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Modeling of solid waste collection and transportation in metropolitan areas using WAGS model: Implication of CO_2 emission and external costs

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ABSTRACT

Annually more than 80% of the overall budget of the uran solid waste management system in Iran is allotted to collection and transportation of the solid wastes. The main objective of the current study is to evaluate the external costs associated with solid waste collection, transfer, and transportation in Tehran for the period of 2018 to 2032 based on the current situation. Waste guidance system as well as Energy and Environment software were applied to anticipate the external costs. Results of the present study indicated that more than 535 million US dollars would be required during the next 15 years in the solid waste collection, transfer, and transportation sector to supply necessary machinery, manpower, fuel, maintenance and other relevant expenses. The principal fraction of the required budget (i.e. 48.99%) should be allocated to provide collection and transportation equipment costs. Manpower, fuel, maintenance, and miscellaneous expenses require 30.34, 7.37, 12.78 and 0.5 percent, respectively of the overall expenses in the solid waste collection, transfer, and transportation sector. In the context of global warming impact, more than 970 million tons of carbon dioxide will be anticipated to be emitted by solid waste collection, transfer, and transportation sector in Tehran during the studied period imposing 23.1 million US dollars to compensate its external effects.

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INTRODUCTION

Rapid urbanization, population growth, lifestyle changes and the prevalence of consumerism during past decades result in an increase in the amount and types of waste. The lack of municipal solid waste (MSW) plans leads to the environmental pollution and health hazards (Mazloomi *et al.,* 2015; Melare *et al.,* 2017; Nguyen-Trong *et al.,* 2017). Therefore, it is necessary to planning and implementing a comprehensive program for waste collection, transportation and disposal based on integrated solid waste management (ISWM) system. Appropriate assessment of the total expenses of the MSW management and unit cost of each of the functional elements are essential in order to establishing ISWM system (Memon, 2010; Parthan *et al.,* 2012; Zsigraiova *et al.,* 2013). Full cost accounting of MSW management can help municipalities to make better decisions about solid waste program, improve the efficiency of services, and better plan for the future

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(Abduli *et al.,* 2011; Guerrero *et al.,* 2013; Son and Louati, 2016). Solid waste collection, transfer, and transportation (SWCTT) embody the leading part of the solid waste system costs, reaching 60-80% of the management and general expenses (Ferreira *et al.,* 2017; Nguyen and Wilson, 2010; Xue *et al.,* 2015). Therefore, SWCTT optimization can remarkably reduce the cost of MSW expenses (Boskovic *et al.,* 2016; Ghiasinejad and Abduli, 2007). SWCTT costs do not include the costs of their side effects which are called external costs or negative externalities. In other words, environmental costs imposed on society without being accounted for in economic transactions are often referred to as external environmental costs. Air pollution emissions from fuel consumption are major parts of these costs (Fahlen and Ahlgren, 2010; Mavrotas *et al.,* 2015). Therefore, by improving SWCTT, not only the total budget of waste management but also detrimental effects on the environment can be improved enormously (Akhtar *et al.,* 2017; Sen *et al.,* 2010). Because the SWCTT often accounts for the bulk of the MSW management budgets, previous studies have been performed to calculate the costs of waste management in different countries. For instance, Ghasemi Gorbandi and Ghiyasi (2016) measured the full costs of the SWCTT processes in Minab, Iran. Similar works have been performed in Flanders, Belgium (De Jaeger and Rogge, 2013), Sarein, Iran (Seiiedsafavian and Fataei, 2012), Malaysia (Akhtar *et al.,* 2017), Ethiopia (Tefera Damtew and Negussie Desta, 2015) and Kuwait (Koushki *et al.,* 2004). In this regard studies fulfilled by Olukanni *et* al. (2015) in order to select the most economic haulage system among conventional, modified and stationary hauled systems for collection and transfer of MSW to disposal sites revealed that the stationary hauled method of waste collection is the optimal and economical method of collection. This method recorded a 56% and 43% reduction in total cost of daily travel per waste collection, as compared to the conventional and the modified systems, respectively. Other studies have been conducted to optimize SWCTT routes to define the most cost-effective waste collection and transfer systems in Kragujevac, Sebria (Boskovic *et al.,* 2016), Oporto, Portugal (Ferreira *et al.,* 2013), Danang and Hagiang,Vietnam (Nguyen-Trong *et al.,* 2017; Son and Louati, 2016), Kampala, Uganda (Kinobe *et al.,* 2015), Dhaka City, Bangladesh (Islam et *al.,* 2016) and Tabriz, Iran (Ansari *et a.l,* 2015). Silimar study was conducted by Purkayastha *et al.* (2015) who proposed a model for optimization of the collection bin and in recycle bin location-allocation issues in solid waste management. They reported that optimization of the collection bin and recycle bin location- allocation problems in solid waste management can be advantageous with respect to bin access to every individual person of municipality, reduction in the numbers of open dumping yards, considerable profit if the recycled products are properly processed, and as an effort toward sustainable and green world. Tehran city is one of the cities facing challenges of solid waste management (Akhavan Limoodehi *et al.,* 2017; Dehghanifard and Dehghani, 2018; Nabavi-Pelesaraei *et al.,* 2017). About 8092 tons of waste is generated in the city per day, on an average (TWMO, 2018). Most of the generated waste is collected and disposed of at Kahrizak landfill. Only a small proportion of the waste comprising of plastics and metals in Tehran is reused or recycled (Akbarpour Shirazi *et al.,* 2016; Damghani *et al.,* 2008; Rajaeifar *et al.,* 2015). Since a huge amount of the budget is spent on collection and transportation sector (Hannan *et al.,* 2018; Kinobe *et al.,* 2015; Xue *et al.,* 2015), cost estimation and budgeting for MSW management in Tehran as a metropolitan city becomes increasingly imperative. The main objective of this study was to estimated SWCTT costs in 22 district of Tehran in the period of 2018-2032. This includes the capital required to supply machinery, manpower (including drivers, labourers and management overhead), fuel, maintenance and miscellaneous expenses (including increase in the price of fuel, payments, insurance and maintenance expenses). A further objective is to estimate the external costs of air pollution caused by fuel consumption in SWCTT processes.

MATERIALS AND METHODS

Introduction to waste guidance system (WAGS) software

The UN-Habitat WAGS software was developed to assist with the selection of the most cost-effective waste collection system for any location by matching the most appropriate collection vehicle to each local situation. The program asks for around 50 inputs relating to the local situation, including population densities and growth rates, waste generation rates, waste density and constituents, travel distances and road surfaces, street widths and traffic speeds.

Cost information includes labour, fuel, interest rates, taxes, and import duties, and shadow factors are included for economic costing. From this it builds up a local data base. The program then asks for a further 50 inputs concerning each vehicle being considered and provides 15 years (y) projections for vehicle and equipment requirements, including life expectancies, operating, fuel and maintenance costs and financial projections for using that type of vehicle in the particular location (UN-Habitat, 2010). Required information to run the WAGS software was collected from the Tehran Municipality (TM, 2018) and Tehran Waste Management Organization (TWMO, 2018). A summary of the input information for the WAGS software is provided below.

Population growth

According to the 2016 population census, the population of Tehran was 8693706. Table 1 shows the population information in 22 district of Tehran.

Quantitative and qualitative characteristics of MSW

Tehran estimated to be generating 2953.7 thousand t of waste in 2017 (Table 2). On an average, the generation of waste per capita in Tehran is about 1.06 kg/d (Table 2). Generated waste are collected and transported to Arad Kouh Complex Waste Process and Disposal (AKCWPD). This center is located in the south of Kahrizak City and at the beginning of old Tehran- Ghom Road with an area roughly 1400 ha. This center has been deemed as the receiver of the Tehran City wastes as of 1976. Considering the available statistics, on average a daily rate of 7460 t of wastes are entered into this center (TWMO, 2018). The wastes submitted to this center are sent from various centers including the 22 district of Tehran (6800 t/d), hospitals and health and treatment centers (80 t/d) and companies and towns (580 t/d). After weighed, the wastes entered into this center are either directed to the process and recycle units of AKCWPD for the waste processing plans and production of compost or are transferred to the trenches of the disposal site to be buried. About 87% of MSW is disposed of in AKCWPD landfill and 8.3% is composted. The remaining waste (approximately 5%) is recycled (Abduli *et al*., 2011).

Table 3 shows the MSW characteristic in 22 district of Tehran in 2017. As it is shown in the Table 3, the

Table 1. Population and population growth rate of Tehran in 2016 (TM, 2018)

Region	Population	Average annual growth (%)	Region	Population	Average annual growth (%)
1	487508	2.86	12	241831	-0.70
2	701303	0.76	13	248952	1.45
3	330649	1.35	14	515795	-4.11
4	919001	0.06	15	641279	-0.49
5	858346	3.06	16	268406	-1.79
6	251384	-0.85	17	273231	-0.54
7	312194	0.04	18	419882	3.98
8	425197	-0.03	19	261027	-0.81
9	174239	-0.07	20	365259	0.93
10	327115	-1.05	21	186821	-0.17
11	307940	0.92	22	176347	3.25

Table 2. The amount of municipal solid waste production in Tehran in 2017 (TWMO, 2018)

Region	Waste amount (thousand t)	Waste generation rate (kg/person/d)	Region	Waste amount (thousand t)	Waste generation rate (kg/person/d)
1	181.01	0.98	12	124.25	0.71
2	227.17	1.12	13	77.69	1.16
3	125.16	0.96	14	132.85	1.41
4	312.23	1.07	15	208.05	1.12
5	252.17	1.24	16	100.21	0.97
6	115.1	0.79	17	80.52	1.23
7	120.69	0.94	18	133.74	1.14
8	133.7	1.16	19	94.78	1
9	58.48	1.08	20	141.77	0.94
10	97.29	1.22	21	74.96	0.9
11	106.18	1.05	22	55.7	1.15

Table 3. Composition of MSW generated in Tehran in 2017 (%) (TWMO, 2018)

Region No.	Wet waste	Used bread	Soft plastic	Plaster	Paper and cardboard	Ferrous metal	Non-ferrous metal	Electronic waste	PET	Glass	Bulk waste	Textile	Others
1	89.22	0.39	1.8	2.25	5.22	0.38	0.14	0.04	0.36	0.02	0	0.05	0.13
2	84.26	1.74	2.01	1.16	5.9	1.23	0.98	0.02	1.04	1.02	0.15	0.32	0.18
3	85.06	0.64	0.9	1.08	8.35	1.06	0.53	0.63	0.94	0.36	0.47	0	0
4	82.66	2.85	2.02	1.48	4.29	1.55	0.42	0.05	1.37	0.74	0.1	1.23	1.24
5	84.73	2.44	1.98	0.61	5.65	1.83	0.46	0	0.92	0.46	0.15	0.61	0.15
6	84.32	0.97	1.83	0.38	9.66	0.7	0.31	0.01	1.37	0.15	0.01	0.11	0.18
7	81.56	3.15	1.19	1.46	7.27	2.18	0.85	0	1.19	0.64	0.01	0.44	0.06
8	75.99	1.69	4.41	0.08	10.67	1.56	0.79	0.05	2.29	1.55	0.75	0	0.18
9	79.32	3.74	3.45	0.38	7.58	2.74	0.07	0.05	1.38	0.4	0.09	0.06	0.74
10	84.32	3.43	3.09	2.66	0.83	0.87	0.07	0.25	0.29	0.79	0.18	0.06	3.16
11	82.42	2.18	3.02	2.86	6.03	1.32	0.16	0.03	1.03	0.09	0.38	0.37	0.1
12	89.24	1.23	0.83	0.87	6.49	0.4	0.06	0	0.39	0	0.02	0.36	0.11
13	85.33	1.67	1.75	0.13	5.55	1.41	0.11	0.01	1.19	0.5	0.15	0.88	1.31
14	82.49	3.6	3.3	0.72	3.73	3.13	1.25	0	1.24	0.06	0.21	0.24	0.03
15	82.85	3.89	3.86	1.36	1.9	2.85	0.2	0	1.93	0.42	0.14	0.35	0.25
16	79.55	5.36	3.32	1.42	7.78	1.32	0.14	0.01	0.93	0.1	0.07	0	0
17	88.9	2.17	1.64	1.24	2.24	0.86	0.2	0.01	0.98	0.16	1.23	0	0.36
18	86.2	1.73	1.32	1.18	1.41	2.63	1.09	0	1.12	1.19	0.04	0.65	1.42
19	79.5	2.56	2.53	0.69	3.55	4.23	1.66	0.04	3.47	1.36	0.05	0.38	0
20	83.38	5.24	2.95	0.52	4.33	1.54	0.27	0.03	0.75	0.36	0.1	0.54	0
21	80.31	2.4	2.41	1.3	7.49	2.08	0.26	0.05	1.25	1.2	0.24	0.5	0.5
22	82.81	2.44	1.94	1.89	3.4	1.42	0.17	0.04	1.93	0.38	0.18	0.85	2.56

main components of the waste stream in Tehran were wet waste (83.38%), paper and cardboard (5.42%), used bread (2.52%), soft plastic (2.34%), ferrous metal (1.69%), polyethylene terephthalate (PET) (1.24%), plaster (1.16%), glass (0.54%), non-ferrous metal (0.46%), textile (0.36%), bulk waste (0.21%), electronic waste (0.06%) and others (0.57%).

Energy and Environment software

Energy and Environment software which was developed by Iran's Ministry of Energy is a model for calculating air emissions from the energy sector. This software has the ability to estimate the emissions of air pollutants and calculate the external costs of each of the pollutants in 5 sections including power plants, households-commerical, agriculture, industry and transportation in terms of fuel type.

RESULTS AND DISCUSSION

Economic cost evaluation of SWCTT

Waste collection vehicles characterization

Mechanized waste collection machinery is used in Tehran. Therefore, the required collection vehicles were chosen based on current status. Same type of vehicle is assumed to be used for waste collection and transportation of all 22 district of Tehran (volvo-Kabiri). The vehicle has diesel engine and on an average, fuel consumption is 8 L/h while the vehicle is working. Table 4 shows the characterization of the vehicle to be used for SWCTT in different district of Tehran.

Table 4. Characterization of SWCTT vehicles

Characteristic	Amount
Compacted waste capacity per trip (by volume)	15 (m^3)
Compacted waste capacity per trip (by weight)	9 (t)
Uptime	85 (%)
Economic life	4.8 (y)

According to Table 4 waste compact volume and maximum weight of waste were 15 m^3 and 9 t, respectively. Performance of vehicle in SWCTT to waste disposal site was determined to be 85%. The economic life of vehicle under conditions of Tehran City was determined to be 4.8 y.

Total time of collection and vehicle round trip time

Total time of collection and vehicle round trip time to waste disposal site for different district of Tehran is shown in Table 5.

Projected the amount of generated waste

Waste generation rate growth in Tehran is 1.1% per year during the period 2018-2032. So that, waste generation per capita in Tehran has increased from 1.07 kg/d in 2018 to 1.24 kg/d in 2032. Considering the population growth rate in district (Table 1) and increasing the waste generation per capita, the amount of produced waste will be increasing in all

22 district of Tehran during the period 2018-2032, except district 14 and 16. That could be related to the negative population growth rate (Table 1) and the amount of waste generation per capita (Table 2) in district 14 and 16. The highest amount of produced waste during the period 2018-2032 is related to region 5, with average waste generation of 562.8 thousand tons followed by district 4 and 2, with average waste generation of 393.2 and 357.2 thousand T, while district 12, 21 and 9 had the lowest record with average waste generation of 63.86, 65.46 and 73.93 thousand tons during the period 2018-2032, respectively.

Projected the required machinery for SWCTT

The highest number of required vehicles for SWCTT in Tehran in 2018 is for district 5, 4 and 2 with the numbers of 128, 110 and 88 vehicles, respectively. 14 year from 2018, district 5, 4 and 2 still have the highest number of required vehicles for SWCTT with the numbers of 228, 129 and 114 vehicles, respectively. The lowest number of required vehicles in 2018 for SWCTT is in region 12 with the required vehicles number of 16, followed by district 9 and 21 with the required vehicles numbers of 18 and 20, respectively. After spending 15 years the least needed for SWCTT vehicles is related to district 12, 16 and 9 with the numbers of 17, 20 and 21 vehicles. Buying large numberes of vehicles is required every 5 years and it is because that the economic life of SWCTT vehicles was 4.8 years under conditions of Tehran City (Table 4). The number of annual required vehicles for SWCTT in district 14 and 16 was negative for some years and it is due to the negative population growth rate (Table 1) and consequently reducing the amount of waste generated by these district. The highest number of required containers for SWCTT in 2018 is in region 5 with the required containers of 3937, followed by district 4 and 2 whith the rerquired containers of 3433 and 2799, respectively. After 14 years, district 5 and 4 still stand at the 1st and 2nd place of highest container requirement with the numbers of 7289 and 4203, respectively and region 18 stands at the 3rd place of highest container requirement with the number of 3782. The lowest number of container requirement in 2018 is for district 21, 12 and 9 with the numbers of 586, 594 and 656 containers, respectively. In 2032, the lowest number of container requirement is related to district 12, 21 and 6 with the numbers of 653, 694 and 736 containers. Buying large numberes of containers is required every 8 years. That could be bacause of the expiration of containers econimic life after 8 years. The number of annual required container for SWCTT in district 14 and 16 was negative for some years and it is in consistent with no need for buying waste collection vehicles during those years.

Projected the machinery cost for SWCTT

Table 6 shows the amount of capital required to purchase vehicles and containers for SWCTT in Tehran from 2018-2032. According to Table 6, the total amount of 262169 thousand US dollars is required to supply vehicles and containers for

Table 5. Total time of solid waste collection and vehicle round trip to waste disposal site in different district of Tehran

Region	Time (min)	Region	Time (min)
1	339	12	264
2	318	13	259
3	326	14	259
4	323	15	259
5	328	16	243
6	312	17	275
7	312	18	275
8	323	19	243
9	275	20	222
10	296	21	328
11	264	22	328

Table 6. Projected the machinery cost for SWCTT in different district of Tehran from 2018-2032 (thousand US dollars)

Year	Vehicle	Container	Year	Vehicle	Container
2018	51522	31413	2026	2040	32211
2019	888	608	2027	2459	1443
2020	941	633	2028	53611	1501
2021	887	661	2029	3190	1562
2022	1097	684	2030	3659	1621
2023	52516	715	2031	3346	1692
2024	1883	740	2032	3923	1753
2025	2196	774	2018-2032	184158	78011

SWCTT in Tehran during the period 2018-2032. As can be seen, the capital requirement to purchase vehicles and containers increases every 5 and 8 years, respectively. It is because of the expiration of vehicles and containers econimic life after these years.

Projected the manpower cost for SWCTT

The highest number of labour (including drivers and assistants) required during year 2018-2032 is for region 5, followed by district 4 and 2 with the total number of 7815, 5376 and 4533 labours in these years and it is related to the highest number of required vahicles for SWCTT in these district. The lowest number of labour required in 2018 is for region 12 with the number of 48 labour, followed by district 9 and 21 with the number of 54 and 60 labour. In year 2032 region 12 is still stands at the 1st place of the lowest number of labour required and district 16 and 9 stand at the 2nd and 3rd places. It is related to the population growth rate (Table 1) and the amount of produced waste in these district. Table 7 shows the supplying manpower cost projections including drivers, labours and management overhead from 2018-2032. As can be observed, the most capital needed for supplying manpower cost in 2018 is for region 5 with the amount of 1228 thousand US dollars, followed by district 4 and 2 with the amounts of 1055 and 844 thousand US dollars, respectively, while district 12, 9 and 21 have the lowest record with the amounts of 153, 173 and 192 thousand US dollars, respectively. After spending 14 y, in year 2032 the most capital needed for supplying manpower cost is still for district 5, 4 and 2 with the amounts of 2187, 1237 and 1093 thousand US dollars, respectively. In that y, district 12, 16 and 9 have the lowest capital needed for supplying manpower cost with the amounts of 163, 192 and 201 thousand US dollars, respectively.

Projected the fuel usage and costing for SWCTT

As mentioned earlier, the vehicles that used for SWCTT in different district of Tehran have diesel engines. On an average, fuel consumption is 8 L/h while the vehicle is working. Table 8 shows the fuel consumption in SWCTT in different district of Tehran from 2018-2032. According to Table 8, the most fuel needed for SWCTT in 2018 is for region 5 with 2771 thousand L, followed by district 4 and 2 with 2380 and 1906 thousand L, respectively, while district 12, 9 and 21 have the lowest record with 344, 390 and 437 thousand L, respectively. After spending 14 y, in year 2032 the most fuel needed for SWCTT is still for district 5, 4 and 2 with the 4938, 2799 and 2473 thousand L, respectively. In that y, district 12, 16 and 9 have the lowest fuel needed for SWCTT with 372, 437 and 455 thousand L, respectively.

Table 7. Projected the manpower cost for SWCTT in different district of Tehran from 2018-2032 (thousand US dollars)

Year	Manpower cost	Year	Manpower cost
2018	9460	2026	10966
2019	9620	2027	11212
2020	9794	2028	11414
2021	9957	2029	11653
2022	10157	2030	11922
2023	10338	2031	12164
2024	10521	2032	12430
2025	10751	2018-2032	162359

Table 8. Evaluated the fuel consumption in SWCTT in different district of Tehran from 2018-2032 (thousand L)

Year	Fuel consumption	Year	Fuel consumption
2018	21342	2026	24794
2019	21716	2027	25315
2020	22015	2028	25798
2021	22487	2029	26320
2022	22935	2030	26942
2023	23343	2031	27471
2024	23742	2032	28104
2025	24290	2018-2032	366704

The fuel cost of waste collection and transportation in different district of Tehran from 2018-2032 is shown in Table 9. As can bee seen, the most expensive region in terms of fuel supply is region 5 with the amount of 298 thousand US dollars, followed by district 4 and 2 with the amounts of 256 and 205 thousand US dollars, respectively, while the least expensive region in terms of fuel supply is region 12 with the amount of 37 thousand US dollars, followed by district 9 and 21 with the amounts of 42 and 47 thousand US dollars. In year 2032, district 5, 4 and 2 are still the most expensive district in terms of fuel supply with the amounts of 531, 301 and 266 thousand US dollars. In that year district 12, 16 and 9 have the lowest record for fuel cost supply with the amounts of 40, 47 and 49 thousand US dollars.

Projected the overall costs for SWCTT

The results of the total financial cost of SWCTT in 22 district of Tehran from 2018-2032 including the capital required to supply machinery, manpower (including drivers, labours and management overhead), fuel, maintenance and miscellaneous expenses (including increase in the price of fuel, payments, insurance and maintenance expenses) are presented in Fig. 1. In the first year (2018), district 5, 4 and 2 are the most expensive district in terms of SWCTT with the amounts of 12435, 10735 and 8639 thousand US dollars. This is due to the fact that mentioned district had the highest amount of produced waste and the most capital needed for machinery, manpower, fuel and maintenance supply in 2018. At the same time, district 12, 9 and 21 have the least capital needed for SWCTT with the amounts of 1655, 1851 and 1914 thousand US dollars owing to the fact that the mentioned district have the lowest amount of waste production in this year. After spending 14 years, the most capital needed for SWCTT is still for region 5 with the amount of 5358 thousand US dollars, followed by district 18 and 1 with the amounts of 2442 and 2432 thousand US dollars. The least capital needed is related to region 12 as in 2018 (with the amount of 286 thousand US dollars). After that, district 16 and 14 are stand at the 2nd and 3rd place of the least capital needed for SWCTT with the amounts of 322 and 335

Table 9. Projected the fuel cost for SWCTT in different district of Tehran from 2018-2032 (thousand US dollars)

Year	Fuel cost	Year	Fuel cost
2018	2296	2026	2667
2019	2336	2027	2723
2020	2378	2028	2775
2021	2419	2029	2831
2022	2467	2030	2898
2023	2511	2031	2955
2024	2554	2032	3023
2025	2613	2018-2032	39446

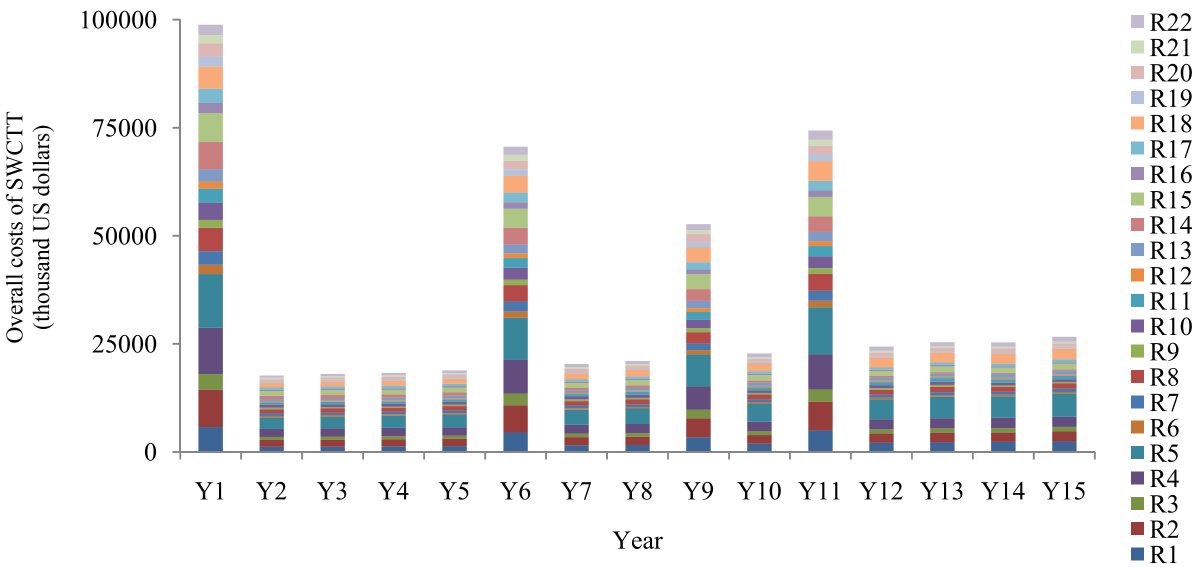

Fig. 1. Projected the overall costs for SWCTT in different district of Tehran from 2018-2032

thousand US dollars. These changes compared to the based year (2018), could be related to changes in population growth rate and waste per capita in district during 2018 to 2032. In 2018, 2023 and 2028 financial costs of waste collection and tarnasportation are increased significantly and it is because of the need to buy new waste collection vehicles due to the expiring their economic life after 4.8 y (Table 4). Also the increasing demand for containers supply due to expiring their economic life after 8 y has led to raised costs in 2026.

Evaluation of CO_2 emissions from SWCTT

The SWCTT can produce emissions of several greenhouse gases (GHGs), which contribute to global climate change. Emissions are released from fuel consumption during the SWCTT. CO_2 is one of the most significant GHG produced from SWCTT (Agar and Baetz, 2007; Larsen *et al.,* 2009, Fontaras *et al.,* 2012, Sandhu *et al.,* 2016). CO_2 emissions were calculated with Energy and Environment software and data obtained from the WAGS software. Results are presented in Fig. 2. As can be observed, district 5, 4 and 2 are the largest producer of CO_2 (with the average emission amounts of 9962, 6856 and 5780 t, respectively) in the period of 2018-2032. While district 12, 9 and 16 are the smallest producer of CO_2 (with the average emission amounts of 945, 1129 and 1186 t, respectively) during these y.

Evaluation of external costs in SWCTT

Fig. 3 shows the external cost projections of CO_2 emissions caused by diesel consumption for SWCTT in 22 district of Tehran from 2018-2032. As stated in Fig. 3, district 5, 4 and 2 have the highest external cost of CO_2 in 2018 with the amounts of 176, 151 and 121 thousand US dollars, while district 12, 9 and 21 have the lowest external cost of CO_2 with the amounts of 21, 24 and 27 thousand US dollars. In 2032 the highest external cost of CO_2 is still related to district 5, 4 and 2 with the amounts of 313, 177 and 157 thousand US dollars and district 12, 16 and 9 have the lowest external cost of CO_2 with the amounts of 23, 27 and 28 thousand US dollars.

The results obtained in the present study showed that Tehran population in 2018 are 8786811 people and the amount of waste production in the city is 3526 thousand t. The population and the amount of produced waste are projected to increase by 9802560 people and 4579 thousand t, respectively in 2032. 986 collection vehicles and 33400 containers are needed to SWCTT in 2018. These numbers will be increased to 1296 and 45253 in 2032, respectively. In order to provide the capital required to purchase

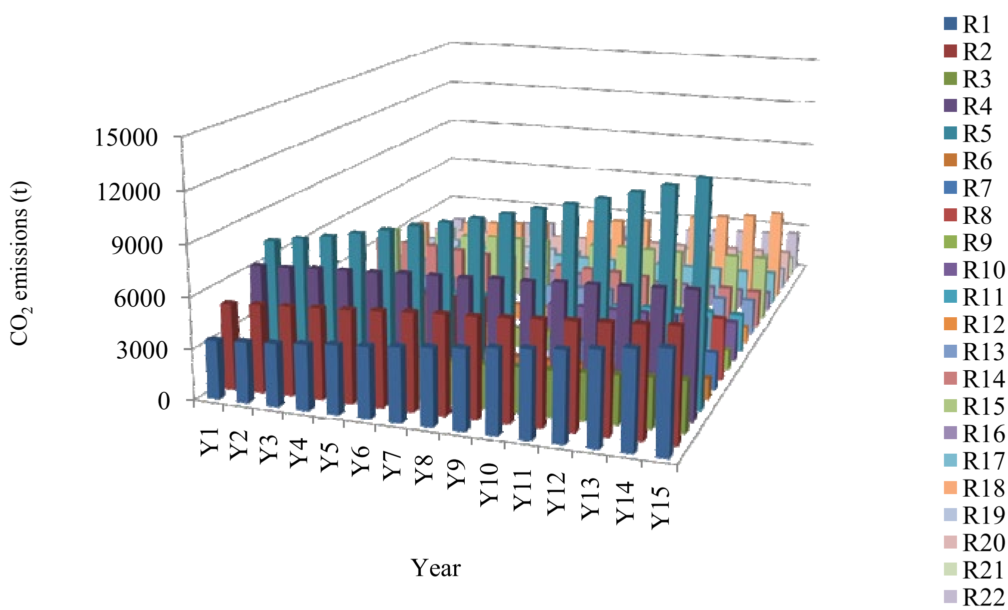

Fig. 2. CO_2 emissions from SWCTT in different district of Tehran from 2018-2032

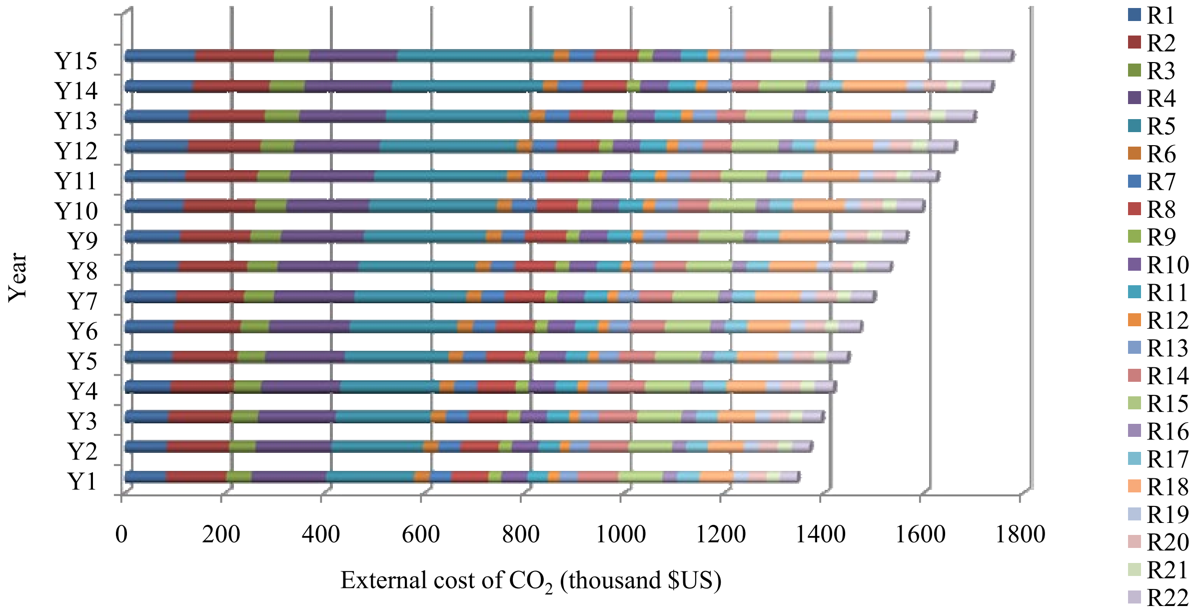

Fig. 3. External cost of CO_2 emissions caused by diesel consumption for SWCTT in different district of Tehran from 2018-2032

vehicles in the base year (2018), 51522 thousand US dollars are needed. In y 2023 and 2028, reinvestment of 52516 and 53611 thousand US dollars is needed, respectively and it is due to the economic life of waste vehicles equal to 4.8 y under conditons of Tehran City. Tehran needs 31413 thousand US dollars to provide the required containers in 2018. In year 2026, reinvestment of 32211 thousand US dollars is needed. It chould be related to expiration the economic life after 8 y. The number of 2958 labour (including drivers and assistants) are required for SWCTT in Tehran in 2018. This number will be increased to 3888 in 2032. Manpower supply costs (including drivers, labours and management overhead) will increase from 9460 thousand US dollars in 2018 to 12430 thousand US dollars in 2032. Annual cost of required fuel which is 2296 thousand US dollars in 2018 will get to 3023 thousand US dollars by the year 2032 and also maintenance cost will increase from 3970 to 5278 thousand US dollars. In y 2018, 2023, 2026 and 2028 the highest percentages of total transport budget is allocated to supply machinery with the percentages of 83.92 %, 75.38 %, 64.98 % and 74.14 %. The highest percentages of total SWCTT budget is assigned to supply manpower (including drivers, labours and management overhead) for the rest of y. Over a 15-year period the capital required to supply machinery has the highest percentage of total SWCTT budget with the percentage of 48.99 % of total required fund. The share of supply manpower (including drivers, labours and management overhead), fuel, maintenance and miscellaneous expenses (including increase in the price of fuel, payments, insurance and maintenance expenses) of total required fund are 30.34 %, 7.37 %, 12.78 % and 0.5 %, respectively. Similar observation was reported by Seiiedsafavian and Fataei (2012) who used management economic software (WAGS) to design the storage, collection, and transportation system of MSW for the Sarein City, Iran. They found that Sarein Municipality should purchase collecting machinery worth 5585.6 thousand dollars from 2011 to 2025 which is equal to 37% of its needed budgets during these y. They also reported that the personnel cost during these 15 y was 1832.8 thousand dollars that includes 34% of the total cost of collecting and transporting solid waste. Cost associated with repairs and maintenance of collecting machines was estimated to be 1049.9 thousand dollars by the end of 2025, that is equal to 24% of the total budget of Sarein city over 15 y. Fuel cost over the 15 y is 915.6 thousand dollars , which is 4% of the total anticipated budget. In addition, about 1% equivalent to 660.7

thousand dollars was allocated for other expenses such as rises in fuel prices, wages and also in the costs associated with repairs. In this regard, studies fulfilled by Ghasemi Gorbandi and Ghiyasi (2016) in Minab, Iran and Mazloomi *et al.* (2015) in Tabriz, Iran showed that the highest cost of waste collection was related to supplying man power and machinery. The study on the collection and transportation cost of household solid waste in Kuwait has revealed that the low energy and manpower costs are mainly responsible for the favorable cost of management, collection and transportation of residential waste in Kuwait (Koushki *et al.,* 2004). Another research conducted on operation costs reduction in Barreiro, Portugal showed that labour being the greatest contributor in waste collection and transportation (Zsigraiova *et al.,* 2013).

CONCLUSION

The present study aims to evaluate the SWCTT costs in Tehran City. For this purpose, WAGS and Energy and Environment software were applied. Results based on WAGS outputs revealed that the average amount of wastes generated in Tehran, has been 3516 thousand t in 2018 that will increase by 4579 thousand tons in 2032. The total amount of capital required for SWCTT in Tehran for the next 15 y is 535.113 million US dollars that includes the capital required to supply machinery, manpower (including drivers, labours and management overhead), fuel, maintenance and miscellaneous expenses (including increase in the price of fuel, payments, insurance and maintenance expenses). In other words, base fund of 98.821 million US dollars is needed for base year and additional capital of 436.292 million US dollars will be required for the rest of the year. The results showed that in the period of 2018-2032 about 48.99% of the credits required for waste collection and transportation in Tehran should assigned to supply machinery. After that, supply manpower, fuel, maintenance and miscellaneous expenses account for 30.34%, 7.37%, 12.78% and 0.5% of the total required fund, respectively. The results of energy and environment software demonstrate the CO_2 emissions in 2018 are 56540 t with the external costs of 1347 thousand US dollars. These amounts of emissions are projected to increase by 74447 t in 2032 with the external costs of 1774 thousand US dollars. The total amount of 970 Mt of CO_2 were amitted by waste collection and transportation in Tehran during 2018 to 2032 with the external costs of 23.137 million US dollars. Since the SWCTT accounts for a majority of expenditure on MSW management, the results of this research as a long term budget projections can help TM to planning and decision making for MSW management programs over the next 15 years.

CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

AKCWPD	Arad Kouh Complex Waste Process and Disposal
CO_2	Carbon dioxide
d	Day
Fig.	Figure
GHG	Greenhouse gas
h	Hour
ha	Hectare
i.e.	That is
IME	Iran's ministry of energy
ISWM	Integrated solid waste management
kg	Kilogram
km	Kilometer
L	Liter
m^3	Cubic meter
min	Minute
MSW	Municipal solid waste
Mt	Megaton
PET	Polyethylene terephthalate
SCI	Statistical Center of Iran
SWCTT	Solid waste collection, transfer, and transportation
t	ton
TM	Tehran Municipality

TWMO	Tehran Waste Management Organization
WAGS	Waste guidance system
y	year
%	Percent

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