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Environmental and Economic Evaluation of Municipal Solid Waste Management using WAGS Model – Air Pollutant Emission and Fuel Economy in Waste Collection Sector

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Abstract
Solid waste collection, transfer and transportation (SWCTT) is a fundamental component of solid waste management systems that contributes to both the costs and environmental emissions associated with managing solid waste. The objective of this study is to project the fuel consumption and fuel costs of SWCTT in Tehran from 2018 to 2032. A further objective is to evaluate the air pollutant emissions from fuel consumption of SWCTT vehicles. For these purposes Waste Guidance System (WAGS) and Energy and Environment software were applied. Results of the present study showed that more than 39 million dollars would be required during the next 15 years in the SWCTT sector to supply 366 million liters of diesel fuel. In the context of local air pollution impact, about 9902.8, 6161.7, 73.5, 2639.6, 8065.5 and 4839.2 of NO_X, SO_2, SO_3, CO, CH and SPM will be anticipated to be emitted by SWCTT sector in Tehran during the studied period.

Keywords: Waste management, Collection, Transportation, Fuel consumption, Air pollutant emissions

Introduction

The quantity and characteristics of municipal solid waste (MSW) arising from domestic, commercial and industrial activities as a result of growing population, rising standards of living and technology development (Vahidi et al., 2017; Zhang at al., 2010; Mazloomi et al., 2015; Melare et al., 2017). MSW is regarded as perilous in relation to its physical, chemical, and infectious properties. So, the inadequate removal and collection of waste, as well as insufficient destination and final treatment, can cause a great impact on the environment (Abbasi and Kamalan, 2018; Ansari et al., 2015; Das and Bhattacharyya, 2015; Nguyen-Trong et al., 2017). The problem of MSW encompasses several factors, such as generation, collection, processing and disposal (Vecchi et al., 2016).

Solid waste collection, transfer and transportation (SWCTT) is a waste management activity that contributes substantially to hazardous environmental impact due to fuel consumption and consequent pollutant emissions, and can absorb a considerable share of the waste management system budget (Xue et al., 2015; Akhtar et al., 2017; Ferreira et al., 2017).

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SWCTT constitutes more than 70% of total MSW management costs due to the large fuel consumption (Nguyen and Wilson, 2010; Boskovic et al., 2016). Previous studies have been performed to evaluate the fuel costs of SWCTT. For instance, De Jaeger and Rogge, 2013 measured the full costs of the SWCTT processes including fuel expenses in Flanders, Belgium. Similar works have been performed in different countries (Table 1).

Table 1. Literature on fuel cost estimation for SWCTT

Region	Fuel cost	Reference
Minab ,Iran	193977.9 million rials	Ghasemi Gorbandi and Ghiyasi, 2016
Sarein, Iran	915.6 thousand dollars	Seiiedsafavian and Fataei, 2012
Malaysia	11.41 RM	Akhtar et al., 2017
Kuwait	1.5 $ per gallon	Koushki et al., 2004

Emissions from SWCTT vehicles vary based on factors such as truck type, fuel type, efficiency, and route characteristics, but SWCTT has consistently been found to be the most fuel-intensive process in SWM systems (Fahlen and Ahlgren, 2010; Mavrotas et al., 2015). Table 2 shows the air pollutant emissions from SWCTT vehicles evaluated in some countries. Similar study has been conducted to measure emissions from diesel side loader refuse trucks. The study showed that fuel use for trash collection and transportation is 73 gal with the emissions of 78, 67, 86 and 80 g of NO_X, HC, CO and PM, respectively (Sandhu et al., 2016).

Table 2. Literature on air pollutant emissions evaluation from SWCTT vehicles

Region	HC	CO	NOX	PM	Reference
Milan, Italy	0.2 g/km	7.4 g/km	32.3 g/km	46.4 mg/km	Fontaras et al., 2012
Madrid, Spain	1 g/km	2.5 g/km	18.1 g/km	0.2 g/km	Lopez et al., 2010
U.S.	-	12.1 g/km	38.2 g/km	-	Maimoun et al., 2013
Denmark	1.5 g/L	2.9 g/L	20.9 g/L	0.4 g/L	Larsen at al., 2009
Hamilton, Canada	-	459.9 kg	231.3 kg	4.8 kg	Agar et al., 2007

SWCTT is a complex procedure for any municipality, especially in cities of developing countries, in terms of logistics, fuel and air pollutant emissions (Sen et al., 2010; Boskovic et al., 2016). Tehran city is one of the cities facing challenges of MSW management (Akhavan Limoodehi et al., 2017; Nabavi-Pelesaraei et al., 2017). Tehran Waste Management Organization (TWMO) reported that about 8092 tonnes of waste is generated in the city per day, on an average. 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; Rajaeifar et al., 2015). The objective of this study was to projected fuel consumption and its costs for SWCTT in Tehran from 2018 to 2032. A further objective was to evaluated air pollutant emissions caused by fuel consumption in SWCTT processes.

Material and Methods

Introduction to Waste Guidance System (WAGS) software

The UN-HABITAT Waste Guidance System (WAGS) computer 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 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 Statistical Center of Iran (SCI), Tehran Municipality (TM), TWMO and Ministry of Cooperatives, Labour, and Social Welfare (MCLSW). A summary of the input information for the WAGS software is provided below.

Population of Tehran City

According to the 2016 population census, the population of Tehran was 8693706. Between 1996 and 2006, an average annual population growth of almost 3.03% was reached, but due to decreasing fertility levels the growth decreased to 1.44% between 2006 and 2011. In the period of 2011 to 2016 the average population growth increased again and reached to 1.72% (SCI).

Quantitative and qualitative characteristics of MSW in Tehran

Tehran estimated to be generating 2953.7 thousand tonnes of waste in 2017. On an average, the generation of waste per capita in Tehran is about 1.06 kg/person/day. Generated waste are collected and transported to Arad Kouh Complex Waste Process and Disposal (AKCWPD). 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; Damghani et al., 2008). Table 3 shows the MSW characteristic of Tehran in 2017. As it is shown in the Table 3, the 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%), 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%).

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

Waste types	Weight (%)	Waste types	Weight (%)
Wet waste	83.38	Non-ferrous metal	0.46
Used bread	2.52	Electronic waste	0.06
Soft plastic	2.34	PET	1.24
Plaster	1.16	Glass	0.54
Paper & cardboard	5.42	Bulk waste	0.21
Ferrous metal	1.69	Textile	0.36

MSW transfer stations in Tehran

After being collected throughout the city, the urban wastes are discharged at the stations to transfer to the heavy vehicles and transported by these vehicles to AKCWPD. There are 11 transfer stations in the MSW management system of Tehran. Table 4 shows current status of the regions allocated to transfer stations, the nominal capacity of these stations and transportation distances to AKCWPD.

Table 4. Transfer stations characterization (Akbarpour Shirazi et al., 2016)

Transfer station	Covered region(s)	Nominal capacity (ton/day)	Distance to landfill (km)
Darabad	1, 3	1299	56
Zanjan	2, 10	1037	48
Bani-hashem	4, 8	485	50
Hakimiyeh	4, 8	485	50
Chitgar	5, 21, 22	2227	52
Beyhaghi	3, 6, 7	864	46
Azadegan	13, 14, 15	1484	26
Yaran	9, 10, 17, 18	1484	32
Jahad	16, 19	1484	20
Shahre-rey	20	323	12
Shoush	11, 12	691	28

Energy and Environment software

Energy and Environment software which was developed by Iran's Ministry of Energy (IME) 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 (IME).

Results and discussion

Results of the WAGS software were obtained in sections as the following:

Projection of the amount of generated waste in Tehran (2018-2032)

Daily per capita MSW generation in Tehran from 2018 to 2032 is shown in Figure 1. As can be seen, waste generation per capita in Tehran has increased from 1.07 kg/capita/day in 2018 to 1.24 kg/capita/day in 2032 (waste generation rate growth is 1.1% per year). Figure 1 also depicts the amount of generated waste in Tehran from 2018 to 2032. Considering the population growth rate in Tehran (1.72%) and increasing the waste generation per capita, the amount of generated waste will be increasing from 3516 thousand tonnes in 2018 to 4579 thousand tonnes in 2032 in Tehran during the period 2018 to 2032. to be 4.8 years.

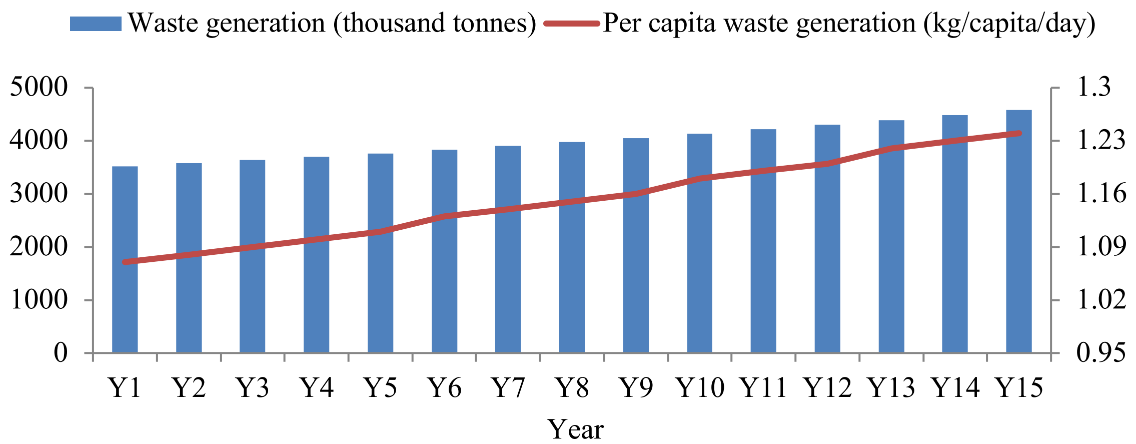

Figure 1. Waste generation and per capita waste generation in Tehran (2018-2032)

Projection of the fuel usage and costing in SWCTT in Tehran (2018-2032)

Mechanized waste collection machinery is used in Tehran. Therefore, the required collection vehicles were chosen based on current status. The same types of vehicles are assumed to be used for SWCTT in different regions of Tehran. Table 5 shows the characterization of the SWCTT vehicles. According to Table 5 waste compact volume and maximum weight of waste were 15 m^3 and 9 tonnes, 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 years.

Table 5. Characterization of SWCTT vehicles

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

The vehicle that used for SWCTT in Tehran has diesel engine. The diesel consumption takes place during acceleration, driving and compaction of the waste and will depend on a range of factors related to the waste, the collection area, the truck, the distance to the unloading point, and the driver (Larsen et al., 2009, Sandhu et al., 2016). Fuel consumption for the vehicle that used for SWCTT in Tehran is 8 L/h while the vehicle is working. Total time of collection and vehicle round trip time to waste disposal site in Tehran is 6371 minute. Table 6 shows the fuel consumption in SWCTT in Tehran from 2018 to 2032. The results of the fuel cost of SWCTT in Tehran from 2018 to 2032 are also presented in Table 6. As can be seen fuel consumption of SWCTT in Tehran has increased from 21342 thousand liters in 2018 with the price of 2296 thousand dollars to 28104 thousand liters in 2032 with the price of 3023 thousand dollars. The total of 366614 thousand liters of fuel is required to SWCTT in Tehran during the period 2018 to 2032 with the price of 39446 thousand dollars.

Table 6. Projected the fuel usage and costing for SWCTT in Tehran from 2018-2032

Year	Fuel consumption (thousand liters)	Fuel cost (thousand dollars)
2018	21342	2296
2019	21716	2336
2020	22015	2378
2021	22487	2419
2022	22935	2467
2023	23343	2511
2024	23742	2554
2025	24290	2613
2026	24794	2667
2027	25315	2723
2028	25798	2775
2029	26320	2831
2030	26942	2898
2031	27471	2955
2032	28104	3023

Projection of the air pollutant emissions from SWCTT in Tehran (2018-2032)

Use of diesel in collection trucks is presumably the most important environmental burden from waste collection because of the emission of exhaust gases from the combustion process (Larsen et al., 2009, Fontaras et al., 2012). Air pollutant emissions including NO_X, SO_2, SO_3, CO, CH and SPM caused by diesel consumption for SWCTT in Tehran were calculated with Energy and Environment software and data obtained from the WAGS software. Results are presented in Table 7. Diesel consumption from SWCTT in Tehran have produced 576.5, 358.7, 4.3, 153.7, 469.5 and 281.7 tonnes of NO_X, SO_2, SO_3, CO, CH and SPM, respectively in 2018. These amounts of emissions will be increased by 759.1, 472.3, 5.6, 202.3, 618.3 and 371, respectively in 2032. Total emissions of NO_X, SO_2, SO_3, CO, CH and SPM in the period of 2018 to 2032 are 9902.8, 6161.7, 73.5, 2639.6, 8065.5, 4839.2 tonnes, respectively.

In this regard, study fulfilled by Fontaras et al. (2012) revealed that the emissions from the diesel waste collection trucks in Milan, Italy were 0.21 g/km for HC, 7.4 g/km for CO, 32.3 g/km for NO_X and 46.4 mg/km for PM. The study carried out to evaluate pollution emissions from diesel refuse collection vehicles in Madrid, Spain showed that 2.52, 1, 18.18 and 0.29 g/km of CO, HC, NO_X and PM are emitted (Lopez et al., 2010). Another research was conducted to measure emissions from diesel side loader refuse trucks. It has been reported that fuel use for trash collection and transportation is 73 gal with the emissions of 78, 67, 86 and 80 g of NO_X, HC, CO and PM, respectively (Sandhu et al., 2016).

Table 7. Projected the air pollutant emissions from SWCTT in Tehran (2018-2032)

	Air pollutant emissions (tonnes)					
Year	NO_X	SO_2	SO_3	CO	CH	SPM
2018	576.5	358.7	4.3	153.7	469.5	281.7
2019	586.3	365	4.3	156.4	477.8	286.7
2020	596.6	371.6	4.4	158.5	484.3	290.6
2021	607.4	378	4.5	161.9	494.7	296.8
2022	619.5	385.4	4.6	165.1	504.6	302.7
2023	630.5	392.2	4.7	168.1	513.5	308.1
2024	639.8	399	4.7	170.9	522.3	313.4
2025	656.1	408.3	4.9	174.9	534.4	320.6
2026	669.8	416.5	5	178.5	545.5	327.3
2027	683.7	425.2	5.1	182.3	556.9	334.2
2028	696.9	433.3	5.2	185.7	567.6	340.5
2029	710.9	442	5.3	189.5	579	347.4
2030	727.6	452.6	5.4	194	592.7	355.6
2031	742.1	461.6	5.5	197.8	604.4	362.6
2032	759.1	472.3	5.6	202.3	618.3	371

Conclusions

This paper aims to measure the fuel consumption, fuel costs and air pollutant emissions of SWCTT in Tehran from 2018 to 2032. For this purpose, WAGS and Energy and Environment software were applied. Results showed that the amount of waste generation in Tehran city in 2018 is 3516 thousand tonnes. The generated waste is projected to increase by 4579 thousand tonnes in 2032. 21342 thousand liters of fuel are needed to SWCTT of Tehran in 2018. This amount will be increased to 28104 thousand liters in 2032. Annual cost of required fuel which is 2296 thousand dollars in 2018 will get to 3023 thousand dollars by the year 2032. NO_X, SO_2, SO_3, CO, CH and SPM emissions in 2018 are 576.5, 358.7, 4.3, 153.7, 469.5 and 281.7

tonnes. These amounts of emissions are projected to increase by 759.1, 472.3, 5.6, 202.3, 618.3 and 371 tonnes in 2032. The total amount of 9902.8, 6161.7, 73.5, 2639.6, 8065.5, 4839.2 tonnes of NO_X, SO_2, SO_3, CO, CH and SPM were emitted by SWCTT in Tehran during 2018 to 2032.

SWCTT embody the leading part of the solid waste system costs do to the large fuel consumption. 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. Therefore, by improving SWCTT, not only the total budget of waste management but also detrimental effects on the environment can be improved enormously. So, for future studies it is recommended to develop new applicable models to optimize SWCTT.

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