

# SUPPLEMENTARY MATERIALS

of the article titled “Analysis of Municipal Solid Waste Collection Methods Focusing on Zero-Waste Management Using an Analytical Hierarchy Process”

**Text S1:** The annual amount of solid waste generated in Türkiye is 32 million tons, according to the data obtained from 1395 municipalities [TUIK , 2023]. Moreover; the daily solid waste generated per capita in Türkiye has been determined as 1.16 kg/person/day. 67.2% of the collected waste is sent to landfills, 20.2% to municipal dumps, 12.3% to recycling facilities, and 0.2% of the collected waste in municipalities that provide solid waste collection services. It is stated that they are disposed of by burning in the open, buried, pouring into a stream or land (Figure S1). Unit solid waste production varies between 1.16 and 1.38 and the daily solid waste amount generated reaches 32209 ton (Figure S2).

## *Zero Waste Regulation in Türkiye.*

Zero Waste Regulation, Official Gazette Date:12.07.2019, Official Gazette Number:30829 [https://www.mevzuat.gov.tr/mevzuat?MevzuatNo=32659&MevzuatTur=7&MevzuatTertip=5. Access date: August 6, 2023.]

Within the scope of the zero waste regulation in Türkiye, article 13 related to "establishment of zero waste management system" and article 14 related to "features of waste collection, collection and collection equipment" are given below.

### Establishment of zero waste management system

ARTICLE 13 – (1) In the establishment of a zero waste management system, the criteria given in ANNEX-3/A by local administrations and in ANNEX-3/B by buildings and campuses are met.

(2) The roadmap to be followed for the installation of the system is given below:

a) Determination of the Working Team: Working teams are formed with the responsible person or persons who will follow the process from the establishment of the zero waste management system to its implementation and monitoring.

b) Planning: In order to configure the zero waste management system to be implemented in the most effective way, a planning is made regarding the things to be done before the implementation. In this context;

1) Current Situation Determination: The current situation is determined regarding the source, type, amount of all wastes, waste collection, collection and transportation methods, temporary storage areas, places where the wastes are delivered.

2) Needs Analysis: Collection equipment and temporary storage area needs are determined for the wastes to be collected separately.

c) Training/Awareness Raising Activities and Implementation: Training/awareness-raising activities are carried out to increase awareness and the system is started to be implemented.

ç) Monitoring, Record Keeping and Improvement Activities: Monitoring studies are carried out on the implementation of the implementation at regular intervals. Measures are taken for the issues that fail, and updates are made if necessary. Outputs related to the application, such as the amount of waste collected separately and the gains obtained, are recorded.

#### Features of waste collection, collection and collection equipment

ARTICLE 14 – (1) Within the scope of zero waste management system; Non-hazardous recyclable paper, glass, metal, plastic wastes originating from households or commercial, industrial enterprises and institutions that are similar in content or structure are collected in different collection equipment from other wastes and collected separately. Paper, glass, metal and plastic wastes can be collected in a single equipment or separately according to material types.

(2) Waste batteries, waste vegetable oil, waste electrical and electronic equipment, other recyclable wastes, waste medicines and large volumes of wastes are collected in accordance with the collection plan of the local administrations and delivered to the authorized administration or to the collection points, waste collection centers and waste collection points established for these wastes. / or delivered to waste treatment facilities.

(3) In the collection equipment to be used, the color of the equipment or the labels on the equipment;

a) In case of accumulation of paper, glass, metal and plastic wastes together, blue color is used, for other wastes dark gray color is used.

b) In case of separate collection according to material types, blue is used for paper waste, yellow for plastic waste, green for glass waste, and light gray for metal waste.

c) In places where biodegradable wastes are intensely formed, such as tea shops, cafeterias, food preparation or food service and similar places, if these wastes are collected separately, brown color is used.

ç) (Amended: OG-9/10/2021-31623) White color is used for the collection equipment to be used for the collection of waste drugs; These equipments are made of stainless metal or high-density plastic material, with lids, the lids are locked, without sharp edges that may cause damage or puncture of the bags during loading and unloading, easy to load, not allowing to be taken again after the waste is thrown into it, and on it "Waste Medicines". " is included.

(4) Collection is carried out by local administrations in residences and public areas within the framework of the following matters:

a) Blue color is used for recyclable wastes and dark gray color is used for other wastes in the collection equipment to be used while collecting from residences.

b) At least two sets of equipment are placed in streets, streets and public areas, and blue and dark gray colors are used in these equipments. Green color is used in the equipment to be placed for glass waste, if necessary.

c) Which wastes can be disposed of on the equipment are indicated with text and/or figures.

ç) (Annex: OG-9/10/2021-31623) In addition to the equipment defined in subparagraphs (a) and (b), in order to obtain a silver, gold or platinum zero waste certificate by meeting the criteria in ANNEX-4, biodegradable For waste, a minimum triple collection system is established, including brown.

(5) Accumulation and collection of wastes are followed in accordance with the explanations given in ANNEX-5.

(6) The management of other hazardous/non-hazardous wastes and medical wastes not mentioned in this article is provided within the scope of the relevant legislation and included in the zero waste management system.

(7) (Annex: RG-9/10/2021-31623) Zero waste logo is used on collection equipment, waste collection centers and collection/transport vehicles placed within the scope of zero waste management system. In addition, the collection/transport vehicles have the phrase "Zero Waste Collection Vehicle".

(8) (Annex: RG-9/10/2021-31623) Chain markets and sales points with a covered sales area of 400 m<sup>2</sup> or more, in case of sale with non-hazardous paper, glass, metal, plastic waste brought by consumers, batteries, electrical It is obliged to establish collection points in easily visible and accessible places for the separate collection of small household appliances or textile wastes, and to take measures for the environment and human health.

(9) (Annex: OG-9/10/2021-31623) Collection activities to be carried out by local administrations are carried out according to the groupings shown in ANNEX-5 in accordance with the Provincial Zero Waste Management System Plan.

(10) (Annex: OG-9/10/2021-31623) Local administrations aim to prepare the wastes of paper/cardboard, glass, metal and plastic types, which are mixed in the blue collection equipment and collected in this way, for recycling according to ANNEX-5. It works with facilities of the type that can serve its population. Type 1 Collection Separation Facility serves a population of 400,000 and above, Type 2 Collection Separation Facility serves a population of 100,000-400,000, and Type 3 Separation Facility serves a population of up to 100,000. Local administrations can meet the collection and sorting facility needs they will determine from a single facility that can serve the total population or from more than one collection and separation facility separately. If more than one collection-separation facility is preferred; It is ensured that the population capacities to be served in the areas of responsibility determined for these facilities are not exceeded.

(11) (Annex: OG-9/10/2021-31623) In order to increase the efficiency of collection activities to be carried out by local administrations within the scope of zero waste management system, waste collection center(s) shall be established in accordance with the principles determined by the Ministry. In this direction;

a) It is essential that the waste collection center be established on a minimum area of 1000 m<sup>2</sup>. However, if there is not enough space, more than one waste collection center with a minimum area of 300 m<sup>2</sup> can be established. In this situation;

1) At least 600 m<sup>2</sup> in total in municipalities with a population of 20,000 to 100,000,

2) At least 1000 m<sup>2</sup> in total in municipalities with a population from 100,000 to 300,000,

3) At least 1200 m<sup>2</sup> in total in municipalities with a population of more than 300,000,

It is obligatory to establish waste collection centers to ensure in municipalities with a population of up to 20,000, it is sufficient to establish a waste collection center with an area of at least 300 m<sup>2</sup>.

b) Mobile waste collection centers are established/established in order to establish collection points in different places by evaluating the location of the waste collection centers and the accessibility of the citizens.

c) In case of mutual agreement, waste collection center(s) may/can be established for joint use by more than one local administration. However, in this case, it is obligatory to establish/establish mobile waste collection centers depending on the waste collection centers.

ç) Technical and administrative issues regarding waste collection centers are determined by the Ministry.

(12) (Annex: OG-9/10/2021-31623) Shopping centers establish a mobile waste collection center in accordance with the criteria determined by the Ministry, with technical and administrative aspects, in order to create collection points where wastes can be brought and left by the citizens. The obligation to create collection points brought by the eighth paragraph is not required in chain markets established in a shopping center with a waste collection center and sales points with a sales area of 400 m<sup>2</sup> or more.

#### ***Annex-3/A Criteria for Local Administrations***

1. Collection or collection of non-hazardous recyclable paper, glass, metal, plastic wastes from residences separately from other wastes, at least in duplicate.
2. Placement of collection equipment in sufficient number and capacity in easily accessible places for separate accumulation of wastes, at least in the form of recyclable wastes and other wastes, in streets, streets and public areas.
3. Placement of waste glass piggy banks in streets, streets and public areas as needed
4. (Amendment: OG-9/10/2021-31623) Provision of waste medicine collection equipment for the collection of waste medicines originating from houses
5. Placement of piggy banks for the collection of textile/clothing wastes and carrying out studies for the reuse of these wastes
6. Establishment of Waste Receiving Center/Centers and collection points in accordance with the principles determined by the Ministry and have started to operate
7. (Amended: OG-9/10/2021-31623) Mobile communication for determining the collection program for waste collection and informing the public, collecting or having the waste collected within the framework of this program, informing the citizens within the scope of the zero waste management system, increasing the service quality and solving the problems line, to be included in the mobile applications prepared by the Ministry
8. Planning, informing and directing the wastes such as waste batteries, vegetable waste oil, waste electrical and electronic equipment, waste medicine and large volumes of waste that can be accumulated in collection points and waste collection centers,
9. (Amendment: OG-9/10/2021-31623) Establishing a system for separate collection at the source in order to take measures to prevent food waste in wholesale markets and market places, and to ensure the recovery of food waste generated\*, bio-degradable wastes are collected separately and recycled Carrying out necessary studies on recycling (Compost, biomethanization, etc.)
10. Recording the data regarding the zero waste management system implemented in the area of responsibility
11. Carrying out awareness and awareness-raising activities on the implementation of the zero waste management system.
12. Compliance with the Provincial Zero Waste Management System Plan

#### ***Annex-3/B Criteria for Buildings and Campuses***



1. Accumulation of non-hazardous recyclable paper, glass, metal, plastic wastes separately from other wastes
2. Separate accumulation of waste batteries, waste vegetable oil, waste electrical and electronic equipment and other recyclable wastes
3. Accumulation of other non-hazardous and hazardous wastes and medical wastes not specified in the 1st and 2nd criteria in accordance with the relevant legislation
4. Separate accumulation of biodegradable wastes at points where they are intensely formed, such as tea shops, cafeterias, food preparation or food service areas.
5. Compliance with the color criteria, and informative signs or writings specific to waste on the collection equipment
6. All accumulation equipment must be in volume, quantity and features in accordance with the requirements and the criteria given in the relevant legislation.
7. Collecting the accumulated waste in the temporary storage area to be delivered to the collection system of the relevant administration and/or waste processing facilities with permission and/or environmental licenses.
8. Giving necessary information trainings on the zero waste management system
9. Availability of permits and/or environmental permits/licenses that it is obliged to obtain in accordance with the Environmental Law and the legislation prepared within the scope of this Law.
10. (Amended: OG-9/10/2021-31623) Of the sales points that sell the products covered by the deposit; Participation and implementation of the deposit management system, the principles of which are determined by the Ministry, in order to take back and collect the returnable products that are requested to be returned by the consumers.

***Waste Management Regulation in Türkiye.***

Waste Management Regulation, Official Gazette Date: 02.04.2015 Official Gazette Number: 29314 [https://www.mevzuat.gov.tr/mevzuat?MevzuatNo=20644&MevzuatTur=7&MevzuatTertip=5, Access date: August 6, 2023.]

Article 8, which includes the responsibilities of municipalities within the scope of waste management regulation in Türkiye, is given below.

ARTICLE 8 – (1) Metropolitan municipalities, metropolitan district municipalities, provincial, district and town municipalities;

- a) Establishing/establishing, operating/operating waste treatment facilities within the framework of their responsibilities, obtaining/receiving environmental licenses for the relevant facilities,
- b) Carrying out or contributing to awareness and training activities with the parties assigned responsibility in this Regulation, within the scope of waste management,
- c) Providing the necessary tools and equipment, providing the necessary tools and equipment, adapting the health and safety measures to the changing conditions, and organizing all kinds of measures, including the provision of periodic training of the personnel in charge of waste management, health checks, prevention of occupational risks, providing training and information. by working to improve the situation and taking other protective and preventive measures,

ç) They are obliged to keep the records of the vehicles they use in the transportation of the wastes for which they are responsible, to establish a vehicle tracking system and to submit the records to the Ministry and the provincial directorate if requested.

(2) Metropolitan municipalities;

a) By complying with the provisions specified in the first paragraph of this article,

b) Coordinating the preparation of waste management plans, including the prevention of waste generation and waste reduction, for which it is responsible, with the district municipalities, submitting them to the Ministry and ensuring that the works are carried out in line with this plan, taking the necessary precautions,

c) To coordinate and support the works carried out by the district municipalities within the scope of this Regulation,

ç) Processing the facilities evaluated within the scope of the Regulation on the Incineration of Wastes and the Regulation on the Regular Storage of Wastes in the zoning plan,

d) To take the necessary measures to prevent the transportation and processing of the wastes for which it is responsible from the transfer station by unauthorized persons,

e) (Annex: OG-23/3/2017-30016) In case of need, they are obliged to establish/have a transfer station established for municipal wastes and to operate/operate them.

(3) Metropolitan district municipalities;

a) By complying with the provisions specified in the first paragraph of this article,

b) To prepare waste management plans, including the prevention of waste generation and waste reduction, for which it is responsible, to submit them to the Ministry, to carry out studies in line with this plan and to take the necessary measures,

c) Contributing to the preparation of the waste management plans of the metropolitan municipality,

ç) Collecting/having collected the wastes that it is responsible for managing separately at the source, transporting them to the transfer station, establishing/establishing a waste collection center with a dual collection system, and submitting information and documents regarding the collected wastes to the Ministry,

d) They are obliged to take the necessary measures in order to prevent the collection, transportation and processing of the wastes for which they are responsible, by unauthorized persons.

(4) Provincial, district and town municipalities;

a) By complying with the provisions specified in the first paragraph of this article,

b) To prepare waste management plans, including the prevention of waste generation and waste reduction, for which it is responsible, to submit it to the provincial directorate, to carry out studies in line with this plan and to take the necessary measures,

c) Processing the facilities evaluated within the scope of the Regulation on the Incineration of Wastes and the Regulation on the Regular Storage of Wastes in the zoning plan,

- c) To collect/recover separately at the source the wastes for which the management is responsible within the scope of the legislation related to municipal wastes, to establish/have dual collection systems installed and to submit the information and documents regarding the collected wastes to the Ministry,
- d) Establishing/to have had a waste collection center established in accordance with the principles to be determined by the Ministry,
- e) They are obliged to take the necessary measures in order to prevent the collection, transportation and processing of the wastes for which they are responsible, by unauthorized persons.

**Table 1 presents how MSW disposal methods are affected by a source-conservation thinking perspective relative to source waste separation methods. The detailed explanations for the interaction of five different decision points (or scenarios) are given in below:**

**Scenario 1:** Since four recyclables (paper, plastic, metal and glass) are collected in separate containers, the load of MRF facilities is reduced, and the quality losses of the parameters are minimized. Organic kitchen wastes are collected in the fifth container and other wastes are collected and collected separately. This can also be considered positive for MRF, CP, BMP and SLF. Because from the perspective of waste hierarchy; both recyclable materials and biorecyclable materials can be managed at the desired level with minimum labor and energy use. Therefore, at the last step of the waste hierarchy, the least amount of waste remains in terms of mass and volume, and the SLF load is the least. In this collection method, the integration of the paper into the secondary production process is ensured with the least loss of quality.

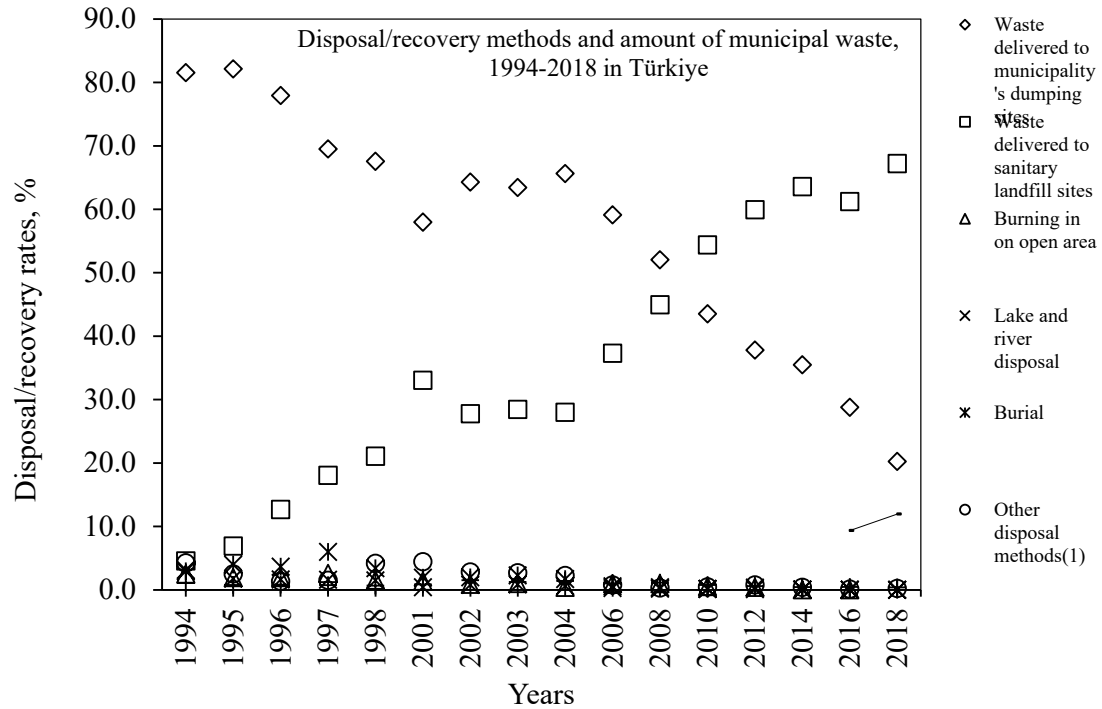
**Scenario 2:** The case of collecting paper and cardboard type waste in one container, three recyclable parameters (plastic, metal and glass) in a second container, organic kitchen waste in a third container and other MSW in a separate container. This can also be considered positive for MRF, CP, BMP and SLF. Because from the perspective of waste hierarchy; both recyclable materials and biorecyclable materials can be managed at the desired level with minimum labor and energy use. In this collection method, the integration of the paper into the secondary production process is ensured with the least loss of quality.

**Scenario 3:** The collection of four recyclable parameters (paper, plastic metal and glass) is collected in same container. Organic kitchen waste and other MSW in separate second and third container, respectively. This can be characterized as positive for MRF, CP, BMP and SLF. Because from the perspective of waste hierarchy; both recyclable materials and biorecyclable materials can be managed at the desired level with minimum labor and energy use. Therefore, at the last step of the waste hierarchy, the least amount of waste remains in terms of mass and volume, and the SLF load is the least.

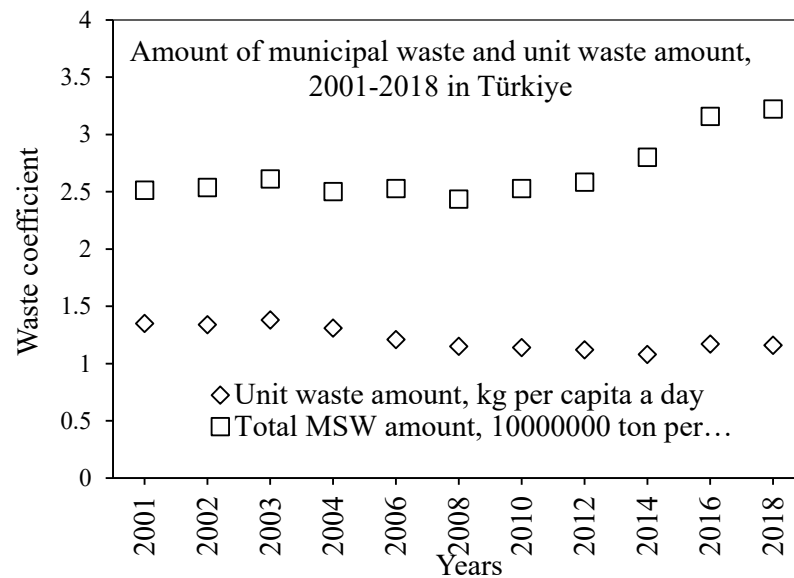
**Scenario 4:** Binary separation. Metal, plastic, glass and paper are collected in a container and delivered to MRF facilities. The other wastes are collected in a different container. Waste free of all four recyclable materials makes a positive contribution to reducing the SLF plant load and thus increasing its useful life. From the point of view of CP and BMP facilities, pre-treatment of organic parts of wastes for both facilities can be evaluated as relatively negative as it will increase the need for labor. In terms of IF facilities; It is considered as negative because the materials with high calorific value are separated.

**Scenario 5:** mixed collection is also a harmful collection method in terms of all disposal methods. Because the waste parameters in the MSW are mixed in the source where it is formed and collected as mixed. Quality losses occur during the separation of mixed-collected wastes at MRF facilities and their

integration into secondary production processes. Mixed wastes for CP and BMP require separation of their organic parts before processing, thus requiring additional labor. When mixed wastes are evaluated for TP, it is evaluated negatively because it contains parameters with low calorific value as well as parameters with high calorific value and considering the waste hierarchy. When evaluated in terms of SLF, it is evaluated negatively in terms of storage space requirement and environmental sustainability, as it is the final disposal method.



**Figure S1.** Disposal/recovery methods and amount of MSW, 1994-2018 in Türkiye



**Figure S2.** Amount of MSW and unit waste amount, 2001-2018 in Türkiye

The population of metropolitan municipalities and the number of districts existing each metropolitan municipality are given Table S1 [TUIK, 2023]

**Table S1.** The metropolitan municipalities and its districts in Türkiye

No	The name of metropolitan municipality	The number of district municipality	Population (Year 2022)
1	Adana	15	2,274,106
2	Ankara	25	5,782,285
3	Antalya	19	2,688,004
4	Aydın	17	1,148,241
5	Balıkesir	20	1,257,590
6	Bursa	17	3,194,720
7	Denizli	19	1,056,332
8	Diyarbakır	17	1,804,880
9	Erzurum	20	749,754
10	Eskişehir	14	906,617
11	Gaziantep	9	2,154,051
12	Hatay	15	1,686,043
13	Mersin	13	1,916,432
14	İstanbul	39	15,907,951
15	İzmir	30	4,462,056
16	Kayseri	16	1,441,523
17	Kocaeli	12	2,079,072
18	Konya	31	2,296,347
19	Malatya	13	812,580
20	Manisa	17	1,468,279
21	Kahramanmaraş	11	1,177,436
22	Mardin	10	870,374
23	Muğla	13	1,048,185
24	Ordu	19	763,190
25	Sakarya	16	1,080,080
26	Samsun	17	1,368,488
27	Tekirdağ	11	1,142,451
28	Trabzon	18	818,023
29	Şanlıurfa	13	2,70,110
30	Van	13	1,128,749
Sum		519	66,653,949
The population of Türkiye (Year 2022)			85,279,553
Population ratio of metropolitan municipalities within the population of Türkiye, %			78.2
Population ratio of İstanbul metropolitan municipality within the population of all metropolitan municipality in Türkiye, %			23.9
Population ratio of İstanbul metropolitan municipality within the population of Türkiye, %			18.7

**Text S2.** The analytical hierarchical process (AHP) developed by Saaty [2006; 1997; 1980] is a multi-criteria methodology formulated to analyze a decision problem following a hierarchical structure. The application of AHP to solve a decision problem involves four main steps for a single decision maker. The first step is to decompose the decision problem into a hierarchy map where the attributes and plans are present as inter-related elements (Figure 3). The second step involves the pair-wise comparison among the elements based on a nine point weighting scale to generate the input data (Table S2).

**Table S2.** AHP pair-wise comparison scale

Numerical rating	Verbal judgments of preferences
9	Extremely preferred
8	Very strongly to extremely
7	Very strongly preferred
6	Strongly to very strongly
5	strongly preferred
4	Moderately to strongly
3	Moderately preferred
2	Equally to moderately
1	Equally preferred

The comparison is carried out to each decision element at  $1-(n-1)$  levels, where  $n$  is the matrix size. During this process, it is possible to know which alternative and attribute are more preferred and for how much greater. The data generated is aggregated according to the hierarchy map to its final value. The decision elements at the hierarchical map are used as a basis for formulating questions on the questionnaire. The decision plans (Figure 3, level 3) are compared with each other according to each decision attribute. Hence, the decision attributes are compared among each other. The third step is based in the use of the pair-wise as input to create a comparison matrix, which follows the four main axioms underlying the theoretical validity of the comparison matrix. If no inconsistencies of judgments are found on the matrix  $A$ , the relative weights could be calculated by solving the equation  $AW = \lambda_{\max}W$ , where  $\lambda$  is the only nonzero eigenvalue of a consistent matrix  $A$ . Having made all the pair wise comparisons, the consistency index (CI) for an  $n \times n$  comparison matrix is largest eigenvalue ( $\lambda_{\max}$ ), where  $CI = (\lambda_{\max} - n)/(n-1)$ . Judgment consistency ratio (CR) can be determined by taking the CI and the randomly index (RI) for a generated matrix  $n \times n$  as  $CR = CI/RI$ , where RI values can be taken from Table S3. CR values are acceptable, if it does not exceed 0.10 or a 10%. If it is more, the judgment matrix is inconsistent. To obtain a consistency matrix, judgments should be reviewed and improved according to the situation. The fourth step involves the estimation and rating of the final weight of the decision plans based on the five MSW disposal methods for each plan and attributes. By comparing the final values, it is possible to determine and suggest the most relevant plan [Al-Harbi, 2001].

**Table S3.** Average random consistency

n	RI
1	0
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Additional information about decision problem solutions with AHP for ZWM is given at below as detailed:

The following steps were done by using MS Excel: 1- synthesizing the pair-wise comparison matrix (example: Table 3); 2- calculating the priority vector for a criterion such as five MSW disposal methods (example: Table 3); 3- calculating the consistency ratio; 4- calculating  $\lambda_{\max}$ ; 5- calculating the consistency index, CI; 6- selecting appropriate value of the random consistency ratio from Table S3; and 7- checking the consistency of the pair-wise comparison matrix to check whether comparisons were consistent or not (Eq.15). The calculations for these items will be explained next for illustration purposes. Synthesizing the pair-wise comparison matrix is performed by dividing each element of the matrix by its column total. For example, the value 0.53 in Table 3 is obtained by dividing 1 (from Table 2) by 1.89, the sum of the column items in Table 2 ( $1+1/3+1/3+1/9+1/9= 1.89$ ). The priority vector in Table 3 can be obtained by finding the row averages. For example, the priority of five MSW disposal methods with respect to the criterion MRF in Table 3 is calculated by dividing the sum of the rows ( $0.53+0.57+0.57+0.34+0.32=2.33$ ) by the number of separation methods (i.e. 5) in order to obtain the value 0.466664 ( $=2.33/5$ ). The priority vector for criteria, indicated in Table 3, is given Eq.S1.

$$\begin{bmatrix} 0.466664 \\ 0.229005 \\ 0.229005 \\ 0.043121 \\ 0.032205 \end{bmatrix} \quad (S1)$$

Estimating the consistency ratio (CR) may be calculated using Eqs. S2-6:

$$\begin{bmatrix} 1 & 3 & 3 & 9 & 9 \\ 1/3 & 1 & 1 & 8 & 8 \\ 1/3 & 1 & 1 & 8 & 8 \\ 1/9 & 1/8 & 1/8 & 1 & 2 \\ 1/9 & 1/8 & 1/8 & 1/2 & 1 \end{bmatrix} \times \begin{bmatrix} 0.466664 \\ 0.229005 \\ 0.229005 \\ 0.043121 \\ 0.032205 \end{bmatrix} = \begin{bmatrix} 2.52 \\ 1.22 \\ 1.22 \\ 0.22 \\ 0.16 \end{bmatrix} \quad (S2)$$

It is divided all the elements of the weighted sum matrices by their respective priority vector element, as shown Eq. S3.

$$\begin{bmatrix} 2.52/0.466664 \\ 1.22/0.229005 \\ 1.22/0.229005 \\ 0.22/0.043121 \\ 0.16/0.032205 \end{bmatrix} = \begin{bmatrix} 5.397095 \\ 5.310697 \\ 5.310697 \\ 5.023818 \\ 5.057247 \end{bmatrix} \quad (S3)$$

Then, it is computed the average of these values to obtain  $\lambda_{\max}$ , as shown Eq. 4.

$$\lambda_{\max} = (5.397095 + 5.310697 + 5.310697 + 5.023818 + 5.057247) / 5 = 5.22 \quad (S4)$$

Now, it is found the consistency index, CI, as shown Eq. S5.

$$CI = (\lambda - n) / (n - 1) = (5.22 - 5) / (5 - 1) = 0.05498 \quad (S5)$$

Selecting appropriate value of random consistency ratio, RI, for a matrix size of five using Table S3, it is found RI = 1.12. After then it is calculated the consistency ratio, CR, as shown Eq.S6.

$$CR = CI / RI = 0.05498 / 1.12 = 0.0491 \quad (S6)$$

As the value of CR is less than 0.1, the judgments are acceptable. Similarly, the pair-wise comparison matrices and priority vectors for decision points (source separation methods) based on MSW disposal methods can be found as shown in Text S2 A1-A6.

All steps of AHP for factor comparison (Text S2-A1) and comparison of decision points for factors MRF (Text S2-A2), CP (Text S2-A3), BMP (Text S2-A4), TP (Text S2-A5) and SLF (Text S2-A6) are given at below separately:

Text S2-A1- Comparison of factors (MSW disposal or treatment methods) affecting decision points

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Priority vector
Scenario 1	1	3	3	9	9	0.466664
Scenario 2	1/3	1	1	8	8	0.229005
Scenario 3	1/3	1	1	8	8	0.229005
Scenario 4	1/9	1/8	1/8	1	2	0.043121
Scenario 5	1/9	1/8	1/8	1/2	1	0.032205
						1.00

Text S2-A1 Step 1: Pair wise comparison

A=	1.00	3.00	3.00	9.00	9.00
	0.33	1.00	1.00	8.00	8.00
	0.33	1.00	1.00	8.00	8.00
	0.11	0.13	0.13	1.00	2.00
	0.11	0.13	0.13	0.50	1.00
Sum	1.89	5.25	5.25	26.50	28.00

Text S2-A1 Sep 2: Normalization

C=	0.53	0.57	0.57	0.34	0.32
	0.18	0.19	0.19	0.30	0.29
	0.18	0.19	0.19	0.30	0.29
	0.06	0.02	0.02	0.04	0.07
	0.06	0.02	0.02	0.02	0.04
Sum	1.00	1.00	1.00	1.00	1.00

Text S2-A1 Step 3: Consistency analysis

D=A <sub>x</sub> W=	1.00	3.00	3.00	9.00	9.00	X	0.47
	0.33	1.00	1.00	8.00	8.00		0.23
	0.33	1.00	1.00	8.00	8.00		0.23
	0.11	0.13	0.13	1.00	2.00		0.04
	0.11	0.13	0.13	0.50	1.00		0.03

D=	2.52		D/W=	5.397095
	1.22			5.310697
	1.22			5.310697
	0.22			5.023818
	0.16			5.057247

$$\lambda = (5.397095 + 5.310697 + 5.310697 + 5.023818 + 5.057247) / 5 = 5.22$$



$$CI = (\lambda - n) / (n - 1) = (5.22 - 5) / (5 - 1) = 0.05498$$

For RI=1.12 from Table S3.

$$CR = CI / RI = 0.05498 / 1.12 = 0.0491 < 0.10 \text{ (suitable)}$$

Text S2-A2- Comparison of decision points for MRF, which is one of the factors affecting decision points

MRF	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Priority vector
Scenario 1	1.00	1.00	3.00	5.00	9.00	0.388335
Scenario 2	1.00	1.00	2.00	3.00	7.00	0.307955
Scenario 3	1/3	1/2	1.00	2.00	5.00	0.161412
Scenario 4	1/5	1/3	1/2	1.00	5.00	0.107346
Scenario 5	1/9	1/7	1/5	1/5	1.00	0.034952
SUM	2.64	2.98	6.70	11.20	27.00	1.00

Text S2-A2 Step 1: Pair wise comparison

A=	1.00	1.00	3.00	5	9
	1.00	1.00	2.00	3	7
	0.33	0.50	1.00	2	5
	0.20	0.33	0.50	1	5
	0.11	0.14	0.20	0.2	1

SUM	2.64	2.98	6.70	11.20	27.00
-----	------	------	------	-------	-------

Text S2-A2 Step 2: Normalization

C=	0.38	0.34	0.45	0.45	0.33
	0.38	0.34	0.30	0.27	0.26
	0.13	0.17	0.15	0.18	0.19
	0.08	0.11	0.07	0.09	0.19
	0.04	0.05	0.03	0.02	0.04
SUM	1	1	1	1	1

Text S2-A2 Step 3: Consistency analysis

D=A <sub>x</sub> W=	1.00	1.00	3.00	5	9.00	X	0.388335
	1.00	1.00	2.00	3	7.00		0.307955
	0.33	0.50	1.00	2	5.00		0.161412
	0.20	0.33	0.50	1	5.00		0.107346
	0.11	0.14	0.2	0.2	1		0.034952

2.03	5.232148
1.59	5.14951

$$D = \begin{vmatrix} 0.83 \\ 0.54 \\ 0.18 \end{vmatrix}, \quad D/W = \begin{vmatrix} 5.168679 \\ 5.059658 \\ 5.031015 \end{vmatrix}$$

$$\lambda = (5.232148 + 5.14951 + 5.168679 + 5.059658 + 5.031015) / 5 = 5.13$$

$$CI = (\lambda - n) / (n - 1) = (5.13 - 5) / (5 - 1) = 0.03205$$

For RI=1.12 from Table S3.

$$CR = CI / RI = 0.03205 / 1.12 = 0.029 < 0.10 \text{ (suitable)}$$

Text S2-A3- Comparison of decision points for CP, which is one of the factors affecting decision points

CP	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Priority vector
Scenario 1	1.00	1.00	2.00	3.00	3.00	0.312509
Scenario 2	1.00	1.00	1.00	3.00	3.00	0.269651
Scenario 3	1/2	1.00	1.00	3.00	3.00	0.238072
Scenario 4	1/3	1/3	1/3	1.00	1.00	0.089884
Scenario 5	1/3	1/3	1/3	1.00	1.00	0.089884
SUM	3.17	3.67	4.67	11.00	11.00	1.00

Text S2-A3 Step 1: Pair wise comparison

A=	1.00	1.00	2.00	3	3
	1.00	1.00	1.00	3	3
	0.50	1.00	1.00	3	3
	0.33	0.33	0.33	1	1
	0.33	0.33	0.33	1	1
SUM	3.17	3.67	4.67	11.00	11.00

Text S2-A3 Step 2: Normalization

C=	0.32	0.27	0.43	0.27	0.27
	0.32	0.27	0.21	0.27	0.27
	0.16	0.27	0.21	0.27	0.27
	0.11	0.09	0.07	0.09	0.09
	0.11	0.09	0.07	0.09	0.09
SUM	1	1	1	1	1

Text S2-A3 Step 3: Consistency analysis

D=A <sub>x</sub> W=	1.00	1.00	2.00	3	3.00	X	0.312509
	1.00	1.00	1.00	3	3.00		0.269651

0.50	1.00	1.00	3	3.00	0.238072
0.33	0.33	0.33	1	1.00	0.089884
0.33	0.33	0.33	1	1	0.089884

D=	1.60		D/W=	5.112205
	1.36			5.041825
	1.20			5.054264
	0.45			5.041825
	0.45			5.041825

$$\lambda = (5.112205 + 5.041825 + 5.054264 + 5.041825 + 5.041825) / 5 = 5.06$$

$$CI = (\lambda - n) / (n - 1) = (5.06 - 5) / (5 - 1) = 0.0146$$

For RI=1.12 from Table S3.

$$CR = CI / RI = 0.0146 / 1.12 = 0.013 < 0.10 \text{ (suitable)}$$

Text S2-A4- Comparison of decision points for BMP, which is one of the factors affecting decision points

BMP	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Priority Vvector
Scenario 1	1.00	1.00	2.00	3.00	3.00	0.312509
Scenario 2	1.00	1.00	1.00	3.00	3.00	0.269651
Scenario 3	1/2	1.00	1.00	3.00	3.00	0.238072
Scenario 4	1/3	1/3	1/3	1.00	1.00	0.089884
Scenario 5	1/3	1/3	1/3	1.00	1.00	0.089884
SUM	3.17	3.67	4.67	11.00	11.00	1.00

Text S2-A4 Step 1: Pair wise comparison

A=	1.00	1.00	2.00	3.00	3.00
	1.00	1.00	1.00	3.00	3.00
	0.50	1.00	1.00	3.00	3.00
	0.33	0.33	0.33	1.00	1.00
	0.33	0.33	0.33	1.00	1.00

SUM 3.17 3.67 4.67 11.00 11.00

Text S2-A4 Step 2: Normalization

C=	0.32	0.27	0.43	0.27	0.27
	0.32	0.27	0.21	0.27	0.27
	0.16	0.27	0.21	0.27	0.27
	0.11	0.09	0.07	0.09	0.09
	0.11	0.09	0.07	0.09	0.09

SUM 1 1 1 1 1

Text S2-A4 Step 3: Consistency analysis

D=A <sub>x</sub> W=	1.00	1.00	2.00	3.00	3.00	X	0.31
	1.00	1.00	1.00	3.00	3.00		0.27
	0.50	1.00	1.00	3.00	3.00		0.24
	0.33	0.33	0.33	1.00	1.00		0.09
	0.33	0.33	0.33	1.00	1.00		0.09

D=	1.60	,	D/W=	5.112205
	1.36			5.041825
	1.20			5.054264
	0.45			5.041825
	0.45			5.041825

$$\lambda = (5.112205 + 5.041825 + 5.054264 + 5.041825 + 5.041825) / 5 = 5.06$$

$$CI = (\lambda - n) / (n - 1) = (5.06 - 5) / (5 - 1) = 0.0146$$

For RI=1.12 from Table S3.

$$CR = CI / RI = 0.0146 / 1.12 = 0.013 < 0.10 \text{ (suitable)}$$

Text S2-A5- Comparison of decision points for TP, which is one of the factors affecting decision points

TP	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Priority vector
Scenario 1	1.00	1.00	1.00	2.00	3.00	0.262412
Scenario 2	1.00	1.00	1.00	2.00	3.00	0.262412
Scenario 3	1.00	1/2	1.00	2.00	3.00	0.232412
Scenario 4	1/2	1/2	1/2	1.00	1/3	0.108626
Scenario 5	1/3	1/3	1/3	3.00	1.00	0.134137
SUM	3.83	3.33	3.83	10.00	10.33	1.00

Text S2-A5 Step 1: Pair wise comparison

A=	1.00	1.00	1.00	2.00	3.00
	1.00	1.00	1.00	2.00	3.00
	1.00	0.50	1.00	2.00	3.00
	0.50	0.50	0.50	1.00	0.33
	0.33	0.33	0.33	3.00	1.00

TOPL 3.83 3.33 3.83 10.00 10.33

Text S2-A5 Step 2: Normalization

C=	0.26	0.30	0.26	0.20	0.29
	0.26	0.30	0.26	0.20	0.29
	0.26	0.15	0.26	0.20	0.29
	0.13	0.15	0.13	0.10	0.03

	0.09	0.10	0.09	0.30	0.10	
SUM	1	1	1	1	1	
Text S2-A5 Step 3: Consistency analysis						
D=A <sub>x</sub> W=	1.00	1.00	1.00	2.00	3.00	0.26
	1.00	1.00	1.00	2.00	3.00	0.26
	1.00	0.50	1.00	2.00	3.00	0.23
	0.50	0.50	0.50	1.00	0.33	0.11
	0.33	0.33	0.33	3.00	1.00	0.13

D=	1.38		D/W=	5.247087
	1.38			5.247087
	1.25	,		5.359846
	0.53			4.897159
	0.71			5.311167

$$\lambda = (5.247087 + 5.247087 + 5.359846 + 4.897159 + 5.311167) / 5 = 5.21$$

$$CI = (\lambda - n) / (n - 1) = (5.21 - 5) / (5 - 1) = 0.05312$$

For RI=1.12 from Table S3.

$$CR = CI / RI = 0.05312 / 1.12 = 0.047 < 0.10 \text{ (suitable)}$$

Text S2-A6- Comparison of decision points for SLF, which is one of the factors affecting decision points

SLF	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Priority vector
Scenario 1	1.00	1.00	1.00	2.00	3.00	0.352445
Scenario 2	1.00	1.00	1.00	2.00	3.00	0.228916
Scenario 3	1.00	1/2	1.00	2.00	3.00	0.181269
Scenario 4	1/2	1/2	1/2	1.00	3.00	0.155182
Scenario 5	1/3	1/3	1/3	1/3	1.00	0.082188
SUM	3.83	3.33	3.83	7.33	13.00	1.00

Text S2-A6 Step 1: Pair wise comparison

A=	1.00	1.00	1.00	7.00	3.00
	1.00	0.50	1.00	2.00	3.00
	1.00	0.50	0.50	1.00	3.00
	0.50	0.50	0.50	1.00	3.00
	0.33	0.33	0.33	0.33	1.00
TOPL	3.83	2.83	3.33	11.33	13.00

Text S2-A6 Step 2: Normalization

C=	0.26	0.35	0.30	0.62	0.23
	0.26	0.18	0.30	0.18	0.23
	0.26	0.18	0.15	0.09	0.23
	0.13	0.18	0.15	0.09	0.23
	0.09	0.12	0.10	0.03	0.08
SUM	1	1	1	1	1

Text S2-A6 Step 3: Consistency analysis

D=A <sub>x</sub> W=	1.00	1.00	1.00	7.00	3.00	X	0.35
	1.00	0.50	1.00	2.00	3.00		0.23
	1.00	0.50	0.50	1.00	3.00		0.18
	0.50	0.50	0.50	1.00	3.00		0.16
	0.33	0.33	0.33	0.33	1.00		0.08

D=	2.10	,	D/W=	5.945509
	1.09			4.764374
	0.96			5.292042
	0.68			4.410489
	0.39			4.722424

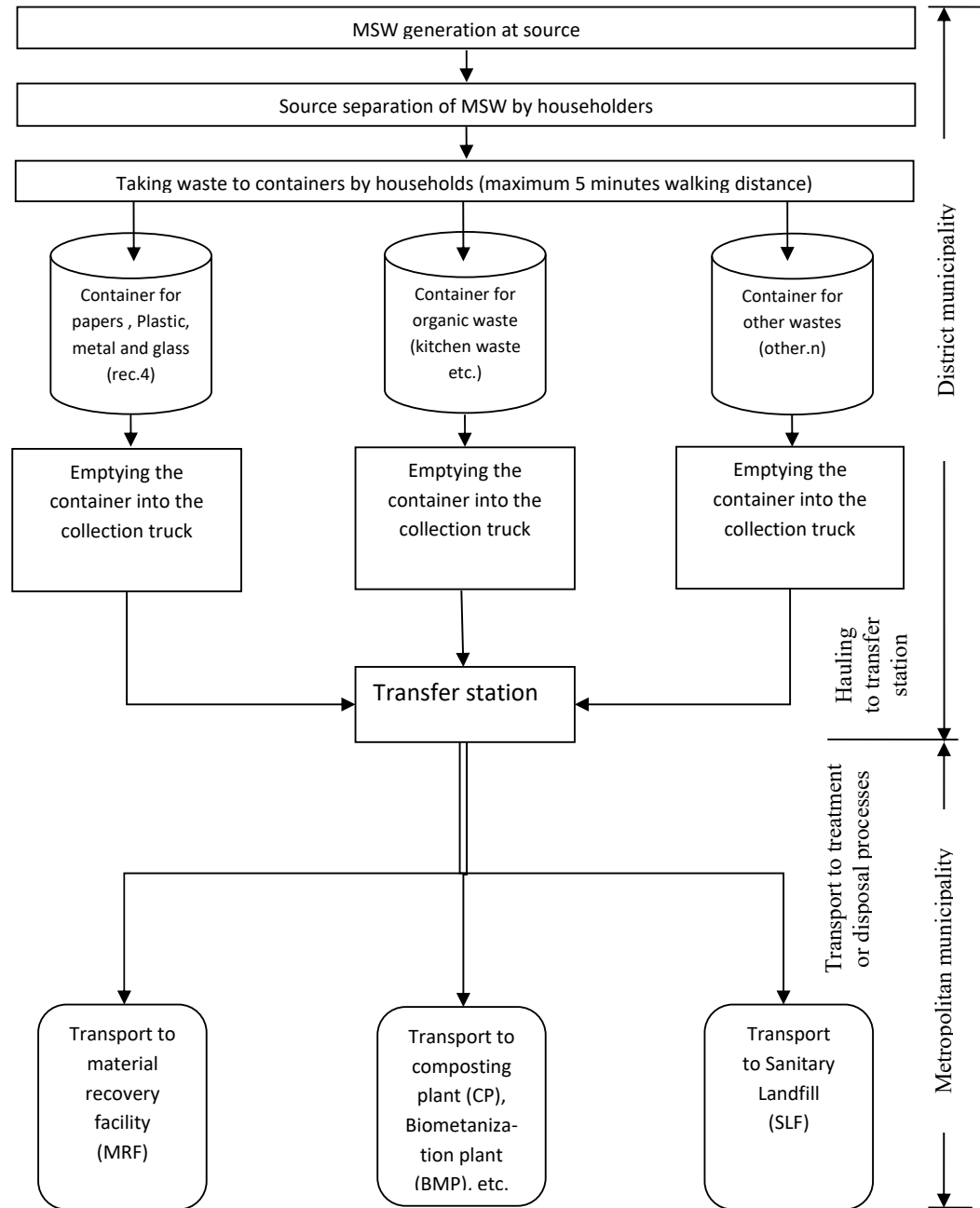
$$\lambda = (5.945509 + 4.764374 + 5.292042 + 4.410489 + 4.722424) / 5 = 5.03$$

$$CI = (\lambda - n) / (n - 1) = (5.03 - 5) / (5 - 1) = 0.00674$$

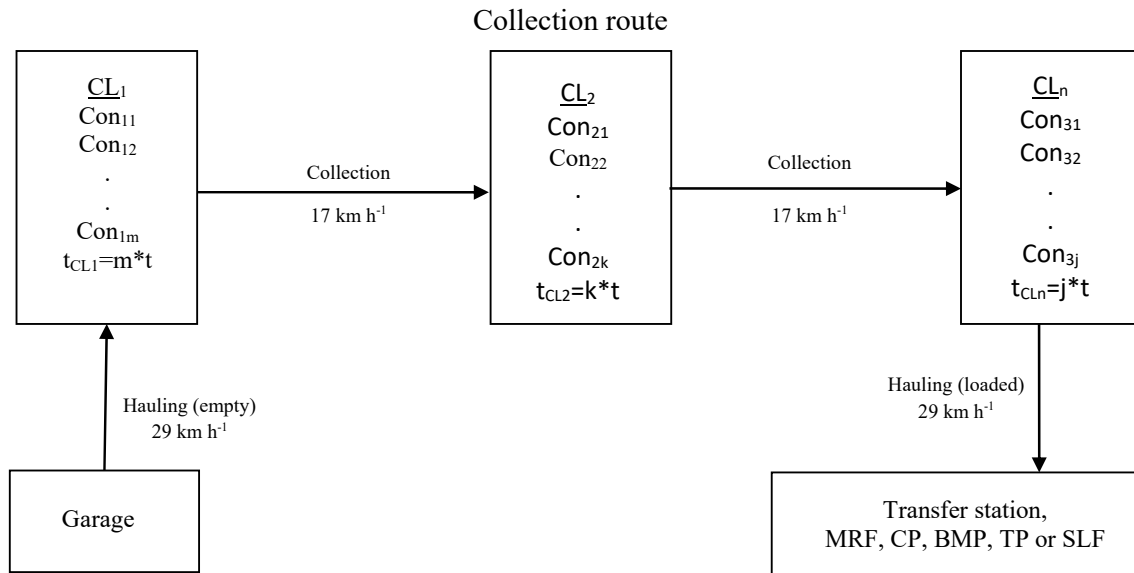
For RI=1.12 from Table S3.

$$CR = CI / RI = 0.00674 / 1.12 = 0.006 < 0.10 \text{ (suitable)}$$

**Text S3.** In this study, based on the ZWM minimum requirements, separation option at the source point (Figures S3-S4) was examined in all its aspects and the optimization of the solid waste collection process was evaluated within the scope of this option.



**Figure S3.** Triple separation systems model at the source of municipal solid wastes



**Figure S4.** Separation systems model at the source of municipal solid wastes



#### **Text S4.** General information about Beşiktaş District selected as case study area.

*History of Beşiktaş District:* Located on the Bosphorus, where it has been inhabited for several millennia, Beşiktaş has many interesting historical sites. It is thought that the region was first settled by Constantine the Great during his reign. Especially from the middle of the fifteenth century, during the Ottoman Empire, the Bosphorus villages became safe and attractive again, after the sultans had established dominance over the Black Sea coast. After the great sailor Barbarossa Hayreddin had his palace and mosque built in the district, Beşiktaş became a Bosphorus crossing established for the Ottoman armies and caravans trading in Anatolia and along the Silk Road. After the establishment of the Turkish Republic in 1923, it has become a center of attraction for the residents of the region. In addition to more historical areas such as Yıldız, Ortaköy, Kuruçeşme, Arnavutköy and Bebek, many residential areas started to form in the district in the 1950s and the district is increasing its attractiveness day by day (Beşiktaş Municipality, 22 February, 2023).

*Population:* According to the census results based on the address, the population of Beşiktaş district has decreased from 185,447 to 178,938 in the last five years (from 2017 to 2021). The resident population is generally at these levels. On the contrary, the number of households increased from 70,232 to 71,210 in the same time period. The average household size decreased from 2.50 to 2.36 in the same time period [TUIK, 2023]. The biggest population mobility in the district in the last 10 years has been the increase of the population from 2,663 to 2,010. When we look at the population declining trends, the district has a decrease of 986 people from 187,053 to 186,067 between 2011 and 2012, and 677 people from 190,033 to 189,356 between 2015 and 2016. We see that a decrease of 3,909 people this year was the largest population movement in the last 10 years. When we look at the population change of the last 10 years in Beşiktaş District, 1,000 people decreased from 2008 to 2010 and 3,000 people rose after 2010. In 2011, we see that a decrease of 1,000 people, a rise of 4,000 people by 2015, and the population of the district, which increased over 190 thousand in 2015, fell suddenly. Etiler and its vicinity, which has been converted to the city plan as a “Prestige Zone” with its modern urban layout, have transformed into many residential buildings as a stage of rapid transformation. Moreover, It is a district where many historical monuments such as Yıldız Palace and Çırağan Palace are also located. Although there is a general decrease in the settled population by years, 2 million people pass through Beşiktaş during the day (Beşiktaş Municipality, 22 February, 2023).

*Climate:* The annual average temperature in Beşiktaş district is 18 degrees Celsius during the day and 14 degrees Celsius at night. The lowest temperatures took place in January and were measured as 9 and 5 degrees Celsius during the day and night, respectively. While the annual average precipitation was 83 mm, the highest precipitation was 135.55 mm (in January) and the lowest precipitation was 25.63 mm (in August). Humidity, on the other hand, is 72% on annual average, with the highest 77% (January) and the lowest 68% (In July and In September) (World weather, 22 February, 2023).

*Geography of Beşiktaş District:* Beşiktaş district is one of the oldest settlements in Istanbul. Beşiktaş is a suburb of Istanbul situated on the European side of the city within the boundaries of the Grater Istanbul Municipality. It is surrounded by Bosphorus on the east, the suburb of Sarıyer on the north, Şişli on the west and Beyoğlu on the south. Directly across the Bosphorus is the municipality of Üsküdar. It covers area of 1,520 hectares with an 8,375 cost line along the Bosphorus. Although it is a small district in terms of its surface area (11 km<sup>2</sup>), it consists of twenty three neighborhoods (Figure S5), four boulevards, one hundred and nine avenues, nine hundred forty nine streets.

*Municipal solid waste management:* In this study, the resident population during the pandemic process and the population coming as guests during the day and the urban solid waste generated by the settled population in the first place were determined and the collection system was rearranged. The amount of waste per capita was obtained from the Environmental Status Report as 1.3 kg for Istanbul. In the light of these data, it has been calculated that the annual urban solid waste amount of Beşiktaş district with a population of 182,657 is 86,670 tons. MSW is collected by using approximately 5,000 containers (galvanized, plastic and multi-purpose containers) with a volume of 0.77 cubic meters in Beşiktaş district. Daily changes of MSW amount collected in Beşiktaş District are presented in Figure 2

for the year 2020. Moreover, Monthly variations of the MSW and unit solid waste generated in Beşiktaş District from 2017 to 2020 are given at Figure S8.

**Table S4.** The composition of MSW in Beşiktaş District

<i>i</i>	The components of MSW	Mass fractions of MSW, %	Specific weight of MSW components, kg/m <sup>3</sup>
1	Papers&cardboards	27.55±3.01	110±108
2	Glasses	4.65±0.02	194±381
3	Plastics	13.08±0.57	100±106
4	Metals	1.19±0.22	540±1216
-	P <sub>rec.4</sub>	46.47	-
-	Y <sub>rec.4</sub>	-	126
5	Food wastes (organics)	34.95±2.13	825±703
6	Electrical&electronical wastes	0.14±0.16	270±209
7	Domestic hazardous wastes	1.24±0.19	220±109
8	Textiles	1.48±0.03	185±119
9	Diapers	1.16±0.23	400±226
10	Other organics	12.80±0.06	300±160
11	Other inorganics	1.76±0.09	810±809
-	P <sub>other.6</sub>	53.53	-
-	Y <sub>other.6</sub>	-	656

It is foreseen from Table S4 that 4 of these components (metal, cardboard and paper, glass and plastic or rec.4) be collected in one container, organic wastes in the other container and the remaining 6 components (textile, etc.) in another container (this is one of the minimum requirements of ZW regulation in Türkiye). One of the most important processes in this study is the calculation of a specific weight for 11 solid waste components with different specific weights. In order to determine the container requirement with a volume of 0.77 m<sup>3</sup> (Text S4), which is planned to be used in the process of the minimum requirement of MSW within the scope of zero waste management [TCCB, 2023a]. Total mass fraction of selected waste component and the mean specific weights of the waste components for collection were calculated by using Eq.S7 and Eq.S8, respectively.

$$P_c = \sum_{i=1}^n p_i \quad (S7)$$

$$\gamma_c = \frac{\sum_{i=1}^n p_i \gamma_i}{\sum_{i=1}^n p_i} \quad (S8)$$

where,

$P_c$  is total mass fraction of selected waste component, %

$\gamma_c$  is mean specific weight of selected waste component, kg/m<sup>3</sup>

$p_i$  is mass fraction of any  $i$ th MSW component, %

$\gamma_i$  is specific weight of any  $i$ th MSW component, kg/m<sup>3</sup>

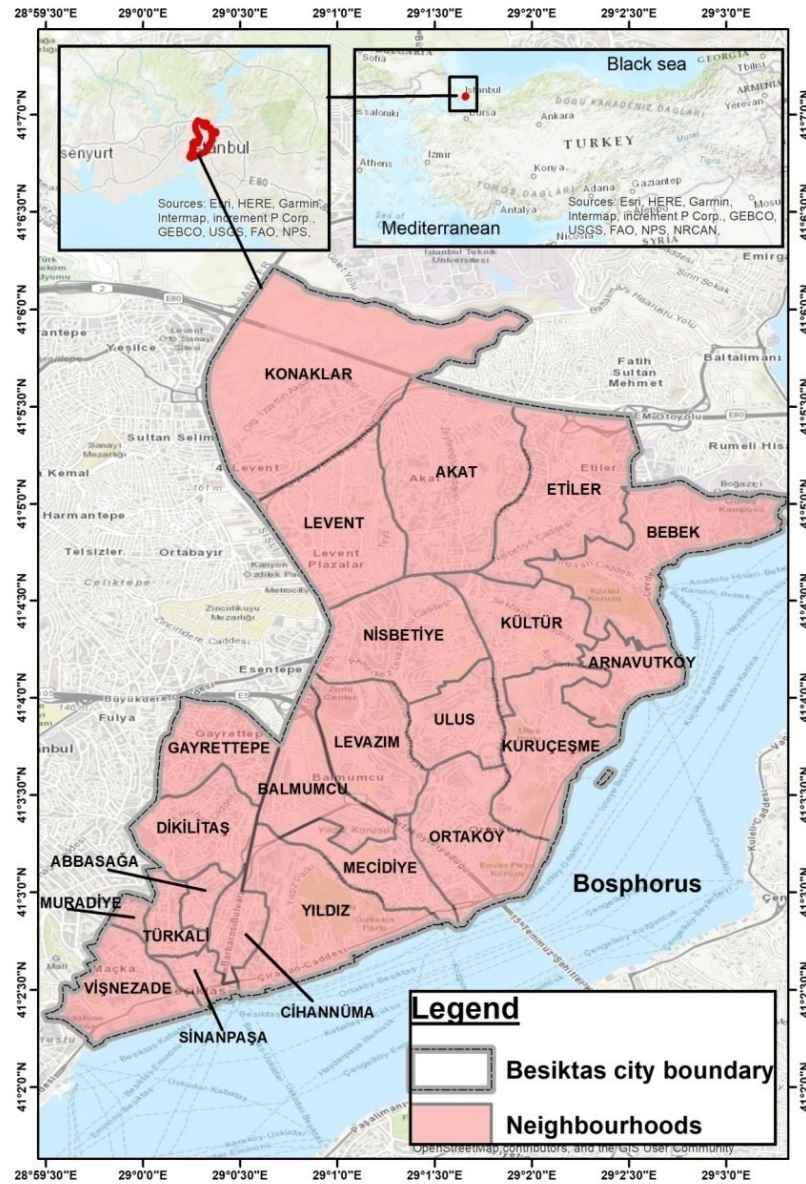
$i$  is the  $i$ th MSW component (The first column of the Table S4.  $i=1$  represents paper&cardboard,  $i=5$  represents organic kitchen waste, etc.).

Required container number and waste collection vehicle number for MSW were calculated by using Eq.S9 and Eq.S10, respectively.

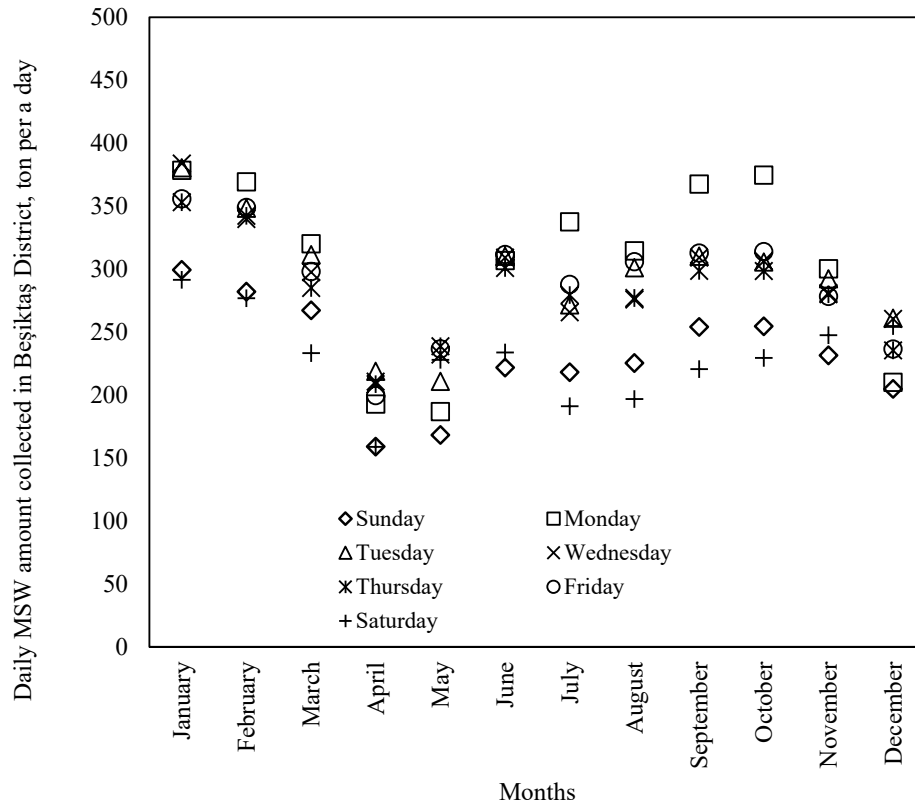
$$NoC_i = \frac{W_r}{V_c \gamma_c} \quad (S9)$$

$$NoV_i = \frac{W_r}{V_v \alpha_v} \quad (S10)$$

where;  $V_k$  is volume of a container,  $NoC_i$  is any container number, and  $W_r$  is the amount of domestic solid waste per route in the study area (kg/route).  $V_v$  is volume of any waste collection vehicle (WCV),  $NoV_i$  is any WCV number, and  $\alpha_v$  is the compaction factor of any WCV.

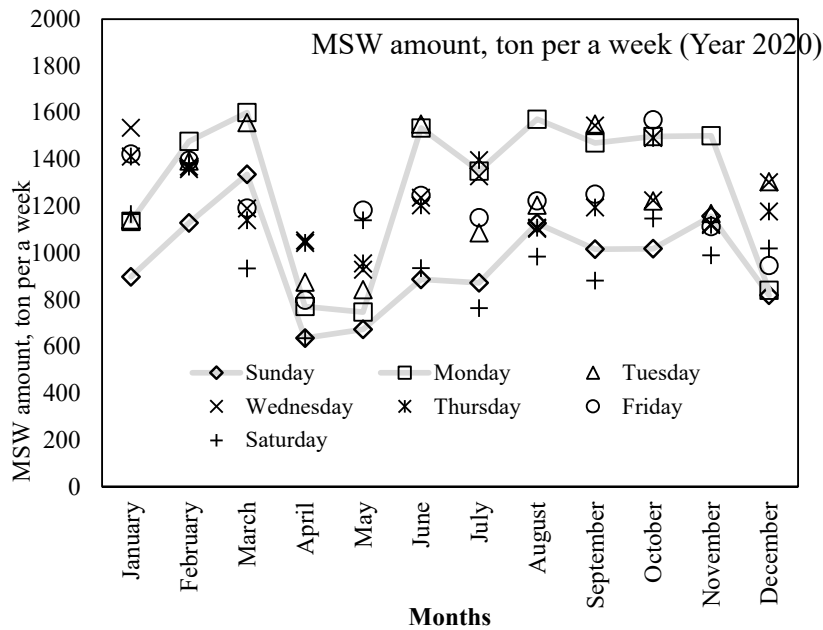


**Figure S5.** The neighborhoods of Beşiktaş District Municipality

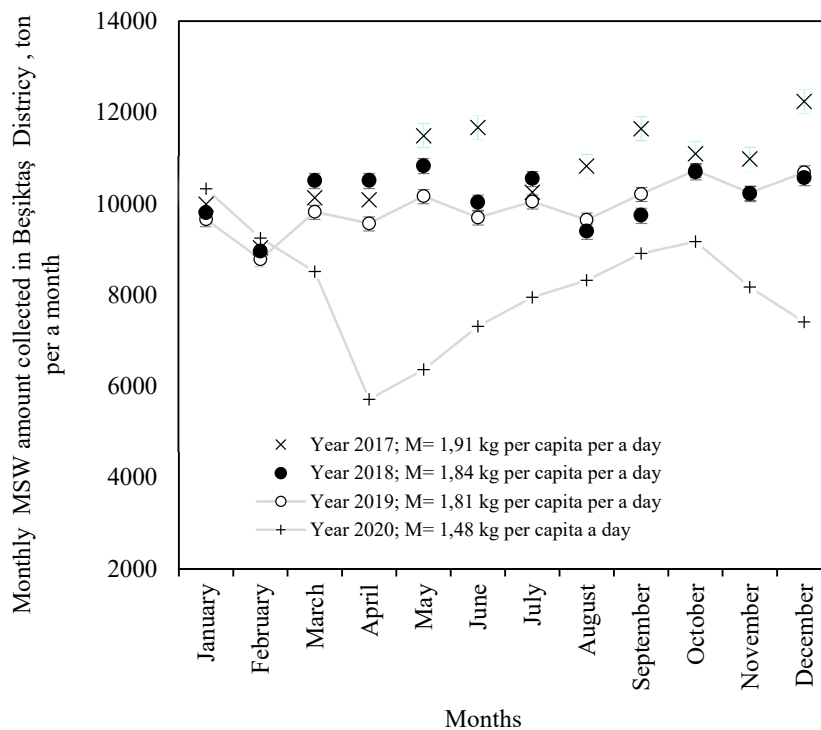


**Figure S6.** Daily changes in mass of municipal solid waste collected in Beşiktaş District in 2020.

Figure S6 gives the daily solid waste amounts collected every month in 2020. On a monthly average, the highest amount of waste is collected on Mondays (305 ton/day) and the lowest amount of waste is collected on Saturdays (230 ton/day). The amount of solid waste collected by municipal vehicles on an average of 12 months is 275 ton/day. As seen in Figure S6, the decrease in the amount of solid waste collected between February 2020 and April 2020 was due to the curfew imposed due to the Covid 19 pandemic. In this process, the fact that the people did not go out to the cold and the lack of intensive human circulation in Beşiktaş caused a decrease in the amount of solid waste generated and thus the amount of solid waste collected. While an average of 275 tons of solid waste was collected daily in April of previous years, the average for April 2020 was 193 ton/day.



**Figure S7.** Weekly changes in mass of municipal solid waste collected in Beşiktaş District in 2020.

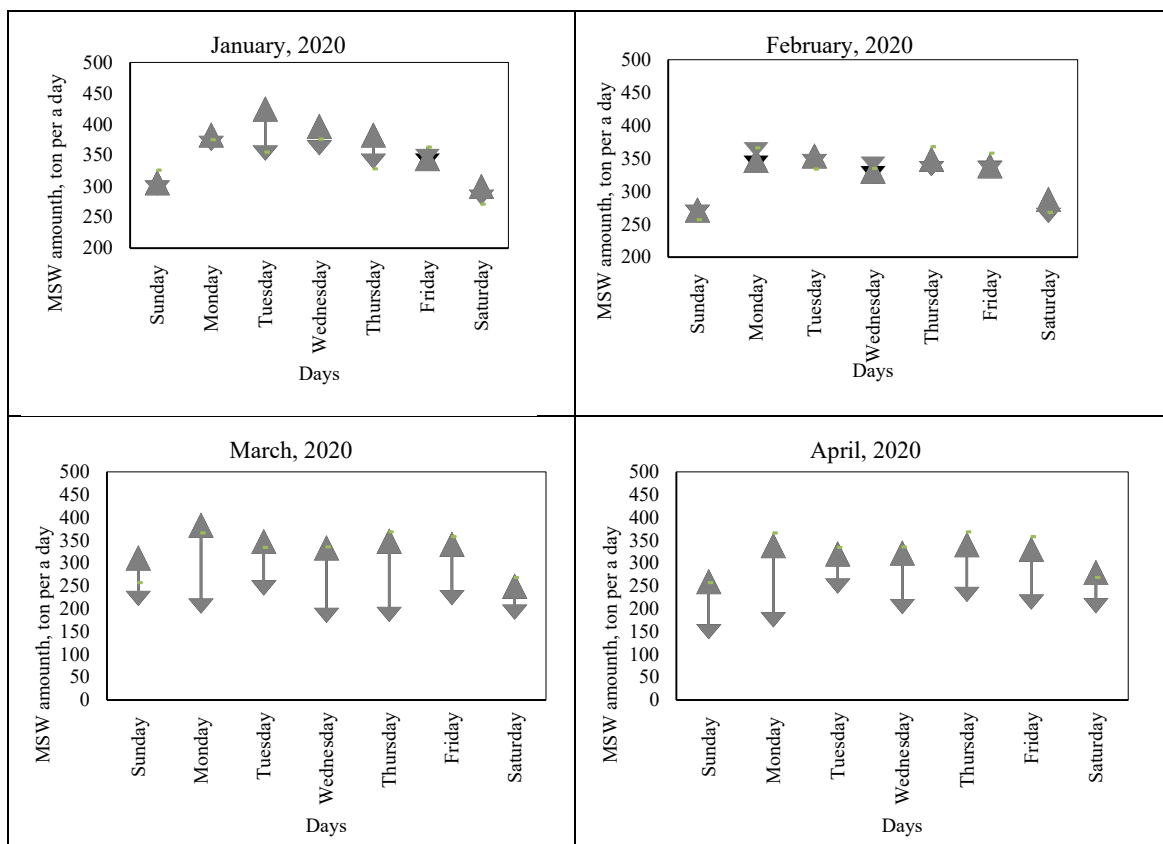


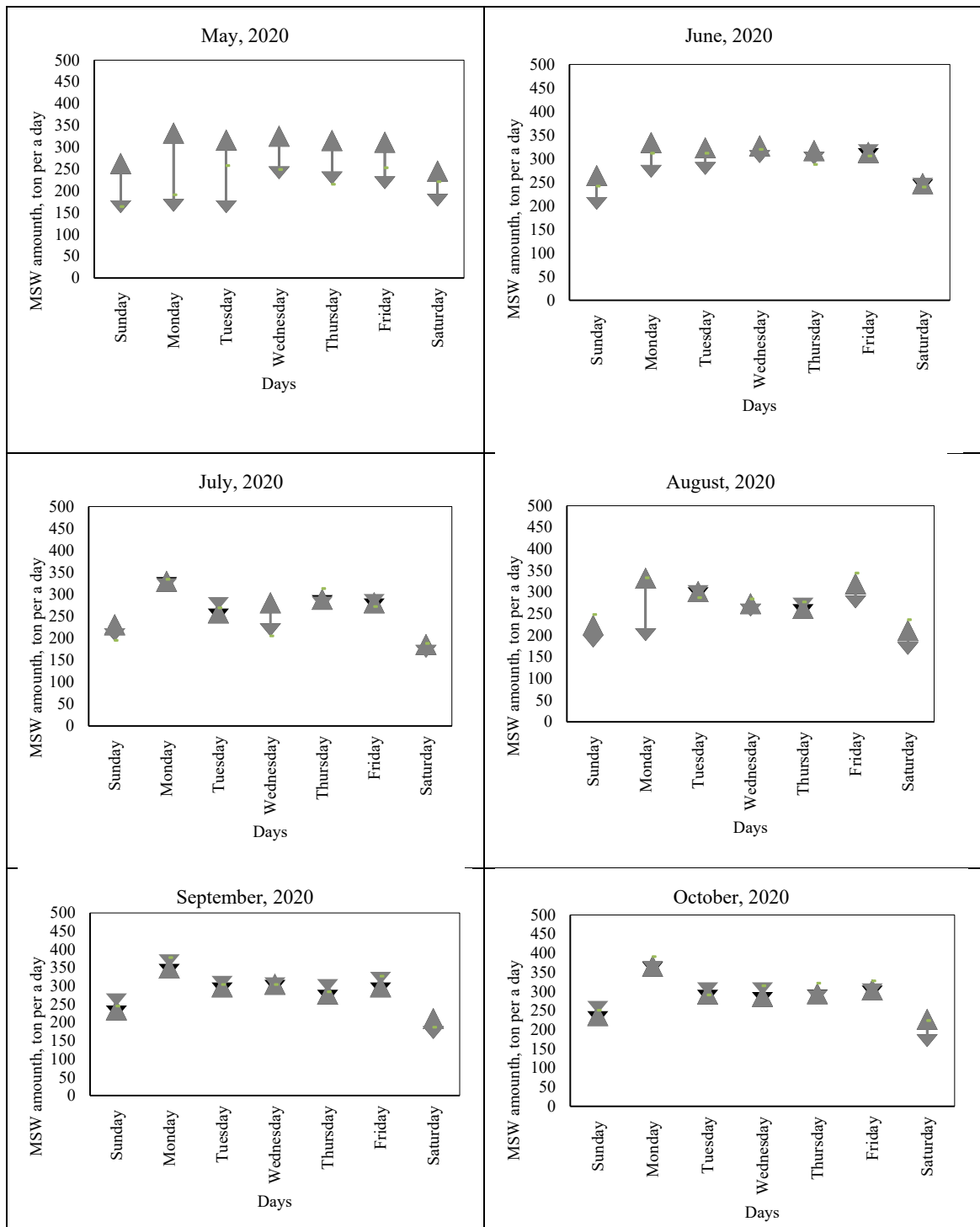
**Figure S8.** Monthly variations of the municipal solid waste and unit solid waste generated in Beşiktaş District in 2017-2020.

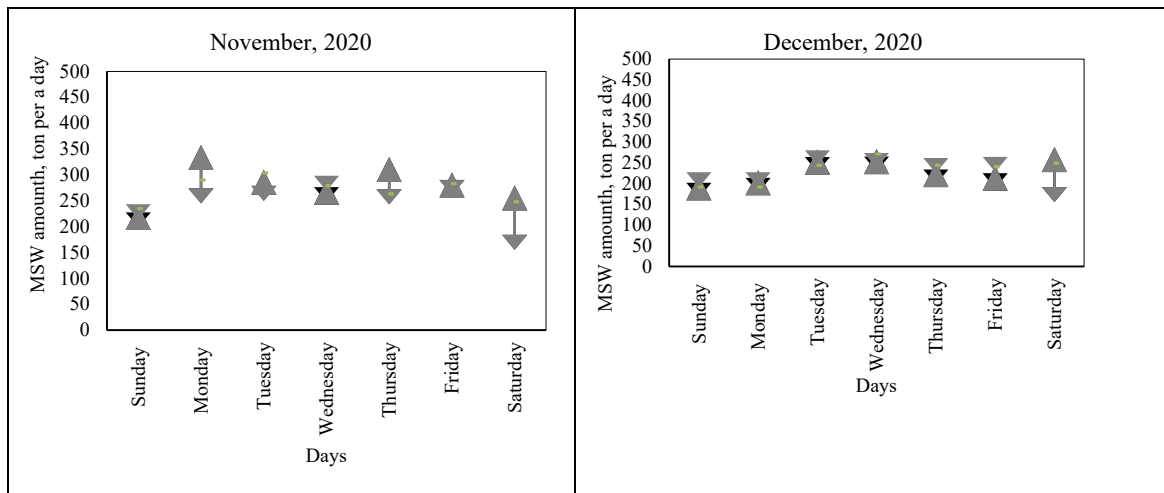
Figure S8 shows the average amount of solid waste collected each month between 2017 and 2020. On a monthly average, the highest amount of waste was collected in the range (12,239 ton/month) and the lowest amount of waste was collected in April of 2020 (5,715 ton/month). The amount of solid waste

collected by municipal vehicles on an average of 12 months was 10,795 ton/month. Due to the curfew imposed due to the Covid 19 pandemic, the lowest waste collection took place in April 2020. Due to the amount of solid waste generated due to the Covid 19 pandemic, the amount of solid waste collected has decreased by 43% in mass. It is also seen in Figure S8 that the unit solid waste production between 2017 and 2020 varies between 1.48 and 1.91 kg/person.day.

In this study; a database of solid waste collection points and waste quantities originating from homes and workplaces where Beşiktaş Municipality is responsible for the collection of urban solid waste has been established in Beşiktaş District. The tours of the existing solid waste collection vehicles should be examined and optimization should be made in terms of collecting the waste with the lowest cost and the highest occupancy in the shortest time and distance and in terms of route distances. According to the Zero Waste Regulation Article 3 (2) prepared based on the Environment Law No. 2872 [TCCB, 2023a]. District municipalities with a population of less than 25,000 had to install the ZWM management system by December 31, 2021. Therefore, Beşiktaş Municipality has to establish the system in accordance with the specified deadline and still continues to revise its system effectively.







**Figure S9.** Daily MSW amount in Beşiktaş District Municipality in 2020



### Text S5. Determination of residence density in the sample study area.

In the study, Beşiktaş district was selected for the sample residential area in order to make a statistical analysis according to the residence density. For Beşiktaş district, a classification based on housing density was made by considering the number of independent houses and workplaces in 23 neighborhoods. In here, n=23 (number of neighborhoods in the adjacent area of Beşiktaş District Municipality), the lowest value of the RoR was determined as 0.3114 and the highest value as 0.9374 (from Eq.1 and presented at Table S5 in Text S5).

**Table S5.** Preliminary studies on RDN, WDN and ODN depending on the neighborhoods in Beşiktaş District and the number of residences and workplaces built within the scope of ZWM

The name of Neighborhood	The population of Neighborhood	The number of workplace	The number of residence	The number of all units	The amount of unit solid waste (kg/person/day)	The rate of residence	The category of Neighborhood
(1)	(2)	(3)	(4)	(3)+(4)+(5)	(6)	(7) *	(8)
Abbasağa	5502	373	2690	3063	2,05	0,8782	RDN
Akat	15161	1380	6777	8157	2,24	0,8308	ODN
Arnavutköy	3788	530	2314	2844	1,64	0,8136	ODN
Balmumcu	3455	981	1159	2140	2,98	0,5416	ODN
Bebek	5734	640	3026	3666	1,89	0,8254	ODN
Cihannuma	3882	1057	2141	3198	1,81	0,6695	ODN
Dikilitaş	16889	1405	7722	9127	2,19	0,8461	RDN
Etiler	11703	1233	5381	6614	2,17	0,8136	ODN
Gayrettepe	14417	1679	5841	7520	2,47	0,7767	ODN
Konaklar	15881	636	4996	5632	3,18	0,8871	RDN
Kuruçeşme	3039	305	1454	1759	2,09	0,8266	ODN
Kültür	4755	969	2354	3323	2,02	0,7084	ODN
Levazım	6166	675	3103	3778	1,99	0,8213	ODN
Levent	3045	1503	1145	2648	2,66	0,4324	WDN
Mecidiye	10250	1096	4934	6030	2,08	0,8182	ODN
Muradiye	4903	198	2886	3084	1,70	0,9358	RDN
Nispetiye	12262	1605	5585	7190	2,20	0,7768	ODN
Ortaköy	9440	556	4656	5212	2,03	0,8933	RDN
Sinanpaşa	2480	2594	1173	3767	2,11	0,3114	WDN

The name of Neighborhood	The population of Neighborhood	The number of workplace	The number of residence	The number of all units	The amount of unit solid waste (kg/person/day)	The rate of residence	The category of Neighborhood
Türkali	10356	958	5333	6291	1,94	0,8477	RDN
Ulus	7041	200	2997	3197	2,35	0,9374	RDN
Vişnezade	6317	1023	3591	4614	1,76	0,7783	ODN
Yıldız	6573	683	2935	3618	2,24	0,8112	ODN
<b>Total</b>	<b>183039</b>	<b>22279</b>	<b>84193</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>
Mean	7958.22	968.65	3660.57	4629.22	2,16	0,7731	-
Standard dev.	4541.45	564.99	1877.10	2058.35	0,37	0,1535	-
Range	14409	1207	6549	5360	0,0729	0,626	-
Number of class	4,7958	4,7958	4,7958	4,7958	4,7958	0,47958	-
Clas width	2881,8	241,4	1309,8	1072	0,0146	0,1252	-

(\*)Rate of residence (RoR)= (Number of residence)/( Number of residence+ Number of workplace)

The number of classes was calculated as 4.79 and the integer value was taken as 5 (NoC=5 from Eq.2). The distribution range was calculated as 0.626. Moreover, class range (from Eq.3) was calculated as 0.2087 and 0.1252 for class number of 5 and 3, respectively. The results obtained by making other calculations in a similar way for class number of 3 and are given in Table S6. Table S6. Residence dense neighborhood (RDN), workplace dense neighborhood (WDN) and other dense neighborhood (ODN) classes according to the number of residences and workplaces in the neighborhoods.

**Table S6.** RDN, WDN and ODN classes according to the number of residences and workplaces in the neighborhoods

Classes	Lower value	Upper value	Frequency	The category of neighborhood
(1)	()	(3)	(4)	(5)
1	0,3114	0,5201	2	WDN
2	0,5201	0,8315	14	ODN
3	0,8315	1,1429	7	RDN
Total			23	-

As can be seen in Table S6, the neighborhoods in Beşiktaş District are grouped into 3 classes: class 1 (0.3114-0.5201), class 2 (0.5201-0.8315) and class 3 (0.8315-1.1429). The number of neighborhoods per class is shown in column (5) in Table S6. Information about which group the 23 neighborhoods in Beşiktaş District will belong to is shown in Table S5 in columns (7) and (8). For example; since the residence ratio of Konaklar district is 0.8871, it is in the 3rd class. As can be seen from the column (5) in Table S6, class 3 is considered within the scope of residence density.

**Text S6.** Within the scope of the modeling study, the application was planned in 3 neighborhoods in the Beşiktaş district of Istanbul, which were selected as the study area. The current MSW collection route information in these cases is given in Table S7. In Table S7, route 1-3 is located in Konaklar neighborhood representing RDN type neighborhoods, route 4-6 is in Nispetiye neighborhood representing ODN type neighborhoods and route 7 is in Sinanpaşa District representing WDN type neighborhoods.

**Table S7.** Optimized current routes (MSW collection in one container as mixed)

Route Name	Route distances, m	Route time, min	Vehicle capacity, m <sup>3</sup>
Route 1	5805	154	13
Route 2	10722	178	13
Route 3	6814	68	20
Route 4	3653	35	15
Route 5	7735	257	15
Route 6	7274	194	20
Route 7	7492	106	7

As a result of the studies carried out within the scope of ZWM, the new MSW collection route information planned in the 3 neighborhoods is given in Table S8. In Table S8, route 8-13 was planned in Konaklar Neighborhood representing RDN type neighborhoods, route 14-19 was planned in Nispetiye Neighborhood representing ODN type neighborhoods and route 20-22 was planned in Sinanpaşa Neighborhood representing WDN type neighborhoods.

**Table S8.** Optimized routes based on ZWM (scenario 3: MSW collected in three different containers)

Route Name	Route distances, m	Route time, min	Vehicle capacity, m <sup>3</sup>	Waste type
Route 8	11324	89	7	organic
Route 9	8590	71	7	organic
Route 10	7249	89	7	other.6
Route 11	9513	96	7	other.6
Route 12	7427	76	7	rec.4
Route 13	10729	75	7	rec.4
Route 14	17077	159	7	organic

Route Name	Route distances, m	Route time, min	Vehicle capacity, m <sup>3</sup>	Waste type
Route 15	5655	39	7	organic
Route 16	7002	101	7	other.6
Route 17	8774	106	7	other.6
Route 18	7926	78	7	rec.4
Route 19	6966	72	7	rec.4
Route 20	8309	76	7	organic
Route 21	8383	91	7	other.6
Route 22	8309	61	7	rec.4

rec.4: Metal, plastic, paper, glass;

other.6: Other materials in Table S4 except rec.4 and organic

The number of containers that will be needed within the scope of ZWM in each neighborhood is given in Table S9, depending on the types of waste components.

**Table S9.** Required numbers of containers on routes with the scope of ZWM (scenario 3)

Routes	The category of neighborhood	W <sub>r</sub> , kg/route	Container numbers with a volume of 0.77 m <sup>3</sup>			
			rec.4	organics	other.6	Total
Route 8	RDN	5,000	27	3	5	35
Route 9	RDN	3,200	18	2	3	23
Route 10	RDN	2,560	14	2	3	19
Route 11	RDN	2,560	14	2	3	19
Route 12	RDN	4,300	23	3	4	30
Route 13	RDN	3,140	17	2	3	22
Route 14	ODN	7,680	42	5	5	52
Route 15	ODN	2,400	13	2	2	17
Route 16	ODN	2,887	16	2	3	21
Route 17	ODN	2,887	16	2	3	21
Route 18	ODN	4,300	23	3	4	30
Route 19	ODN	4,061	22	3	4	29

Routes	The category of neighborhood	W <sub>r</sub> , kg/route	Container numbers with a volume of 0.77 m <sup>3</sup>			
			rec.4	organics	other.6	Total
Route 20	WDN	2,160	12	2	3	17
Route 21	WDN	1,198	7	1	1	9
Route 22	WDN	1,433	8	1	2	11
Total	-	-	272	35	11	355

The number of collection vehicles with 13 and 7 m<sup>3</sup> useful volumes that will be needed within the scope of ZWM in each neighborhood are given in Table S10.

**Table S10.** Required numbers of containers on routes with the scope of ZWM (scenario 3)

Routes	The category of neighborhood	W <sub>r</sub> , kg/route	NoVi, vehicle or route per a day		
			rec.4, Vi:13 m <sup>3</sup>	organics, Vi:7 m <sup>3</sup>	other.6, Vi:7 m <sup>3</sup>
Route 8	RWD	5000	0,6	0,3	0,2
Route 9	RWD	3200	0,4	0,2	0,1
Route 10	RWD	2560	0,3	0,2	0,1
Route 11	RWD	2560	0,3	0,2	0,1
Route 12	RWD	4300	0,5	0,3	0,2
Route 13	RWD	3140	0,4	0,2	0,1
Route 14	RWD	7680	1,0	0,4	0,2
Route 15	RD	2400	0,3	0,2	0,1
Route 16	RD	2887	0,4	0,2	0,1
Route 17	RD	2887	0,4	0,2	0,1
Route 18	RD	4300	0,5	0,3	0,2
Route 19	RD	4061	0,5	0,3	0,2
Route 20	WD	2160	0,3	0,2	0,1
Route 21	WD	1198	0,2	0,1	0,04
Route 22	WD	1433	0,2	0,1	0,1

As can be seen from Table S10; only wastes to be taken to MRF facilities (rec.4: paper+plastic+metal+glass) in route 8 and route 11 must be collected daily. There is no harm in collecting the wastes on other routes -with the vehicles with the specified useful volume - every other day or every few days.

**Text S7.** Most of the research has focused on waste management costs; few have considered environmental impacts in addition to the cost of collection/transportation. Most of the research focuses on final disposal. In real terms; while 50-75% of waste management costs are spent on collection/transport in developed countries, this rate can reach 70-90% in developing countries. Information on MSW disposal costs as a literature summary is given in Table S11.

**Table S11.** The disposal costs of MSW [Apaydin, 2004]

Processes	Properties	Unit costs	Reference
Collection	<b>55,000 households</b>	<b>***0.22-1.06 USD/min</b>	<b>2022 (This study)</b>
	57,000 households	0.04-0.06 USD/km.t	Apaydin, 2004
	57,000 households	9.3 USD/t	Apaydin, 2004
	Istanbul/Türkiye	18.1 USD /t	Karadağ and Şakar, 2003
	5,000 households	0.07-0.21 USD /km.t	Modak and Everett, 1996
	-	7.96 USD /t	Agunwamba, 1998
	Istanbul/Türkiye	31.53 USD /t	Yaman, 2012
Collection & transportation	<b>55,000 households</b>	<b>0.11-0.53 USD /min</b>	<b>2022 (This study)</b>
	57,000 households	0.02-0.04 USD/km.t	Apaydin, 2004
	57,000 households	4.3 USD/t	
	5,000 households	0.03-0. USD/km.t	Modak and Everett, 1996
	Istanbul/Türkiye	8.16 USD /t	Yaman, 2012
	-	25.0-37.9 USD/t	Dilek et al., 2002
	Thailand	*2.9-10.4 USD/t	Danteravanich and Siriwong, 1998
Transfer station	Sweden	*21 USD/t	Ljungren, 1996
	Sweden	**105 USD/t	Ljungren, 1996
	Istanbul/Türkiye	5 USD/t	İSTAÇ, 1997
Collection, transportation & Sanitary landfill	698,400 t MSW/year	9.4 USD/m <sup>3</sup>	Modak and Everett, 1996
	95,200 t MSW /year	3.1 USD/m <sup>3</sup>	
	22,509 t MSW /year	5 USD/t	Movassaghi, 1993
	-	2.35 USD/t	Güllü, 1990
	New York	143 USD/ton	Clark, 1993
	Istanbul	49.40 USD/ton	Yaman, 2012
* With transfer station			
**No transfer station			
***Only up to the transfer station			

MSW collection costs of Beşiktaş Municipality are calculated considering the annual average costs for year 2020 and are given in Table S12.

**Table S12.** Current MSW collection costs in study area based on route distance

Capacity of collection vehicle, m <sup>3</sup>	Mean cost, US\$/minute			
	Vehicle	Driver	Worker	Total
13-15	0.13	0.02	0.04	0.19
11-12	0.11	0.02	0.04	0.17
7-8	0.08	0.02	0.04	0.14
20	0.41	0.02	0.04	0.47
15	0.28	0.02	0.02	0.32
5	0.07	0.02	0.02	0.11

Table S12 shows the unit collection costs obtained according to the useful volumes of the collection vehicles. Unit collection costs include worker wages and vehicle fuel and maintenance costs. Unit collection costs tend to increase depending on vehicle useful volumes.

**Table S13.** Information about MSW collection routes in the study area

Routes of Collection/ hauling vehicle	Distance between the garage and the first container, km	Distance between the last container and the transfer station, km	Collection/ hauling vehicle velocity, km/h
Route 1	0.52	14.9	35.74
Route 2	0.96	15.8	31.60
Route 3	0.97	15.8	31.60
Route 4	4.15	9.1	27.30
Route 5	4.25	9.2	27.60
Route 6	3.9	9.0	27.00
Route 7	8.1	6.4	19.20
Route 8	1.4	27.0	28.42
Route 9	0.7	27.7	28.66
Route 10	0.9	27.5	28.45
Route 11	0.7	27.7	28.66
Route 12	0.7	27.7	28.66
Route 13	0.7	27.7	28.63
Route 14	4.1	31.0	28.62
Route 15	4.2	30.9	28.52
Route 16	4.1	31.0	28.62
Route 17	4.2	30.9	28.52
Route 18	4.1	31.0	28.62
Route 19	4.2	30.9	28.52
Route 20	6.4	33.1	27.97
Route 21	6.4	33.1	28.37
Route 22	6.4	33.1	28.37
Mean	3.3	24	29
Std.	2.3	9.3	2.8

**Text S8:** ArcGIS Desktop 10.5 is a GIS-aided method. It has many extensions, such as the ArcGIS Network Analyst which solves the network problem as a route, service area, and closest facility; OD Cost Matrix solvers; VRP; or location-allocation problem. The routing solvers are based on the Dijkstra algorithm [Dijkstra 1959] data, and solved operations. The VRP solver starts by generating an origin-destination matrix of shortest-path costs between all collection nodes (gather site) and depot locations along the network. Using this cost matrix, the algorithm constructs an initial solution by inserting the nodes, one at a time, onto the most appropriate route. The initial solution is then improved by re-sequencing the nodes on each route as well as by moving nodes from one route to another and exchanging nodes between routes. [Esri 2006]. Studies within the scope of GIS were carried out in 3 stages: Moreover, the pick-up time for each container is determined as 2 minutes and the average speed of the collection vehicle is selected as 20 km/h by using in situ observation in the study area and previous studies [Apaydın, 2004; Apaydın and Gönüllü, 2007; Apaydın and Gönüllü, 2008; Apaydın and Gönüllü, 2011].



**Text S9:** Emission factors ( $f_i$ ) for CO<sub>2</sub>, NO<sub>x</sub>, HC, CO and PM emissions were selected as 893.5, 13.81, 1.34, 0.43 and 0.767 g per km, respectively. Furthermore, fuel consumption and smoke capacity of the engine were selected as 32.21 liter per 100 km and 1.47 per meter, respectively. The expected emissions per route for each pollutant were calculated using Eq. S11.

$$EE_i = f_i R_j \quad (S11)$$

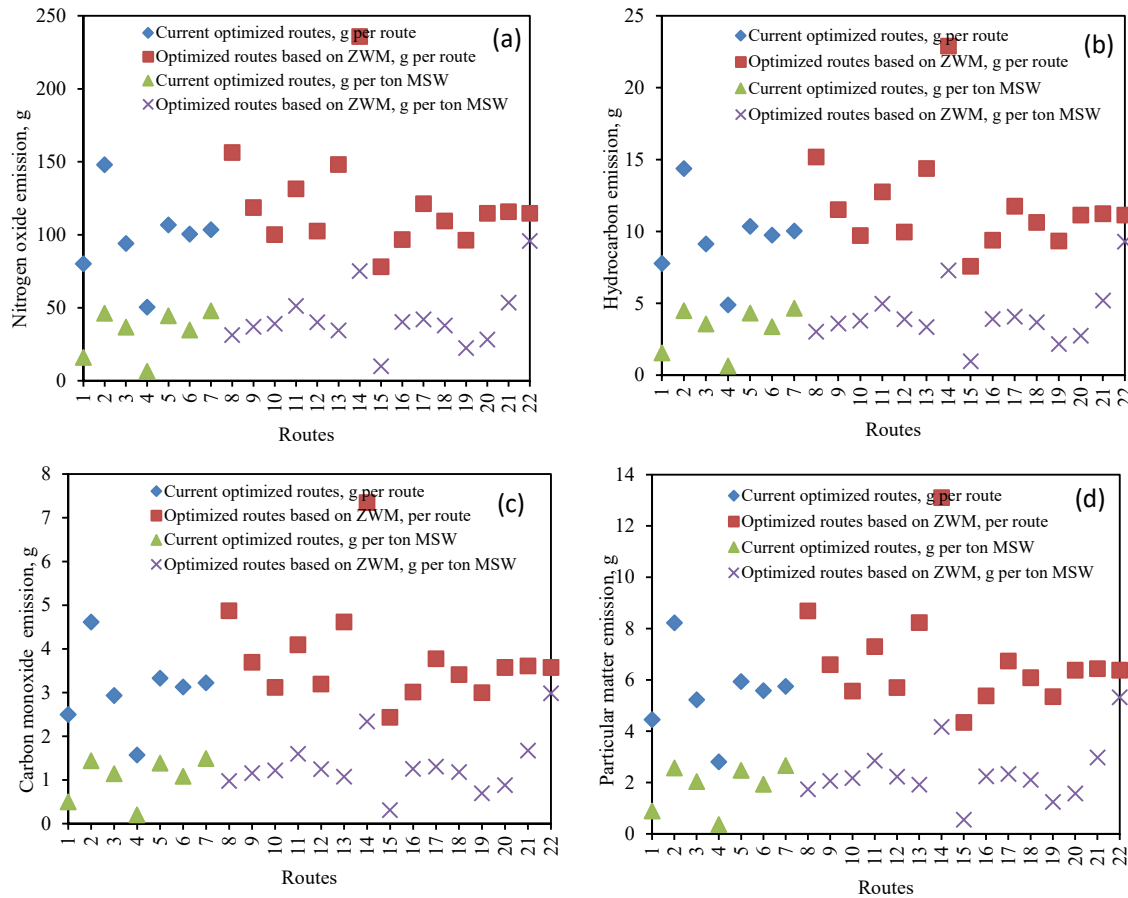
where;  $EE_i$  represents the amount of each pollutant  $i$  generated during the collection process (g/route),  $f_i$  the emission factor based on the distance traveled for each pollutant (g/km),  $R_j$  the distance traveled by each collection vehicle during each route duration (km/route)

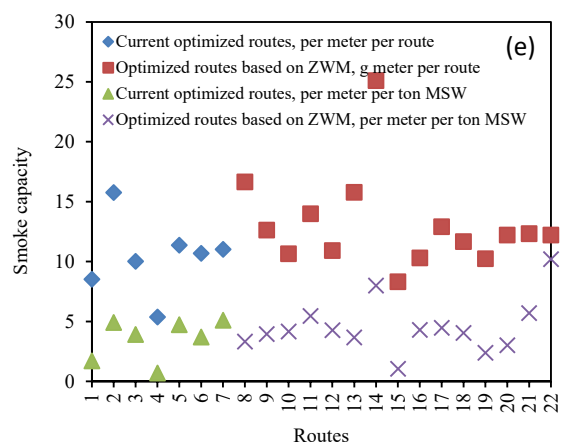
Depending on the amount of waste collected in each route, the pollutant index values ( $C_{EI}$ , g emission per collected kg MSW per route) are given in Eq.S12.

$$C_{EI} = \frac{EE_i}{W_{R_j}} \quad (S12)$$

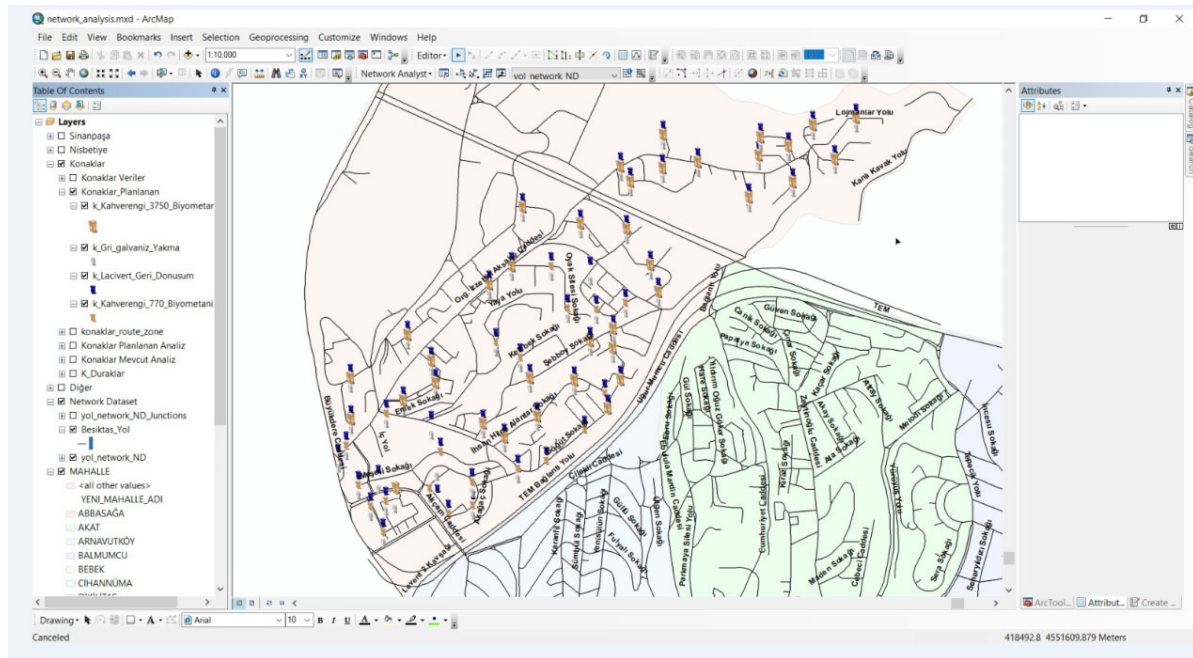
where;  $W_{R_j}$  represents the mass amount of solid waste collected during each route (kg/route).

Exhaust emissions likely to occur on both optimized existing routes (routes from 1 to 7) and optimized new routes determined within the scope of ZWM (routes from 8 to 22), grams per ton of waste collected and km of route traveled as given in Figure 4 for CO<sub>2</sub> emission and in Figure S10 for the other emissions.

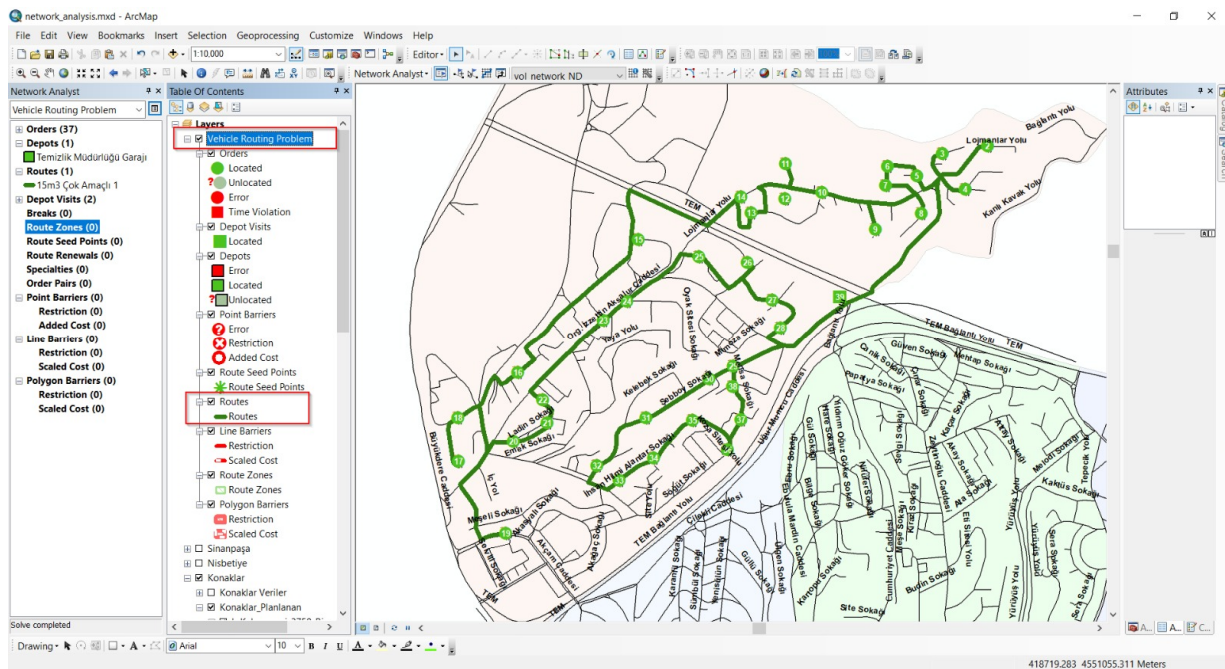




**Figure S10.** (a) Nitrogen oxide emissions, (b) Hydrocarbon emissions, (c) Carbon monoxide emissions, (d) Particular matter emissions, (e) Smog capacities.



**Figure S11.** Network analysis with ArcMap (Determination of container points for MSW collection based on ZWM)



**Figure S12.** Network analysis with ArcMap (Route optimization)

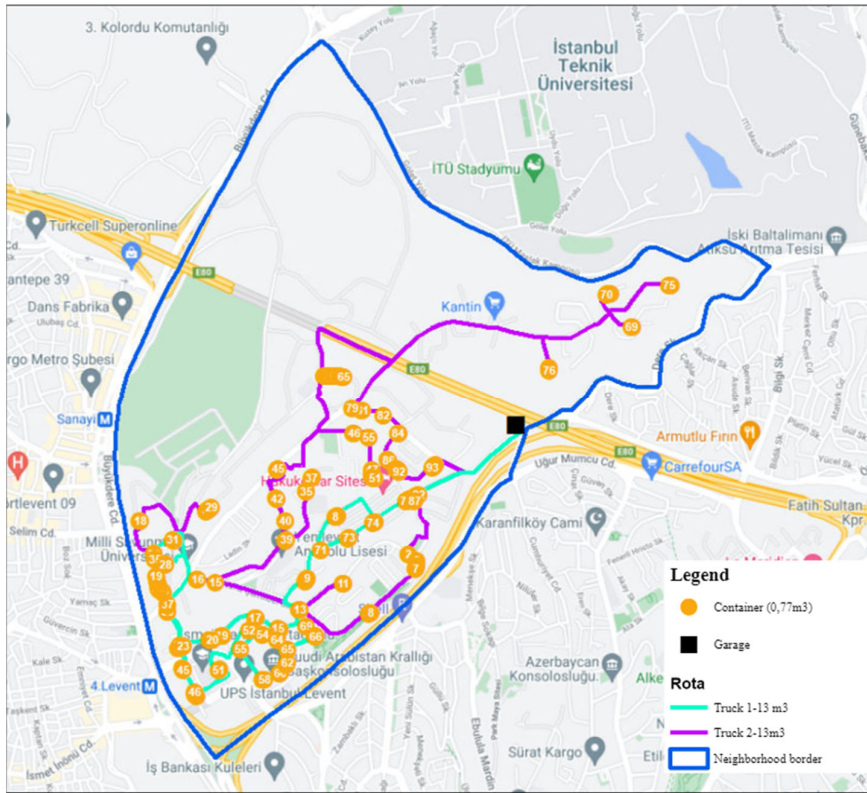


Figure S13. Route 1 and 2 in Konaklar Neighborhood

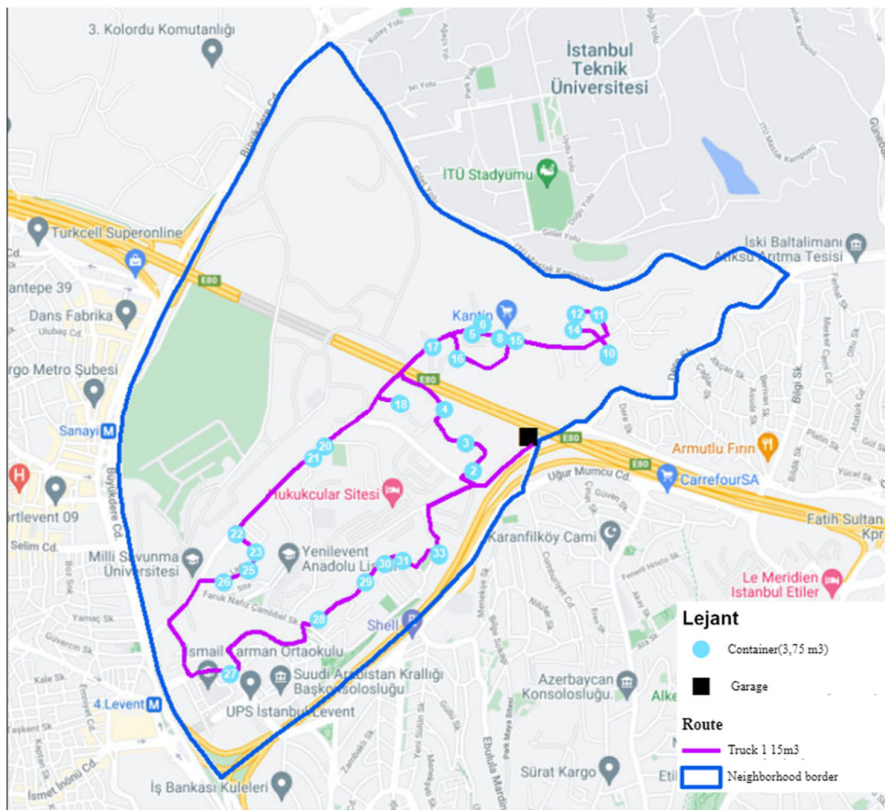
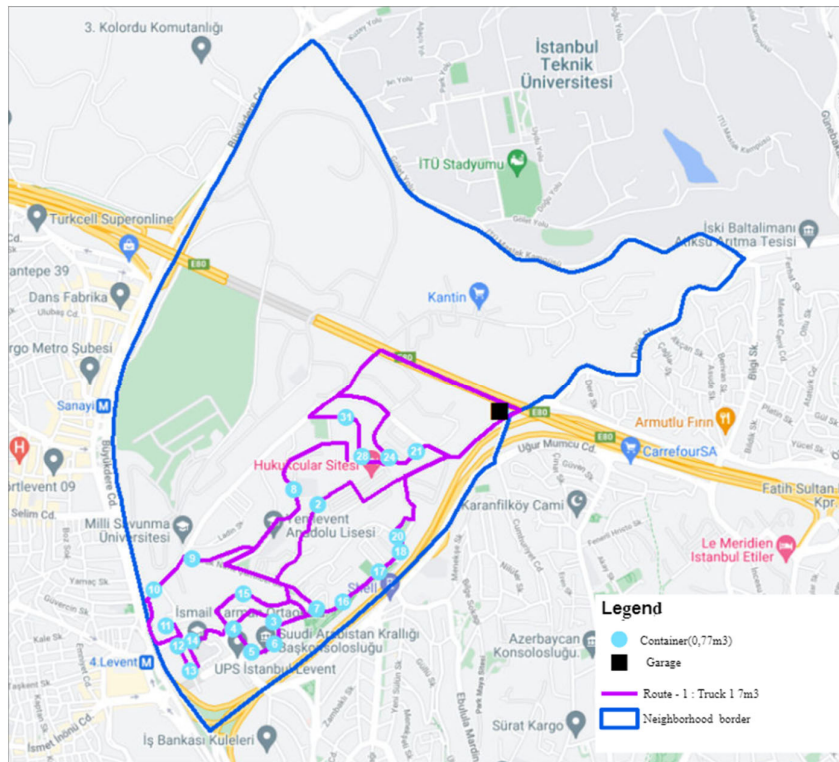
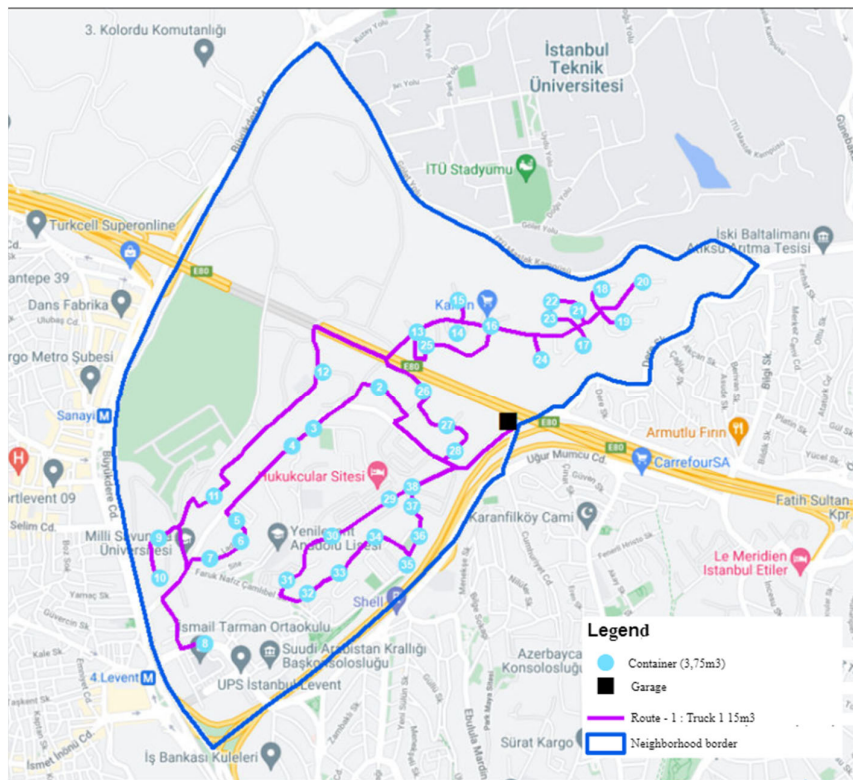


Figure S14. Route 3 in Konaklar Neighborhood

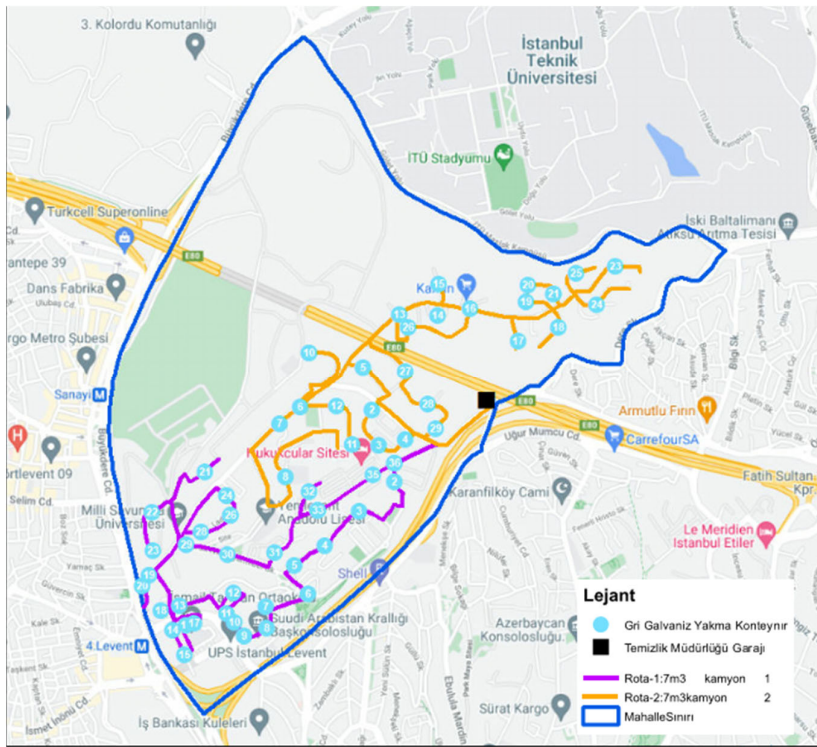




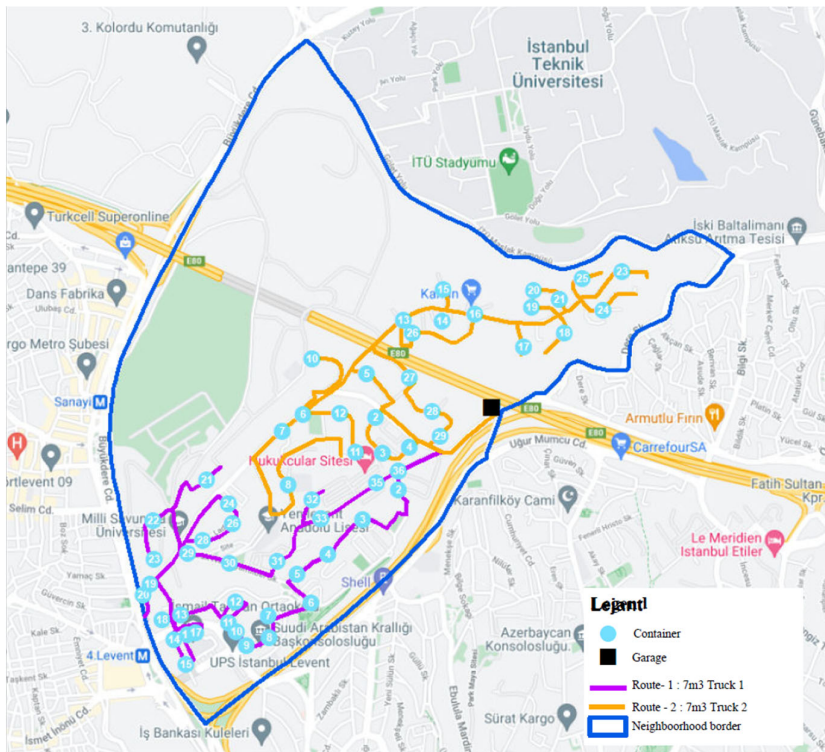
**Figure S15.** Route 8 in Konaklar Neighborhood (for organic kitchen wastes)



**Figure S16.** Route 9 in Konaklar Neighborhood (for organic kitchen wastes)

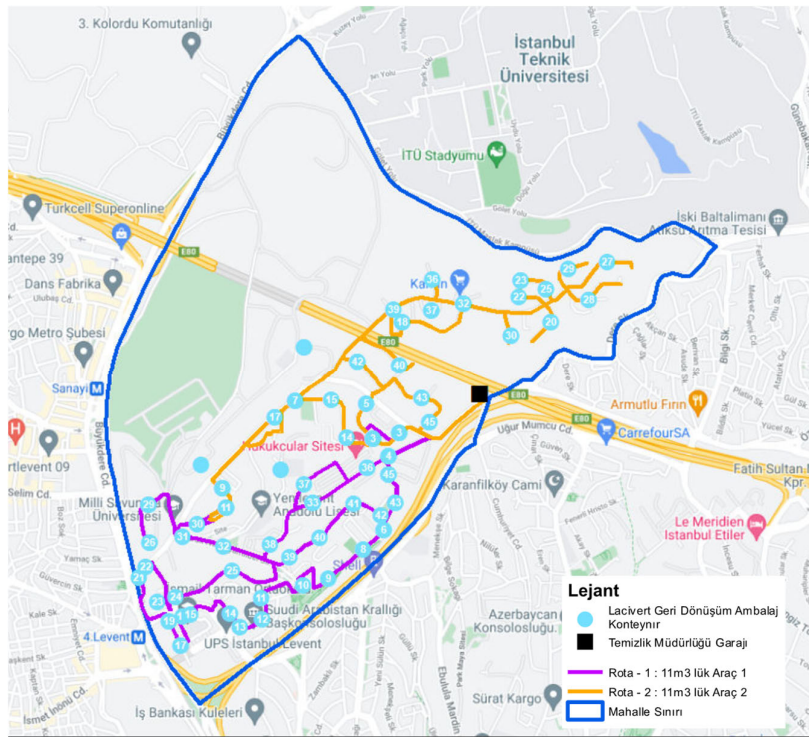


**Figure S17.** Route 10 in Konaklar Neighborhood (for other wastes)

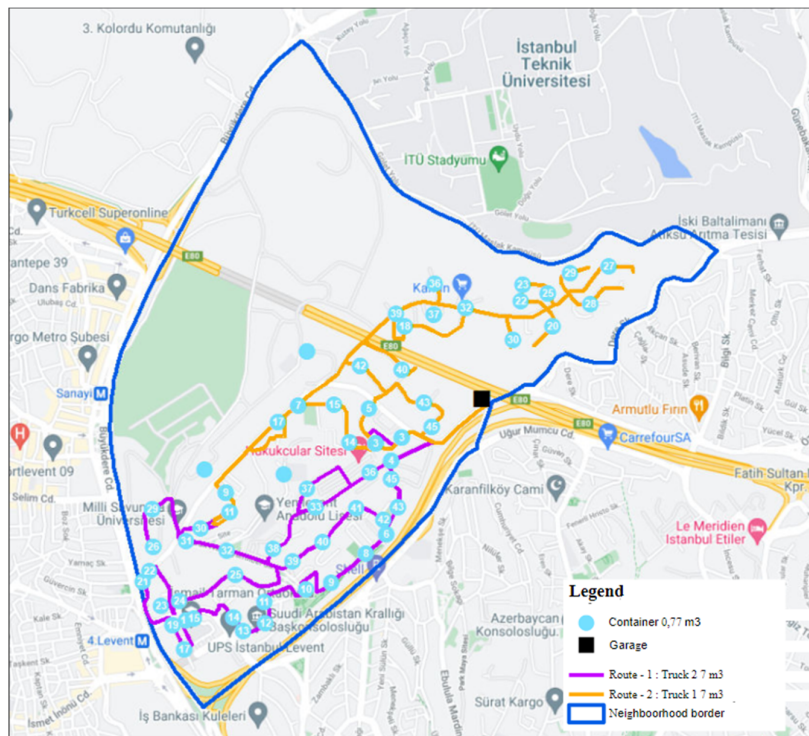


**Figure S18.** Route 11 in Konaklar Neighborhood (for other wastes)





**Figure S19.** Route 12 in Konaklar Neighborhood (for 4rec wastes)



**Figure S20.** Route 13 in Konaklar Neighborhood (for 4rec wastes)





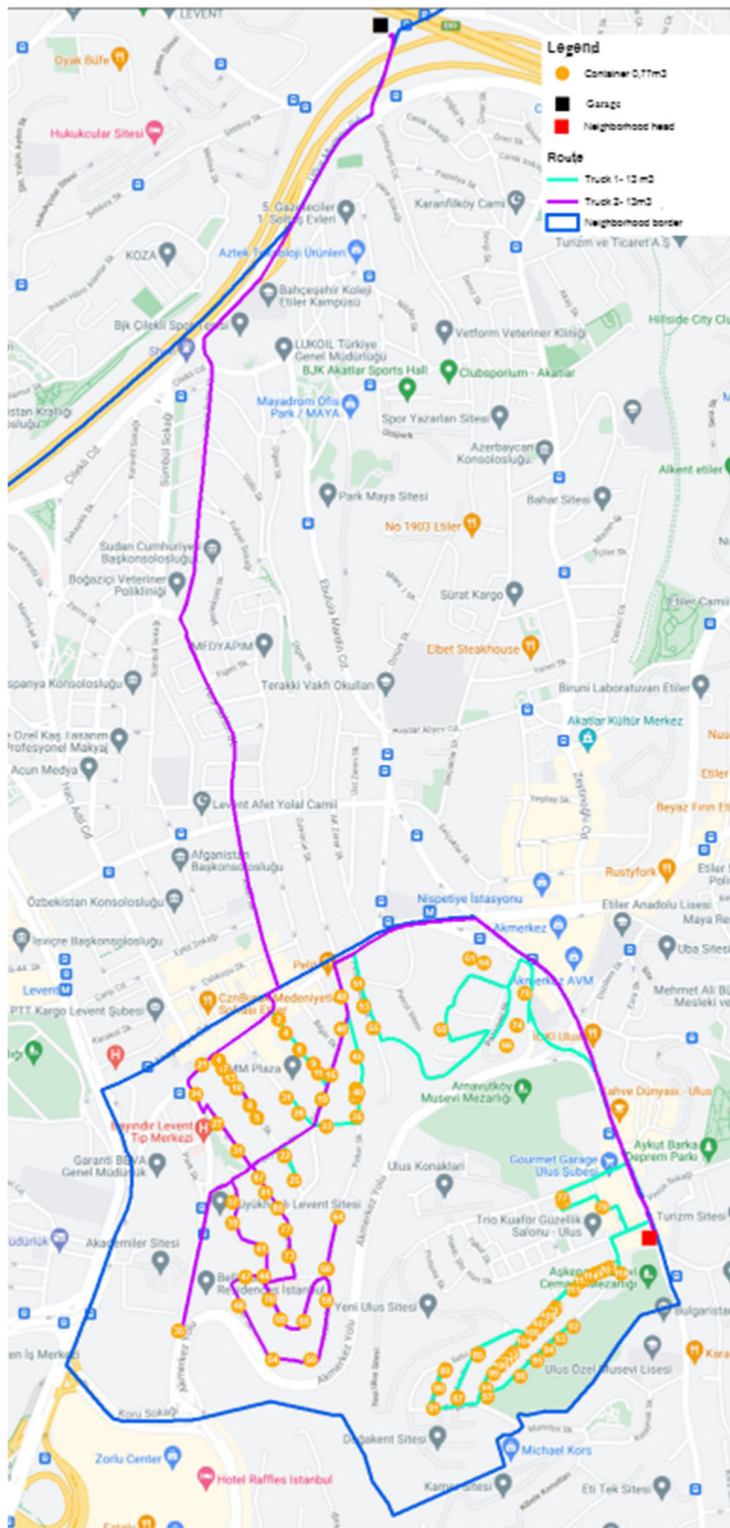
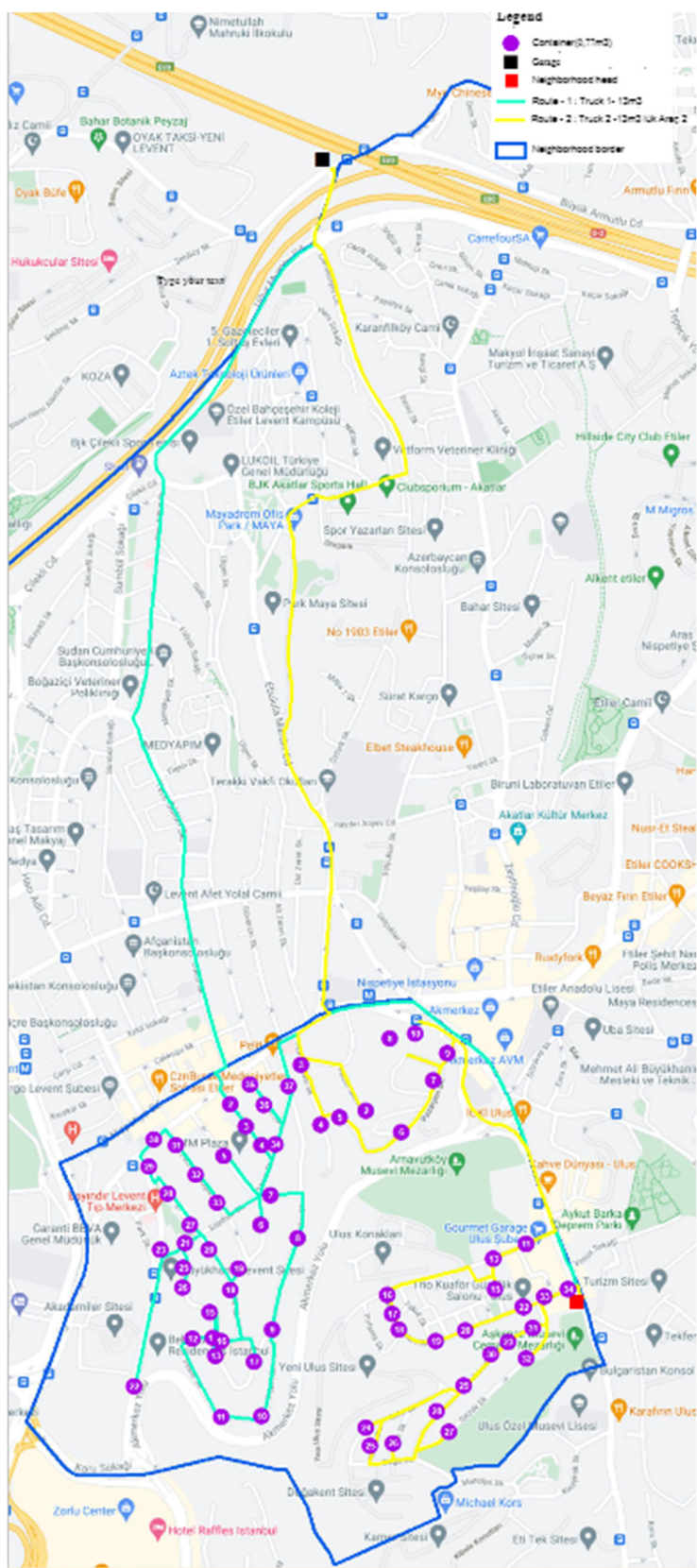


Figure S22. Route 5 and 6 in Nispetiye Neighborhood



**Figure S23.** Route 14 and 15 in Nispetiye Neighborhood (for organic kitchen wastes)

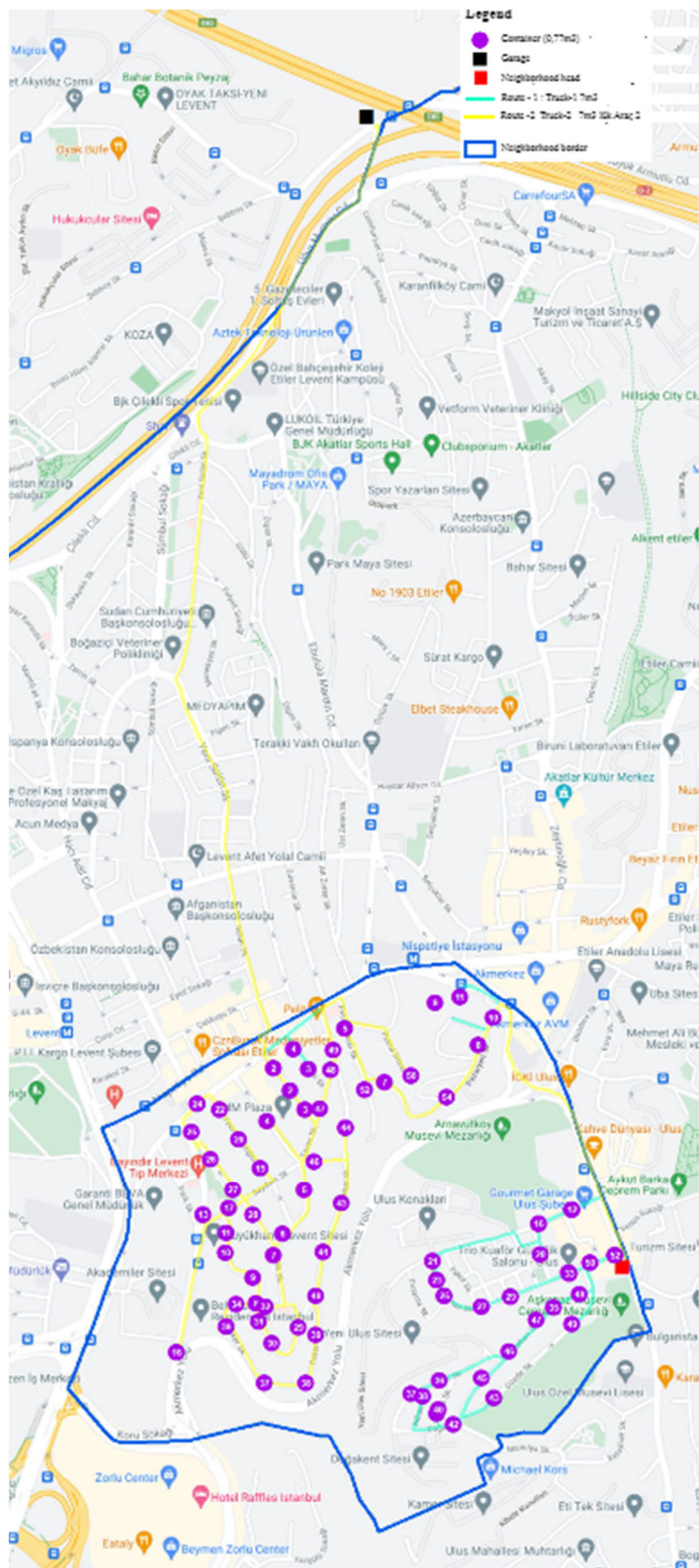


Figure S24. Route 16 and 17 in Nispetiye Neighborhood (for other wastes)



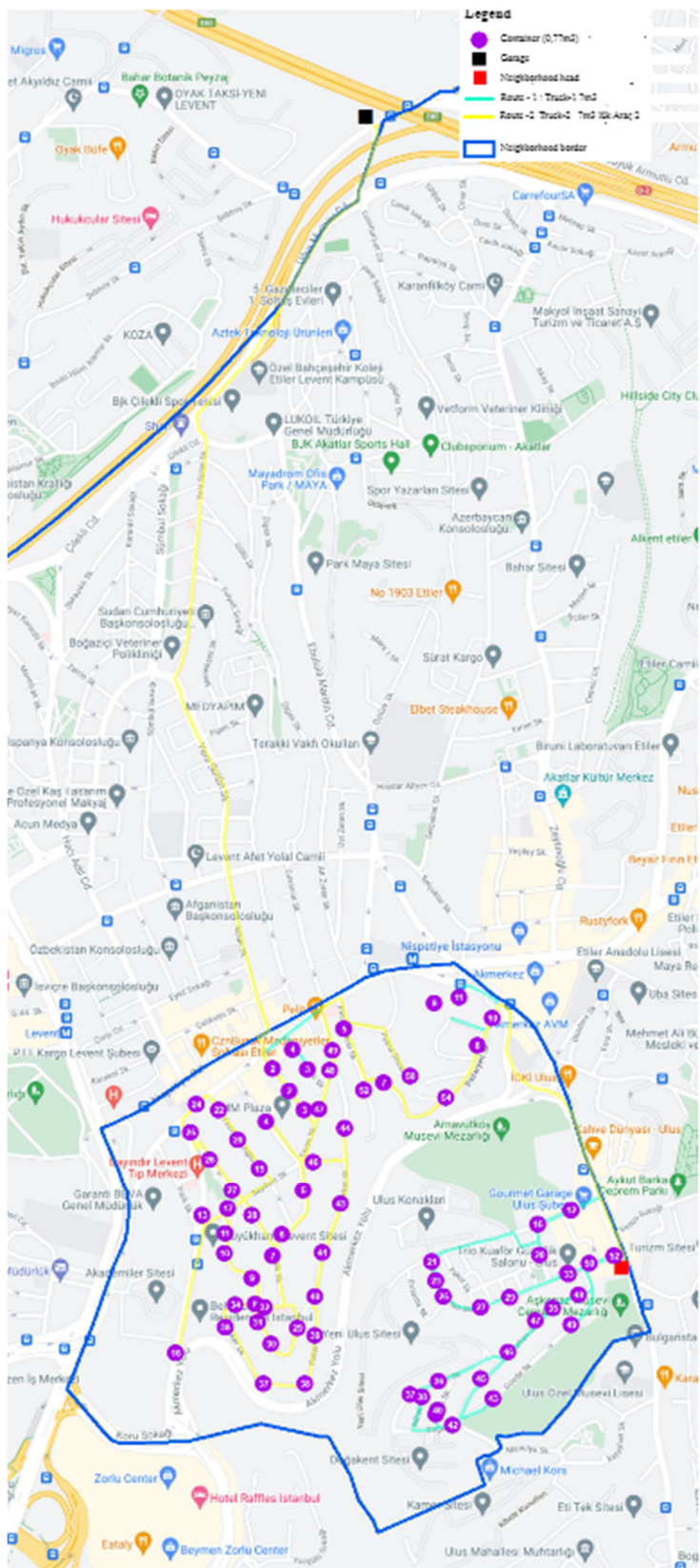


Figure S25. Route 18 and 19 in Nispetiye Neighborhood (for 4rec wastes)

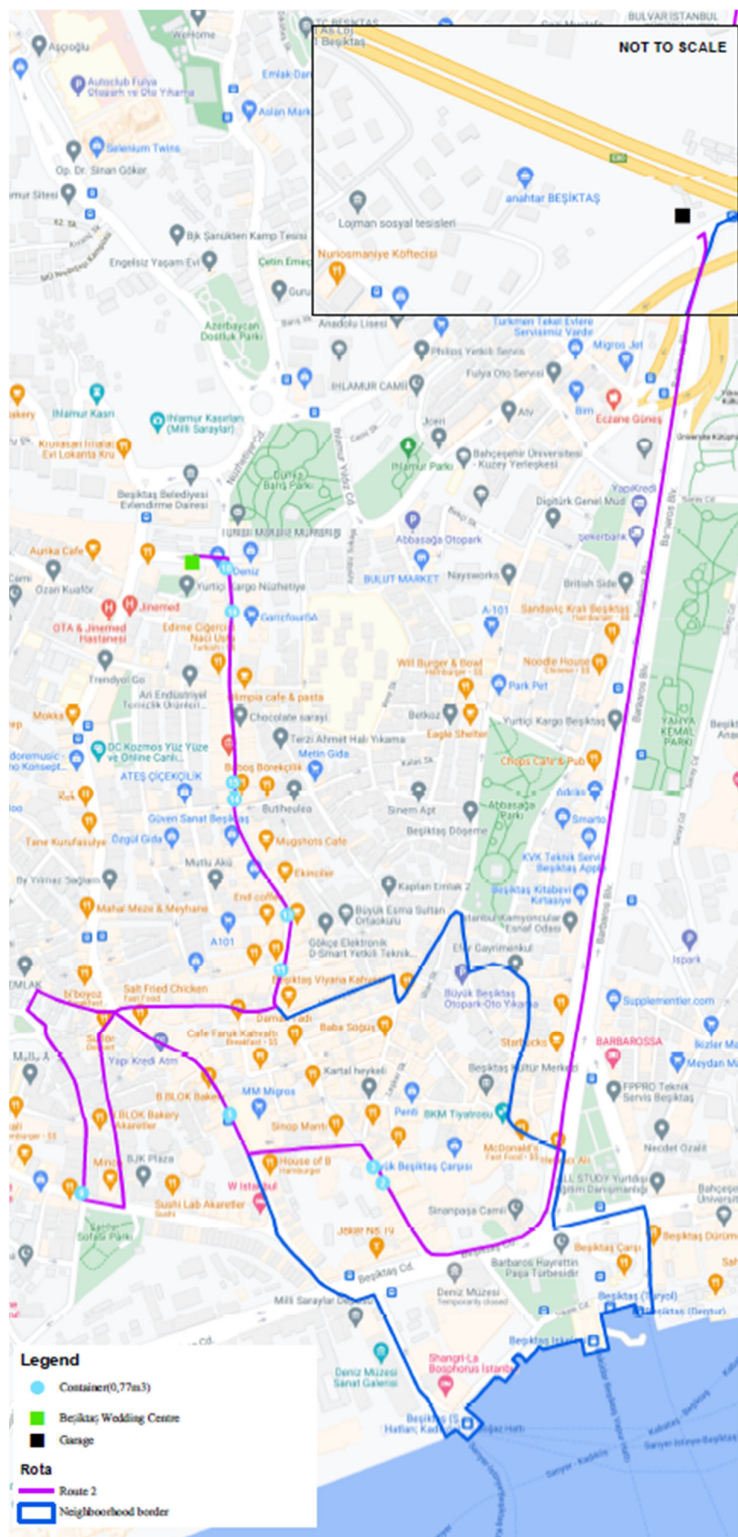


Figure S26. Route 20 in Sinanpaşa Neighborhood (For organic kitchen wastes)





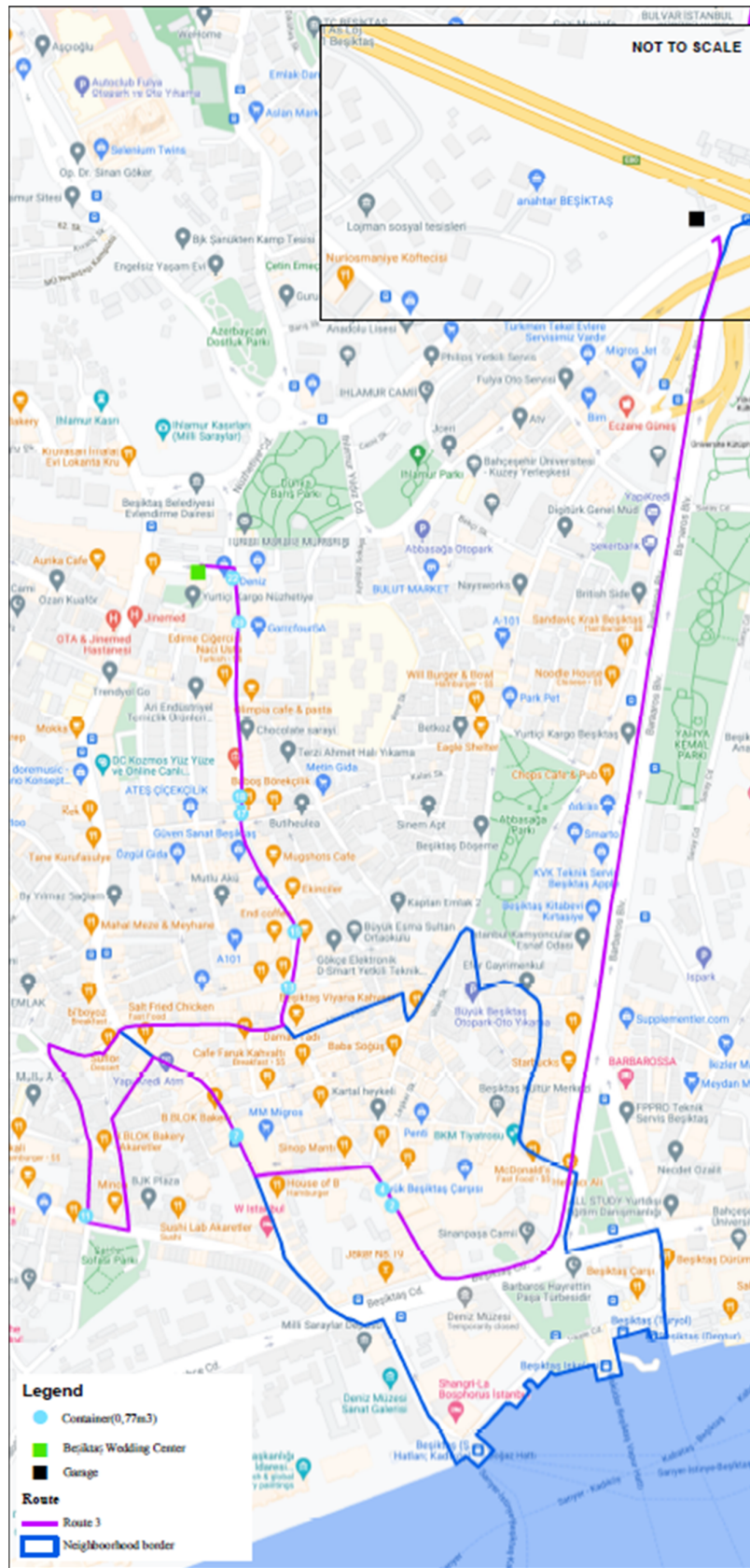


Figure S28. Route 22 in Sinanpaşa Neighborhood (For 4rec wastes)

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