods”, refers to practices that fall outside of standard methods. It is thought that this heading includes both situations where more than one method is used together and local practices that are not fully defined in the legislation. In addition, uncontrolled methods such as temporary storage, dumping on open land and situations with data deficiency or uncertainty are also included in this category. Therefore, “other disposal methods” are evaluated as a group reflecting both administrative confusion and reporting deficiencies.

According to the data in Figure 2b (sent to waste processing facilities), while the regular landfill rate was approximately 95% in 2002, this rate increased until 2014 and reached 98%. However, this rate decreased after 2016 and fell to approximately 84% in 2020.

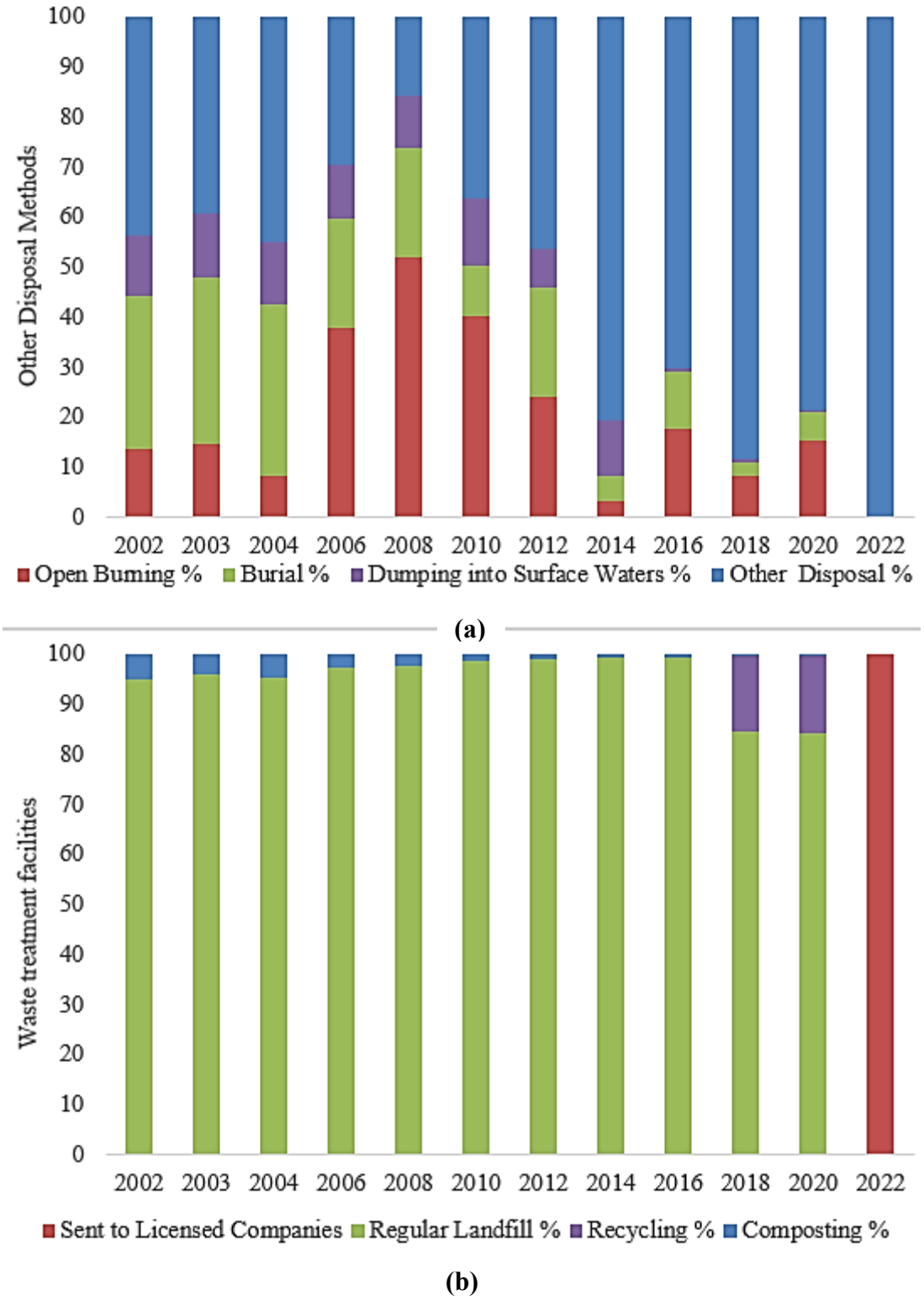


Figure 2. Comparative rate analysis of disposal methods in Türkiye, (a) Other disposal methods, (b) Waste treatment facilities.

This decrease is parallel to the increase in the recycling rate in the same years. The recycling rate, which was below 1% in 2016, exceeded 15% in 2020. The composting rate, however, has remained stable or even declined over the years. In 2022, all of the waste sent to waste

processing facilities was sent to licensed companies, which shows that Türkiye is focusing on waste management policies in the European Union harmonization process and strengthening its recycling infrastructure in line with the principles of the circular economy [21], [22].

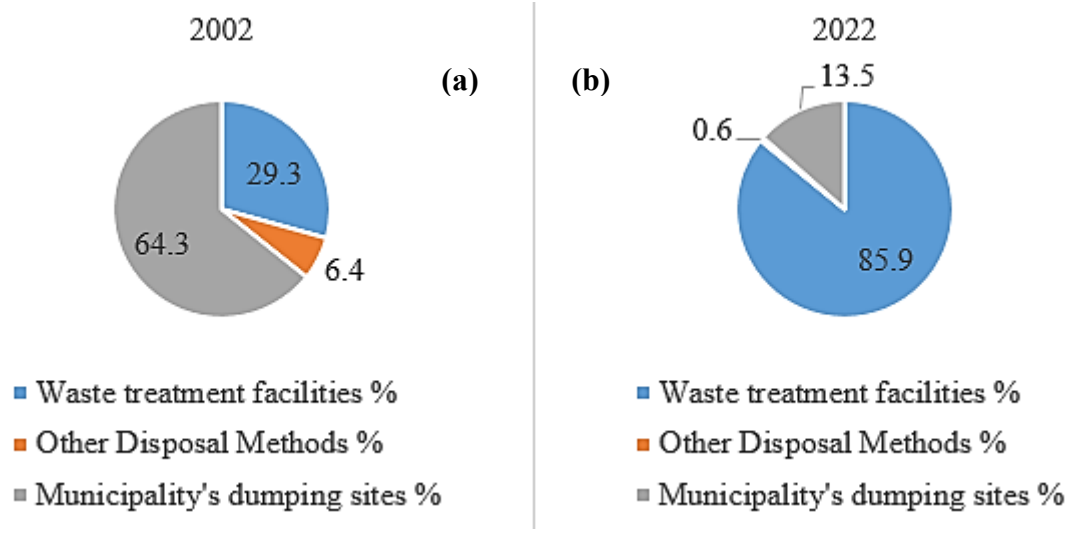


Figure 3. Comparative distribution of waste disposal methods in 2002 (a) and 2022 (b).

The significant increase observed in the proportion of waste treatment facilities among all disposal methods from 2002 to 2022 (Figure 3) is paralleled by investments in waste management infrastructure in developing countries, according to World Bank data [22]. European Environment Agency reports [23], [24] have also documented the decrease in landfill rates and the increase in recycling and treatment rates in EU countries since the 2000s. Similarly, in many developing countries, the use of municipal landfills has declined as the environmental costs of landfilling in urban waste management have become better understood [25]. The Waste Management Regulation, which came into force in Türkiye in 2008, has an undeniable effect on this decline [7]. The analysis of the 20-year timeframe demonstrates an evolution in waste management approaches.

It can be said that Türkiye's solid waste management is transitioning from a landfill-centered system to one that emphasizes recycling and environmental sustainability. However, the low composting rate indicates that the potential for organic waste recovery remains underutilized. In 2022, landfilling still accounted for 13.5% of waste disposal methods (Figure 3b), a figure that remains above the EU's target of reducing landfill rates to below 10%. Although progress toward more sustainable methods continue, further infrastructure investments are needed, particularly in developing regions. Similar transitions in European countries, following the implementation of EU directives, have led to significant increases in recycling rates [26], [27].

3.3 Waste and Cost Analysis Per Capita

During the period from 2002 to 2022, Türkiye exhibited a clear downward trend in daily per capita waste generation (Table 1). While OECD countries reported an average annual reduction of 1.3% [16], Türkiye outperformed this average with a decline rate of 2.1% per year. Despite a significant population increase—from 67.8 million in 2002 to 85.3 million in 2022—the total volume of waste rose only marginally, from 30 999 million tons to 32 422 million tons per year (a 7.8% increase). Given the 25.8% population growth over the same period, this limited rise in total waste generation can be considered a notable achievement. The decline in per capita waste production reflects the positive impact of waste prevention and reduction policies [28].

Table 1. Türkiye's annual population and waste data [5]

Year	Türkiye population	Amount of municipal waste collected (Thousand tons/year)	Average amount of municipal waste per capita (Kg/capita-day)
2002	67 803 927	25 373	1.34
2003	67 803 927	26 118	1.38
2004	67 803 927	25 014	1.31
2006	70 586 256	25 280	1.21
2008	70 586 256	24 361	1.15
2010	73 722 988	25 277	1.14
2012	75 627 384	25 845	1.12
2014	77 695 904	28 011	1.08
2016	79 814 871	31 584	1.17
2018	82 003 882	32 209	1.16
2020	83 614 362	32 324	1.13
2022	85 279 553	30 284	1.03

Table 2 was created to examine waste management in terms of costs. Although disposal costs may vary depending on waste disposal methods, capacity, technology, local labor and infrastructure investments [29], the following ranges were used as references: for landfill: 20-50 USD/ton, for recycling: 20-40 USD/ton and for composting: 13-50 USD/ton [30].

Table 2. Türkiye municipal waste management cost analysis for 2022

Cost Item	Calculation Details	Amount (USD)
COLLECTION & TRANSPORTATION COST		
Total Waste Amount	30 284 000 tons	
Unit Transportation Cost	34 USD/ton	
Total Transportation Cost	30 284 000 tons x 34 USD/ton	**~1 030 000 000**
DISPOSAL COST		
1. Landfill		
Waste Amount	21 863 452 tons	
Unit Cost (Average)	35 USD/ton	
Total Cost	21 863 452 tons x 35 USD/ton	765 220 810
2. Recycling		
Waste Amount	4 039 110 tons	
Unit Cost (Average)	30 USD/ton	
Total Cost	4 039 110 tons x 30 USD/ton	121 173 303
3. Composting		
Waste Amount	114 426 tons	
Unit Cost (Average)	30 USD/ton	
Total Cost	114 426 tons x 30 USD/ton	3 432 785
Total Disposal Cost	765 220 810 + 121 173 303 + 3 432 785	**~889 826 899**

In 2022, the total municipal solid waste disposal costs in Türkiye (including landfill, recycling, and composting operations) were estimated at approximately US$0.89 billion. Since the Turkish Statistical Institute (TUIK) did not separate the 2022 data into landfill, recycling, and composting categories, the calculation was based on data from "waste sent to processing facilities" using 2020 rates. The amount of waste sent to processing facilities in 2022 was stated as 26 017 thousand tons [3]. Applying an uncertainty range of ±US$15 per ton to the total amount of 26 million tons of waste to account for regional cost variations (e.g., differences in labor, energy, and infrastructure), the total cost variation becomes approximately ±US$390 million, and the estimated disposal cost range is found to be ~US$0.50–1.28 billion. The total disposal cost (transportation cost + disposal cost) for 2022 was calculated as US$2.31 billion. Using the average exchange rate for 2022 (US$1 ≈ 16.57 TL), a value of 38.3 billion TL was obtained.

TUIK data indicate that 60.9% (85.44 billion TL) of Türkiye's total environmental protection expenditures (140.3 billion TL) in 2022 were directed to waste management [31]. Calculations show that 44.8% of these waste management expenditures were allocated solely to disposal activities. Total environmental protection expenditures in 2022 correspond to approximately 0.93% of GDP. While the average environmental protection expenditures for

2022 in the OECD were between 1-1.5% of GDP, the EU's sustainable development target is at least 1.2% [16], [23].

For Türkiye, this difference stems from a multitude of simultaneous factors such as legal frameworks, institutional capacity, economic priorities and socio-cultural dynamics. The main legislation and national action plan regulating waste management in Türkiye have been developed over the last 15–20 years; however, there are gaps between the existence of legislation and its implementation on the ground. While tightening legislation and EU harmonization efforts have led to significant progress, enforcement capacity and oversight mechanisms have not developed to the same extent across regions. This has limited the efficient use of public resources and long-term budget commitments [32]. Waste management services are fragmented among multiple actors (municipalities, special provincial administrations, licensed private companies, and public institutions); when task/funding allocations are unclear, investment priorities and sustainable financing become difficult. This institutional fragmentation impacts municipalities' budgeting capacity and long-term investment planning [33].

There are significant disparities among municipalities in Türkiye in terms of technical capacity, human resources, and financial strength; small or rural municipalities, in particular, struggle to invest in waste infrastructure. Such disparities hinder increased resource allocation at the central level and are reflected in the effective share of overall environmental expenditures in GDP. The budgetary pressures and efficiency analyses of waste management in municipal services have also been highlighted in local studies [33]. TUIK reports and sector assessments indicate that a significant portion of environmental protection expenditures (especially investment expenditures) are carried out by companies. This structure limits the direct investment responsibility of the public sector and can create service inequalities when regulatory frameworks and incentive mechanisms are inadequate [31].

In rapidly growing countries like Türkiye with infrastructure needs, budget priorities (infrastructure, health, education, energy) can influence the rate of environmental investment. Furthermore, the ratio of environmental allocations to GDP is related to both real resources and budgetary choices; economic fluctuations, inflation, and exchange rate fluctuations can increase the costs of environmental investment projects and reduce real investment capacity. Some OECD/EU countries have developed regular budget allocations and green fund mechanisms for the environment; the lack of such mechanisms contributes to Türkiye's lower sustainable expenditure profile relative to GDP. Furthermore, OECD data shows that environmental tax

incentives vary across countries and that developed market instruments (e.g., environmental taxes, waste fees) can be effective sources of financing. Limited or untargeted use of these instruments can also constrain the regular financing of sustainable environmental expenditures [34].

Increasing recycling and source separation rates requires long-term public education, fieldwork, and incentives. While programs like Zero Waste have yielded positive results, implementation and public participation are heterogeneous across cities and even districts, making rapid improvements at the national level difficult [35].

3.4 International Benchmarking

Data from TUIK and Eurostat reveal that Türkiye falls behind the European Union (EU) average when it comes to waste disposal practices. While EU countries tend to follow a waste management hierarchy that emphasizes recycling and energy recovery, landfilling is still the most widely used method in Türkiye [5], [15]. Nevertheless, the impact of EU policies on

Table 3. Key waste management policies in Türkiye and EU (2002–2022)

Period	Türkiye – Key Policies	EU – Key Policies	Impact / Notes
2002–2005	First municipal waste statistics published by TÜİK. Waste disposal mainly through uncontrolled landfills and open dumping.	*Landfill Directive* 1999/31/EC (in force since 1999) – restrictions on biodegradable waste to landfill.	Türkiye began preparing for EU environmental acquis alignment.
2008	Waste Management Regulation, Official Gazette No. 26927, 2008) – legal framework for sanitary landfilling, reporting, and monitoring.	*Waste Framework Directive* 2008/98/EC – introduction of the waste hierarchy (prevention, reuse, recycling, recovery, disposal).	Acceleration of sanitary landfill investments in Türkiye; EU emphasizes prevention and recycling.
2010–2014	Large-scale sanitary landfill construction with EU IPA funds; closure of many wild dumps.	Strengthening of the *Landfill Directive* and implementation of landfill taxes in several member states.	Sharp decline in uncontrolled disposal in Türkiye.
2017	Launch of the Zero Waste Project, led by Ministry of Environment – mandatory source separation in public institutions, incentives for municipalities.	*EU Circular Economy Package* (2015–2018) – recycling targets: 55% by 2025, 60% by 2030.	Türkiye moves toward recycling infrastructure; EU sets ambitious long-term targets.
2020–2022	Increased use of licensed waste companies.	*European Green Deal* (2019) – target to reduce landfill to <10% by 2030; *Circular Economy Action Plan* (2020).	Türkiye landfill rate still ~67% (2022), above EU average (23%). Recycling at 13%, below EU's 48%.

developments in Türkiye during the period under review is evident. Key developments and interactions in solid waste management policy during this period are summarized in Table 3 [36]–[39].

According to 2022 data given in Figure 4, 67% of municipal waste in Türkiye was disposed of in regular landfills [5]. In the EU, this rate is 23% on average, and is almost zero in countries such as Austria (2%), Germany (0%) and Belgium (1%) [15]. This situation shows that Türkiye is far behind the EU's target of reducing landfills to less than 10% by 2030. In EU countries, an average of 48% of municipal waste is recycled, while 17% is composted [15]. In Türkiye, the recycling rate is 13% and the composting rate is only 1% [3]. This difference points to the inadequacy of source separation and recovery infrastructure in Türkiye [40]. While 26% of waste in the EU is converted into energy in incineration plants, this rate is around 1% in Türkiye [3], [15]. The low number of waste incineration facilities for energy production in Türkiye reveals the deficiency in this area.

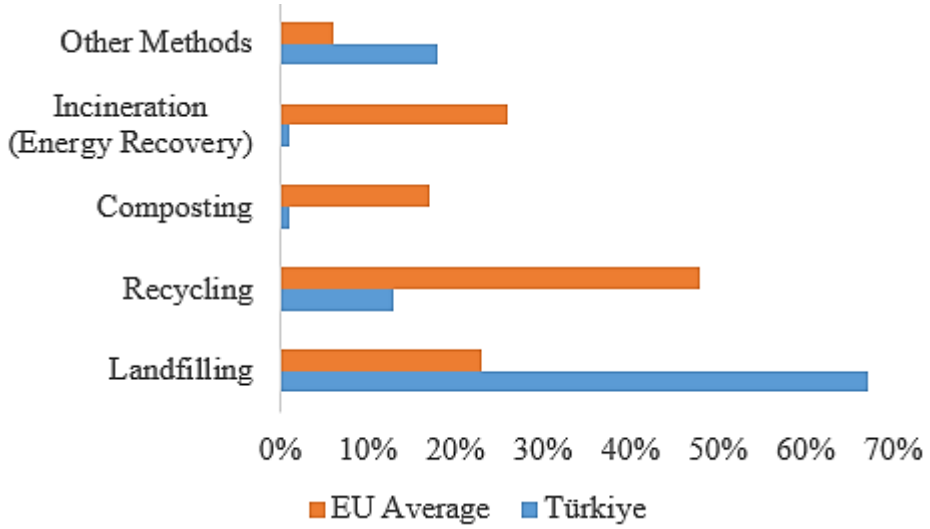


Figure 4. The comparing waste management methods between Türkiye and the EU (2022 data).

3.5 Mann–Kendall Trend Test and Sen's Slope Results

The Mann–Kendall trend test and Sen's slope analyses (Table 4) reveal the long-term trends of different waste disposal methods implemented in Türkiye between 2002 and 2022. The Mann–Kendall test is a nonparametric method used to test the existence of a monotonic (constantly increasing or decreasing) trend in time series. In the test's decision-making process, the sign of the Z statistic indicates the direction of the trend ($Z>0 \rightarrow$ increasing; $Z<0 \rightarrow$ decreasing), and the p-value indicates the statistical significance of the trend. In this study, the significance level was set at 5% ($\alpha = 0.05$). A trend was considered statistically significant when

$p < 0.05$; it was considered "not significant" when $p \geq 0.05$. The magnitude of the trend was calculated using Sen's slope and presented as percentage change (%/year and %/10 years).

According to the analysis results, statistically significant decreasing trends were identified for composting (-0.221%/year), landfilling (-1.623%/year), and surface water discharge (-0.667%/year). These trends demonstrate that Türkiye has succeeded in significantly reducing the riskiest and environmentally harmful disposal methods over the past two decades. The particularly strong decrease in landfilling (approximately -16.2 percentage points/10 years) can be attributed to the expansion of sanitary landfills and the ban on uncontrolled dumping.

Table 4. Mann–Kendall trend test and Sen's Slope results

Disposal Method (%)	S	Z	p	Trend	Sen's Slope (%/year)	Sen's Slope (%/10 years)
Regular landfill	2	0.069	0.9453	Not Significant	0.074	0.74
Recycling	17	1.709	0.0875	Not Significant	0	0
Composting	-62	-4.183	<0.0001	Decreasing	–0.221	–2.21
Open burning	-14	-0.892	0.3727	Not Significant	–0.717	–7.17
Burial	-50	-3.36	0.0008	Decreasing	–1.623	–16.23
Dumping into S.W.*	-46	-3.086	0.002	Decreasing	–0.667	–6.67
Other disposal	38	2.537	0.0112	Increasing	3.056	30.56

*S.W. means surface water

In contrast, a statistically significant increase was found in the "Other Disposal" category (Sen's slope ≈ +3.056%). This suggests that practices other than standard disposal methods or reporting discrepancies are increasingly being included in TUIK data.

No statistically significant trend was found for sanitary landfilling, recycling, or open burning ($p \geq 0.05$). Although landfilling declined after 2018 and recycling rates increased, particularly after 2016, these changes do not constitute a statistically significant trend when examined across the entire series. This is due to the long periods of zero values, particularly in the recycling series, and limited test power.

In conclusion, these findings suggest that Türkiye has been successful in reducing the most environmentally risky methods between 2002 and 2022, but landfilling remains the dominant method, and sustainable options such as recycling/energy recovery do not exhibit a statistically significant upward trend. Therefore, future policy priorities should focus specifically on expanding recycling and energy recovery.

3.6 Bitlis Example

Between 2002 and 2022, solid waste disposal methods implemented in Bitlis province have diversified over time and have shown certain trends. The most notable change during this period is the increase in the amount of waste sent to regular storage and licensed companies. This trend is also parallel to the spread of environmentally friendly waste management policies throughout Türkiye [3].

As Figure 5 shows, 152 and 1684 tons of waste were disposed of by open burning in 2006 and 2010, respectively. However, it is seen that this method was not used in the following years. This shows that open burning was abandoned due to its environmental damage [41]. One of the methods frequently used in the 2002–2022 period is storage in municipal dumps. It is seen that this method was used intensively especially in the years 2003–2006 (for example, 83 076 tons in 2003). However, as of 2018, this method has started to give way to more organized and controlled methods. In 2022, the amount of waste disposed of with this method dropped to 29 752 tons. Data in the other disposal and recovery operations category is available for only a few years. For example, in 2012, 21 460 tons of waste was disposed of with "Other Disposal Operations", and only 200 tons in 2022.

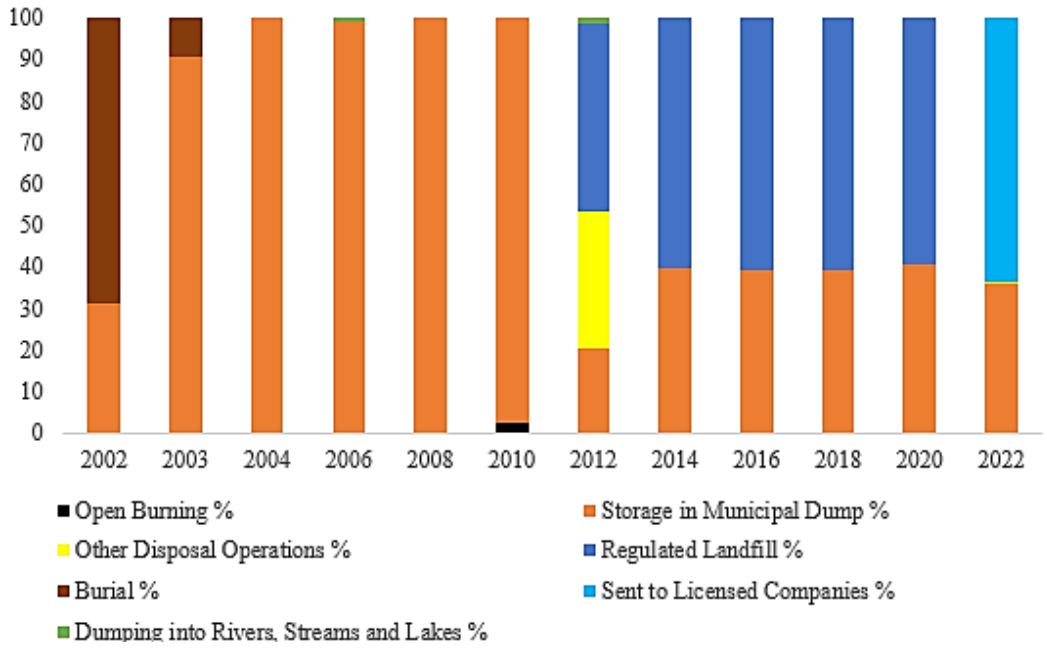


Figure 5. Solid waste disposal methods applied in Bitlis province between 2002 and 2022.

In 2022, only 100 tons of waste was recorded under the name of "Other Recovery Operations". It is seen that the regular storage method has become prominent since 2012. This amount, which was 29 094 tons in 2012, reached 40 250 tons in 2020. This increase reflects

Türkiye's transition to regular storage in line with the EU environmental acquis harmonization process [5], [7]. Methods such as burial and dumping into water sources such as rivers are included in the most environmentally risky group. In 2003, 8 360 tons of waste was disposed of by burial. In 2012, 992 tons of waste was dumped into rivers, streams or lakes. However, it is seen that these methods have been abandoned in recent years. This situation can be associated with the tightening of regulations and increased inspections [7]. There is one solid waste sanitary landfill facility in Bitlis province (Bitlis Province, Districts, and Towns Solid Waste Disposal Facilities Construction and Operation Association), constructed using EU funds. This facility is located in the Güroymak district. The Bitlis Solid Waste Union is a local administration union established to provide solid waste services to the province, district, and town municipalities that are members of the union. Since there are no other similar facilities within the province, surrounding provinces also use this facility for disposal. In 2022, 52 284 tons of waste were disposed of by sending them to licensed companies, and the sanitary landfill facility, which became operational in 2018, had a significant impact on this situation [42].



Figure 6. Solid waste storage facility and waste production potential in the districts of Bitlis province

Figure 6 shows the spatial distribution of solid waste management infrastructure and waste generation potential in the districts of Bitlis province. The black symbol on the map represents the location of a single solid waste storage facility, while the red dots represent the solid waste generation potential by district. Accordingly, waste generation throughout the province is particularly concentrated in the districts of Tatvan, Bitlis city center, Güroymak, and Ahlat, which have higher population densities. These districts also overlap with areas with

relatively higher residential and commercial activity. Assessments conducted specifically for Bitlis (the Regional Solid Waste Management Project and Bitlis city evaluations) also support the finding that Tatvan and the central districts are prioritized for waste generation, and it has been reported that practices for directing resources to regional storage facilities began in 2011 [43].

On the other hand, it is noteworthy that the waste generation potential is lower in the Mutki, Hizan, and Adilcevaz districts. The map allows for discussion of the spatial risks of sanitary landfills in Bitlis. The spatial proximity of concentrated waste generation areas, particularly in Tatvan and around Bitlis city center, to sanitary landfills could lead to increased environmental pressures in these areas (e.g., groundwater pollution, odor, and air quality problems) [44]. Conversely, it is anticipated that the capacity utilization of facilities in districts with low waste generation potential may be limited. Furthermore, while "Zero Waste" policies implemented after 2017 and collection/separation practices carried out by licensed companies have led to some local improvements, heterogeneity in implementation across districts and gaps in registration systems persist. For example, while natural landfilling continues in districts such as Ahlat and Adilcevaz [42], Bitlis province has undergone a significant transition from primitive methods (open burning, burial) to environmentally friendly methods (regulatory landfilling, and sending to licensed companies) between 2002 and 2022. In the last 10 years, in particular, the goal has been to reduce environmental impacts through landfilling and collaboration with private companies. Therefore, the Bitlis example illustrates the discrepancy between policy implementation and local realities. Recent evaluations in Istanbul indicate that Zero Waste practices have achieved varying success depending on local government capacity, and that a detailed assessment of the scope and effectiveness of implementation in Bitlis is necessary [32]. Consequently, this spatial distribution suggests that waste management policies in Bitlis should take into account district-level differences. Prioritizing recycling and reduction practices in districts with the highest waste generation is critical to reducing environmental risks.

4 CONCLUSION AND SUGGESTIONS

The twenty-year period from 2002 to 2022 has witnessed a significant transformation in Türkiye's waste management. While the significant reduction of rampant dumping sites and the expansion of sanitary landfills, which were prevalent in 2002, are undoubtedly progress, the current situation remains inadequate from an environmental and economic perspective. The fact

that approximately 67% of waste was disposed of in sanitary landfills as of 2022 indicates that serious environmental risks such as leachate, groundwater pollution, and methane release persist. From a circular economy perspective, the increase in the recycling rate from 5–7% in 2002 to 13% in 2022 is a positive development. However, this rate falls well short of the EU average (45–50%) [15]. Recycling only 22% of plastic waste creates an additional economic burden by increasing dependence on raw material imports. Furthermore, having an energy recovery capacity of only 1% represents a significant loss of opportunity for a country vulnerable to energy imports. Recycling waste as a resource in line with circular economy principles is critical not only for environmental benefits but also for macroeconomic resilience.

Waste management plays a key role in Türkiye's alignment with sustainable development goals (SDG 11: Sustainable Cities, SDG 12: Responsible Production and Consumption, SDG 13: Climate Action) [45]. However, current practices are not yet robust enough to achieve these goals. In particular, separating waste at source, making recycling chains transparent, and integrating informal recycling actors into the system are among the steps that will directly improve Türkiye's SDG performance [5], [16].

In this context, concrete policy recommendations can be summarized as follows:

Deposit return system: Implementing a national deposit system for plastic, glass, and metal beverage containers is a highly effective short-term tool for increasing recycling rates.

Source separation infrastructure: Mandating separate collection bins and logistical support for municipalities will increase the efficiency of the recycling chain.

Waste-to-energy production: Encouraging investments in biogas and Refuse-Derived Fuel (RDF) will provide dual benefits for both greenhouse gas reduction and energy supply security.

Real-time environmental monitoring systems: Continuous monitoring of leachate and gas emissions with sensors should be made mandatory at sanitary landfills.

Industry-university collaborations: R&D support for recycling technologies and material recovery should be increased, and the participation of young people in "zero waste volunteering" projects should be encouraged.

In conclusion, Türkiye has made significant progress in waste management from 2002 to 2022. However, this progress is insufficient when evaluated in the context of combating climate change, circular economy goals, and sustainable development. To reduce environmental

risks, prevent economic losses, and approach sustainable development goals, waste management must be addressed with a holistic approach and the concrete steps mentioned above must be implemented swiftly.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

Artificial Intelligence (AI) Contribution Statement

This manuscript was entirely written, edited, analyzed, and prepared without the assistance of any artificial intelligence (AI) tools. All content, including text, data analysis, and figures, was solely generated by the author.

REFERENCES

[1] O. Gokkurt Baki and O. N. ERGUN, "Municipal Solid Waste Management: Circular Economy Evaluation in Turkey," *Environ. Manag. Sustain. Dev.*, vol. 10, no. 2, p. 79, 2021, doi: 10.5296/emsd.v10i2.18448.

[2] Ö. Apaydin and G. S. Akçay Han, "Analysis of Municipal Solid Waste Collection Methods Focusing on Zero-Waste Management Using an Analytical Hierarchy Process," *Sustain.*, vol. 15, no. 17, p. 13184, Sep. 2023, doi: 10.3390/SU151713184/S1.

[3] TUIK, "TÜİK Kurumsal," *Türkiye İstatistik Kurumu*. p. 2, 2021. Accessed: Jun. 09, 2025. [Online]. Available: https://data.tuik.gov.tr/Bulten/Index?p=Atik-Istatistikleri-2022-49570

[4] EEA, "Municipal Waste Management in Turkey," 2022. doi: 10.4018/978-1-7998-0198-6.ch018.

[5] "TÜİK - Veri Portalı." Accessed: May 20, 2025. [Online]. Available: https://data.tuik.gov.tr/

[6] N. G. Turan, S. Çoruh, A. Akdemir, and O. N. Ergun, "Municipal solid waste management strategies in Turkey," *Waste Manag.*, vol. 29, no. 1, pp. 465–469, Jan. 2009, doi: 10.1016/J.WASMAN.2008.06.004.

[7] T.C. Çevre ve Şehircilik Bakanlığı, "Ulusal Atık Yönetimi ve Eylem Planı 2023," 2023.

[8] G. Grimaud, B. Laratte, and N. Perry, "To transport waste or transport recycling plant: Insights from life-cycle analysis," *Mater. Tech.*, vol. 105, no. 5–6, 2017, doi: 10.1051/mattech/2018016.

[9] R. Cremiato, M. L. Mastellone, C. Tagliaferri, L. Zaccariello, and P. Lettieri, "Environmental impact of municipal solid waste management using Life Cycle Assessment: The effect of anaerobic digestion, materials recovery and secondary fuels production," *Renew. Energy*, vol. 124, pp. 180–188, Aug. 2018, doi: 10.1016/J.RENENE.2017.06.033.

[10] A. Demir, A. Basturk, B. Ozkaya, and M. S. Bilgili, "Municipal Waste Management in Turkey," in *Sustainable Waste Management Challenges in Developing Countries*, and M. S. B. Agamuthu Pariatamby, Fauziah Shahul Hamid, Ed., Hershey: IGI Global, 2020, pp. 441–465. doi: 10.4018/978-1-7998-0198-6.CH018.

[11] H. Dinçer, S. Yüksel, S. Eti, Y. Gökalp, A. Mikhaylov, and Z. Karpyn, "Effective waste management in service industry: Fuzzy-based modelling approach for strategic decision-making," *Waste Manag. Res.*, 2024, doi: 10.1177/0734242X241242682.

[12] R. Horta Arduin *et al.*, "Influence of scope definition in recycling rate calculation for European e-waste extended producer responsibility," *Waste Manag.*, vol. 84, pp. 256–268, Feb. 2019, doi: 10.1016/J.WASMAN.2018.12.002.

[13] G. Öner, H. Akgün, M. K. Koçkar, and A. Arslan Kelam, "Municipal landfill site selection using TOPSIS

methodology: A case study for Polatlı, Ankara, Türkiye," *Bull. Eng. Geol. Environ.*, vol. 84, no. 3, pp. 1–26, Mar. 2025, doi: 10.1007/S10064-025-04146-W/FIGURES/18.

[14] I. Kamdar, S. Ali, A. Bennui, K. Techato, and W. Jutidamrongphan, "Municipal solid waste landfill siting using an integrated GIS-AHP approach: A case study from Songkhla, Thailand," *Resour. Conserv. Recycl.*, vol. 149, pp. 220–235, Oct. 2019, doi: 10.1016/J.RESCONREC.2019.05.027.

[15] "Municipal waste statistics - Statistics Explained - Eurostat." Accessed: Jun. 08, 2025. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Municipal_waste_statistics

[16] "OECD Data Explorer • Waste - Municipal waste: generation and treatment." Accessed: Jun. 08, 2025. [Online]. Available: https://data-explorer.oecd.org/vis?df[ds]=DisseminateFinalDMZ&df[id]=DSD_MUNW%40DF_MUNW&df[ag]=OECD.ENV.EPI&dq=.A.MUNICIPAL.T&pd=2015%2C&to[TIME_PERIOD]=false

[17] M. Hashim, N. Nayan, D. L. Setyowati, Z. M. Said, H. Mahat, and Y. Saleh, "Analysis of Water Quality Trends Using the Mann-Kendall Test and Sen's Estimator of Slope in a Tropical River Basin," *Pollution*, vol. 7, no. 4, pp. 933–942, Oct. 2021, doi: 10.22059/POLL.2021.325794.1118.

[18] A. Muhammet BANAZILI, "Kati Atik Kavramina Küresel Bir Bakiş Ve Kati Atik Yönetimi Üzerine Politika Önerileri," *G.Ü. İslahiye İİBF Uluslararası E-Dergi*, vol. 8, no. 8, pp. 16–27, Dec. 2024, Accessed: Jun. 08, 2025. [Online]. Available: https://dergipark.org.tr/tr/pub/iiibfud/issue/88745/1596559

[19] A. M. Troschinetz and J. R. Mihelcic, "Sustainable recycling of municipal solid waste in developing countries," *Waste Manag.*, vol. 29, no. 2, pp. 915–923, Feb. 2009, doi: 10.1016/J.WASMAN.2008.04.016.

[20] D. C. Wilson, C. Velis, and C. Cheeseman, "Role of informal sector recycling in waste management in developing countries," *Habitat Int.*, vol. 30, no. 4, pp. 797–808, Dec. 2006, doi: 10.1016/J.HABITATINT.2005.09.005.

[21] F. C. Mihai and C. Ingrao, "Assessment of biowaste losses through unsound waste management practices in rural areas and the role of home composting," *J. Clean. Prod.*, vol. 172, pp. 1631–1638, 2018, doi: 10.1016/j.jclepro.2016.10.163.

[22] N. Ferronato and V. Torretta, "Waste Mismanagement in Developing Countries: A Review of Global Issues," *Int. J. Environ. Res. Public Heal. 2019, Vol. 16, Page 1060*, vol. 16, no. 6, p. 1060, Mar. 2019, doi: 10.3390/IJERPH16061060.

[23] "Waste generation in Europe | European Environment Agency's home page." Accessed: Jun. 09, 2025. [Online]. Available: https://www.eea.europa.eu/en/analysis/indicators/waste-generation-and-decoupling-in-europe

[24] "Waste management in Europe: how can we improve? - Ecostar." Accessed: Jun. 09, 2025. [Online]. Available: https://ecostar.eu.com/waste-management-in-europe-how-can-we-improve/

[25] D. Hoornweg, "A Global Review of Solid Waste Management," *A Glob. Rev.*, vol. 44, no. January 2012, pp. 44–55, 2017.

[26] A. Pires, G. Martinho, and N. Bin Chang, "Solid waste management in European countries: A review of systems analysis techniques," *J. Environ. Manage.*, vol. 92, no. 4, pp. 1033–1050, Apr. 2011, doi: 10.1016/J.JENVMAN.2010.11.024.

[27] A. U. Zaman and S. Lehmann, "The zero waste index: a performance measurement tool for waste management systems in a 'zero waste city,'" *J. Clean. Prod.*, vol. 50, pp. 123–132, Jul. 2013, doi: 10.1016/J.JCLEPRO.2012.11.041.

[28] "Global Waste Management Outlook 2024 | UNEP - UN Environment Programme." Accessed: Jun. 08, 2025. [Online]. Available: https://www.unep.org/resources/global-waste-management-outlook-2024

[29] "What a Waste." Accessed: Jun. 08, 2025. [Online]. Available: https://datatopics.worldbank.org/what-a-waste/

[30] E. Balci, S. Balci, and A. Sofuoglu, "Multi-purpose reverse logistics network design for medical waste management in a megacity: Istanbul, Turkey," *Environ. Syst. Decis.*, vol. 42, no. 3, p. 372, Sep. 2022, doi: 10.1007/S10669-022-09873-Z.

[31] "TÜİK Kurumsal." Accessed: Jun. 11, 2025. [Online]. Available: https://data.tuik.gov.tr/bulten/index?p=environmental-protection-expenditure-statistics-2021-45520&utm_source

[32] H. Burçin and H. Henden¸ Henden¸solt, "Evaluation of the Zero Waste Project in Istanbul District Municipalities from the Perspective of Sustainable Urban Planning," *Sustain. 2023, Vol. 15, Page 11896*, vol. 15, no. 15, p. 11896, Aug. 2023, doi: 10.3390/SU151511896.

[33] H. M. Ay and A. Söylemez, "Belediye Hizmetleri İçinde Katı Atık Yönetiminin Önemi Ve Konya Büyükşehir Belediyesi Örneği," *Toplum Ekon. ve Yönetim Derg.*, vol. 4, no. Özel, pp. 273–292, 2023, doi: 10.58702/teyd.1357353.

[34] "Environment at a Glance Indicators," *Environ. a Glance Indic.*, Nov. 2019, doi: 10.1787/AC4B8B89-EN.

[35] Y. Avşar, "Atık Yönetim i Stratejisi Olarak ' Sıfır Atık Projesi ' ve Türkiye ' deki Uygulama Örnekleri," *Türk Yönetim ve Ekon. Araştırmaları Derg.*, vol. 5, no. 2, pp. 82–93, 2024.

[36] S. Dağıdır and H. Yaylı, "Türkiye ' nin Katı Atık Yönetiminin AB İlerleme Raporları Bağlamında İncelenmesi Exploration of Turkey ' s Solid Waste Management in the Context of EU Progress Reports," pp. 21–38, 2024.

[37] E. Union, "Amending Directive 2008/98/EC on waste," *Off. J. Eur. Union*, pp. 1–28, 2024.

[38] European Parliament, "EU Circular Economy Package: Four Legislative Proposals on Waste," vol. 593, no. March, 2018, [Online]. Available: https://www.europarl.europa.eu/EPRS/EPRS-Briefing-573936-Circular-economy-package-FINAL.pdf

[39] "The European Green Deal — European Environment Agency." Accessed: Oct. 03, 2025. [Online]. Available: https://www.eea.europa.eu/policy-documents/com-2019-640-final

[40] A. S. E. Yay, "Yaşam döngüsü analizinin ambalaj atıklarının yönetiminde kullanılması.," *Sak. Univ. J. Sci. / Sak. Üniversitesi Fen Bilim. Enstitüsü Derg.*, vol. 21, no. 5, pp. 1008–1017, Oct. 2017, doi: 10.16984/SAUFENBILDER.300851.

[41] Ş. ve İ. D. B. Çevre, *Atık Yönetimi Genel Esaslarına İlişkin Yönetmelik*. Accessed: Jun. 09, 2025. [Online]. Available: https://www.lexpera.com.tr/resmi-gazete/metin/atik-yonetimi-genel-esaslarina-iliskin-yonetmelik-26927

[42] Bitlis İl Özel İdaresi, "Bitlis İli 2022 Yili Faaliyet Raporu," 2022.

[43] T. Can, Orhan, A. D. Yetiş, L. Gazigil, M. M. Tütün, and R. Yetiş, "Bitlis Merkez, Tatvan ve Güroymak İlçeleri İçin Sosyo-Ekonomik Gelişmişlik ve Kati Atik Miktarlari Arasindaki İlişki," no. January 2015, 2014, doi: 10.13140/RG.2.1.3995.6645.

[44] G. Akinci, E. D. Guven, and G. Gok, "Evaluation of waste management options and resource conservation potentials according to the waste characteristics and household income: A case study in Aegean Region, Turkey," *Resour. Conserv. Recycl.*, vol. 58, pp. 114–124, Jan. 2012, doi: 10.1016/J.RESCONREC.2011.11.005.

[45] "You searched for Turkey - United Nations Sustainable Development." Accessed: Oct. 03, 2025. [Online]. Available: https://www.un.org/sustainabledevelopment/?s=Turkey