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MUNICIPAL SOLID WASTE MANAGEMENT AND GREENHOUSE GAS EMISSIONS AT INTERNATIONAL AIRPORTS: A CASE STUDY OF ASTANA INTERNATIONAL AIRPORT

Abstract

The steady expansion of the city of Astana and the increase of airport capacity is leading to an increase in municipal solid waste generation. The purpose of this study is to perform compositional analysis of the municipal solid waste produced at the Astana International Airport and evaluate different waste management scenarios in terms of greenhouse gas emissions. Four base greenhouse gas emissions scenarios were proposed in this study, namely scenario-1 describing the current municipal solid waste management case, scenario-2 with integration of 29% recycling and 71% of municipal solid waste landfilling, scenario-3 for 100% of airport municipal solid waste being incinerated and scenario-4 for recycling 29% and the remaining waste being processed for energy recovery purposes. Recyclable and combustible fractions were found to be the major fractions (over 50%) of the total municipal solid waste generated in the Astana International Airport. The proposed scenario 2 demonstrated significantly reduced net greenhouse gas emissions (t CO_2 eq/year) over the existing scenario 1, while scenarios 3 and 4 showed negative net greenhouse gas emissions. The experimental data provided and the scenarios discussed in this work are useful tools for decision makers for environmental waste management at airports.

Keywords: Astana International Airport, Municipal Solid Waste, Recyclable Fractions

1. Introduction

It has been reported that aviation emissions account for more than 2% of global CO_2 emissions and projected CO_2 emissions (Mt) from international aviation is expected to grow to more than three times by 2050 in comparison to 2018 (ICAO, 2016). International airports are typically currently designed with operational and economic efficiency as priorities (Boons, et al., 2010). Thus, successful international airports are normally evaluated by indicators such as financial performance, number of flights and passengers traffic. In some countries like the US, the Federal Aviation Administration (FAA) and other local authorities can demand certain regulation for airports, however typically these regulations are limited (Mansolud et al., 2014). Only in the last decades has the aviation industry started considering the sustainability performance, gradually introducing aspects of environmental stewardship and social responsibility as important issues (Monsalud et al., 2014; SAGA, 2013). Waste management in airports is one of the critical environmental issues that require more attention (Li et al., 2003). Despite the fast growth of aviation in airports, less attention is generally paid to the solid waste management in comparison to noise, aircraft emissions and water consumption (Pitt and Smith, 2003; Carvalho et al., 2013). As noted by Upham et al, (2003,) non-regulated resource and waste outputs in airports are related to carbon dioxide emissions. Thus, public negotiations on emissions and associated limits can be achieved locally as environmental capacity targets. As a result, locally achieved environmental limits have functioned as sustainable capacity limits and targets for airports (Upham, et al., 2003).

The waste management policy recommended by the Airport Council International (ACI) is to divert solid waste going to landfills (ACI Policy Handbook, 2018). This is expressed in the waste management hierarchy as: avoid generating waste, reduce, reuse, recycle and finally dispose the lowest possible quantity. Generally speaking, the purpose of waste management is to reduce the volume of waste being generated and its disposal cost. Typically, airports generate both hazardous and non-hazardous solid wastes that need to be recycled, utilized for energy recovery, or disposed at landfills (US Federal Aviation Administration, 2013). The typical waste streams generated at airports according to the International Civil Aviation Organization are: municipal solid waste (terminal, tenant, airline, cargo waste), construction and demolition waste (C&D), deplaned aircraft, compostable and biodegradable waste and hazardous & industrial waste (ICAO) (US Federal Aviation Administration, 2013; ICAO). According to Baxter et al. (2018b), waste generated by airlines at Kansai International Airport accounted for 20% of the total airport waste. Considering that the choice of airlines is directly influenced by the level of service provided to passengers (Abeyratne, 2001), airports are continuously seeking to achieve further improvement of customer service by providing free newspapers and magazines and amenities. As a result, such measures lead to an extra airport waste. In this regard, it was observed that only sorting and recycling of newspapers on aircrafts at Munich Airport was enough to reduce the waste by half (Pitt and Smith, 2003b). Moreover, the new regulation adopted by German Waste Management and Product Recycling Act in 2012, has forced all products purchased by the Munich airport to satisfy environmental and economic requirements (Baxter, et al., 2014). In addition, continuous improvement of higher recycling rate was achieved by the strict separation of recoverable fractions with trained staff in six recycling stations located nearby airport (Baxter, et al., 2014). Moreover, logistics optimization measures were performed by minimizing container loads, shortening the transport paths in order to reduce the GHG emissions (Baxter, et al., 2014).

Waste management in international airports is recognized as one of the key aspects in sustainability performance (Lam et al., 2018; Upham et al., 2003; Kilkis and Kilkis, 2016). In the study of Kilkiș and Kilkiș (2016), a benchmarking of airports was developed based on the sustainability ranking indexes. According to the authors, environmental management and biodiversity were found to be one of the 5 main drivers to build a ranking of sustainable airports. As expected, water and waste management aspects of airports also servved as main indicators (Kilkiș and Kilkiș 2016). In addition, the authors extended the study by implementing benchmarking metabolism further for airlines based on the sustainability airline index (SAI) (Kilkiș and Kilkiș, 2017). The results showed that top ranking airports such as Amsterdam, Frankfurt, Munich, Atatürk and Heathrow have achieved a high level performance both in terms of operational aspects, such as passenger and cargo traffic, and environmental management. In addition, a comparison of world's best 10 top airports was also conducted by Koç and Durmaz (2015) based on sustainability analysis and performance. According to this study, the airport that perform very well according to the stakeholder expectations do not necessarily perform satisfactorily in terms of sustainability reporting investigations based on empirical findings (Koç and Durmaz, 2015).

According to the annual reports and open data Munich, Naples, Gatwick, Hong Kong and Geneva had the highest recycling rate of municipal solid wastes in recent years

(Munich Airport 2015/2016; Miedico, 2018; Gatwick Airport, 2017; HKIA, 2016/17; Geneva Airport, 2018). In addition, Copenhagen and Brussels International Airports have achieved significant improvements in terms of waste recycling rate of around 26 and 28%, respectively (Copenhagen Airport, 2017; Brussels Airport, 2017). The detailed information on waste recycling rates of some selected international airports are presented in Table 1.

Table 1 Solid waste recycling rate at International Airports

International Airports	**Country**	**Recycling rate, %**	**Passenger traffic, Million**	**Year of report**	**References**
Munich	Germany	79	42.3	2016	(Munich Airport 2015/2016)
Naples	Italy	62	8.6	2017	(Miedico, 2018)
Gatwick	England	58	43.1	2018	(Gatwick Airport, 2017)
Hong Kong	Hong Kong	46	70.5	2016	(HKIA, 2016/17; HKIA)
Geneva	Switzerland	44.4	17	2017	(Geneva Airport, 2016-2018)
Copenhagen	Sweden	28	29.2	2017	(Copenhagen Airport, 2017)
Brussels	Belgium	26	23.5	2017	(Brussels Airport,

					2017)
Kansai	Japan	13.2	28.8	2015	(KIA, Baxter et al., 2018)
Astana	Kazakhstan	11.5	4.2	2017	(Urcha, 2018)

The total weight of the reclaimed solid waste at Munich Airport has continuously decreased from 16 000 to 8 000 t from 2008 and 2011 (Baxter et al., 2014). In 2015, the airport achieved a solid waste recycling rate of 79%, 57% of which was mixed materials and 22% was waste paper (Munich Airport, 2015). Of the non-recycled waste (21%), 11% was sent to a biogas plant, while the remaining 10% was disposed at the Munich landfill (Munich Airport, 2015). In 2016, 6.4 Mt of waste was recycled, while 4.5 Mt of waste was used for energy recovery purposes, and only 309 t was disposed at the landfill (Munich Airport, 2016). Approximately 10.4 kt of waste was generated in 2015 at Kansai International Airport (KIA, 2016) and 83% was characterized as combustible fraction and the remaining 17% as recyclable fractions (KIA, 2016). The combustible fraction includes kitchen, food, rags, non-recycle and other wastes, while the non-combustible fraction consist of glass, ceramic dishes, glass bottles (broken) and metal wastes. The recyclable fraction of KIA airport is further sorted to aluminum, steel cans, unbroken glass bottles, newspaper, magazines, office paper, documents and cardboard (KIA, 2016). The combustible fractions were utilized at the incineration plant located at the Kansai Airport area. The incineration plant is equipped with a fluidized bed combustion system (KIA). Flue gas from the incinerator is treated with a filter-type precipitator, catalysis to reduce NOx emissions and wet ash stabilization technology (Baxter et al., 2018). The exhaust gas from the incinerator is controlled under strict standards limits and kept at or below the following concentrations: dust at 0.02 g/Nm^3, SOx at 20 ppm, HCl at 30 ppm and NOx at 70 ppm (Baxter et al., 2018). it should be noted that there are only a few studies on solid waste management in international airports (Pitt and Smith, 2003a; Mayer et al., 2015; Baxter et al., 2018a). As the first step in any waste management plan for the Astana International Airport, the detailed composition of MSW produced at the airport (TSE) is required and it is presented here for the first time. In addition to the compositional analysis, GHG emissions were estimated from the MSW fractions and four possible scenarios are explored. As experience has shown, the waste management scenarios could potentially reduce the environmental footprint of the airport. At present no recycling program or other waste management measures are implemented in the Astana International Airport. Also, there are limited data on MSW management for any international airports in Kazakhstan. This study will also be useful for airport as well as city authorities to develop an effective solid waste management strategy and also to promote continuous improvement of existing waste management programs.

2. Material and Methods

This section describes in detail the airport MSW sampling procedures implemented for compositional analysis and reports the GHG calculation tool and the model based on a simplified Life Cycle Assessment (LCA) method used to estimate GHG emissions. The case study description is presented in detail along with the proposed scenarios for GHG emissions.

2.1. Waste sampling procedure

A two-step sampling method was applied for the sampling of solid waste according to ASTM D 5231-92 (see Figure 2 (ASTM, 2003). The first sampling was conducted in November of 2017 and the second in August of 2018. Here a loaded truck was delivered to the landfill from Astana International Airport. In total 236 and 214 kg of solid waste were sorted during the first and second sampling campaigns, respectively. As illustrated in Figure 2, large pieces of refuse including recyclables were separated during the first sorting step, typically includeing paper (cardboard, paper, Tetrapak), plastic (HDPE LDPE, PET, other plastics), metals (Fe and non-Fe), glass, wood, textile and leather, waste electrical and electronic equipment (WEEE), construction and demolition (CDW), and others. During the second sorting step, non-recyclable fractions were further sorted into combustible fractions such as mixed paper, mixed plastic, textile and leather, and wood, as well as non-combustible smaller items such as metals (Fe and non-Fe), glass, and WEEE. Each container was then weighed using a digital scale. Schematic illustration of sampling steps can be found in the Figure 2.

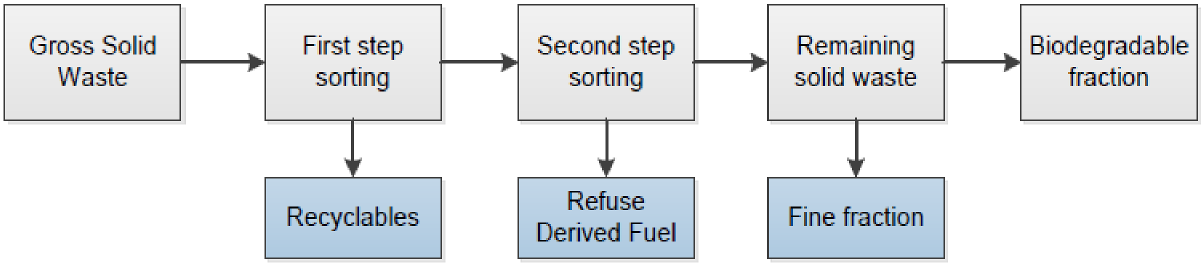

Figure 1. Sampling steps for MSW

2.2. GHG emission tool

For the base calculations of GHG emissions, an open source calculator called the *Tool for Calculating Greenhouse Gases (GHG) in Solid Waste Management (SWM)* was used. The tool was developed by IFEU (Institut für Energie- und Umweltforschung Heidelberg GmbH) and the German Technical Development Cooperation (IFEU, 2016). The calculation method used in the model follow a simplified Life Cycle Assessment (LCA). Different waste management scenarios can be compared by calculating the GHG emissions of recycled and disposed waste fractions.

The annual solid waste production at Astana International Airport and the composition of MSW were used as specific input data. Additionally, the following data were considered for the the estimation of GHG emissions for the abovementioned four scenarios:

1) Waste quantities derived from the weighbridge data provided by Astana Municipality;
2) Waste composition data generated through two waste sampling analyses in November 2017 and July 2018; and
3) The total carbon (C_{total}) and fossil carbon (C_{fossil}) content of given waste fractions (see section 2.3).

2.3. GHG emission methods

A simplified life cycle assessment method was used to determine the GHG emissions from MSW stream. The emission coefficients were taken from the commonly used IPCC database of 2006, with the global warming potential (GWP) values for methane of 28 and for nitrous oxide of 265 (IPCC, 2006a; IPCC, 2006b). The 2019 refinement of IPCC database from 2006 does confirm no refinement on GWP for methane and nitrous oxide values. These emissions for these components were converted to CO_2 eq. Carbon contents of the solid waste fractions, were taken from supplementary IPCC database, see Table 2. GHG emissions factors for biogegradable and recyclable fractions as well as other supportive information used in the estimation are provided in the supplementary material, see Tables S2-S5 (Prognoz, 2008).

CO_2 emissions based on MSW composition were calculated from eq. 1 (IPCC, 2006a; IPCC, 2006b; IPCC, 2006c):

$$CO_2 emissions = MSW * \sum_j \left(WF_j * dm_j * CF_j * FCF_j * OF_j \right) * 44/12 \tag{1}$$

where:

CO_2	CO_2 emissions in the inventory year, Gg/yr;
MSW	total amount of municipal waste as wet weight incinerated or open-burned, Gg/yr;
WF_j	fraction of waste type/materail of component j in the MSW (as wet weight incinerated or open-burned);
dm_j	dry matter content in component j of the MSW incinerated or open-burned, (fraction);
CF_j	fraction of carbon in the dry matter (i.e., carbon content) of component j;
FCF_j	fraction of fossil carbon in the total carbon of component j;
OF_j	oxidation factor (fraction, considered as 100% for incineration;

44/12 conversion factor from C to CO_2; and

j component of the MSW incinerated/open-burned such as paper/cardboard, textiles, food waste, wood, garden (yard) and park waste, disposable nappies, rubber and leather, plastics, metal, glass, other inert waste.

Table 2 Carbon content of MSW fractions (IPCC, 2006a; IPCC, 2006b; IPCC, 2006c)

Fraction	**Total Carbon (%)**	**Fossil Carbon (%)**
Food waste	15.2	0
Garden and park waste	19.6	0
Paper, cardboard	41.4	1
Plastics	75.0	100
Glass	0	0
Ferrous metals	0	0
Aluminum	0	0
Textiles	40.0	20
Rubber, leather	56.3	20
Nappies (diapers)	28.0	10
Wood	42.5	0
Mineral waste	0	0
Others	2.7	100

2.4 Description of the case study: Astana International Airport

According to the Civil Aviation Statistics of the World, a strong relationship exists historically between economic growth of a country and the growth rate of aviation, (ICAO, 2002a). The Astana International Airport of the Kazakhstani capital city is another example that has followed a similar trend of a very fast expansion of aviation along with economic growth, see Figure 2. In addition, Astana city has one of the highest economic growth rates within the country and the highest net migration rate in 2017 (NSC, 2018). According to the National Statistical Committee (NSC), the net migration of Astana city residents was the highest within the country at 33 500 in 2017 (NSC, 2018). During 1998 and 2018, the population of Astana city increased from 327 000 to over 1 030 000 inhabitants (NSC, 2018). In addition, major work on the expansion of the transportation systems such as airport and train stations has occurred in Astana city. Currently, roughly 90% of the MSW produced in Astana city, including the solid waste from the airport, is disposed in the sanitary MSW landfill. The remaining 10% of MSW is separated as recyclable fraction at the sorting plant (Urcha, 2018). Generally speaking, this MSW disposal trend can be compared to other countries such as Poland and the Russian Federation where 90% and 95% of MSW are disposed at the landfills, respectively (IFC WBG, 2012; Renou et al., 2008). According to four seasonal investigations on morphology of MSW in Astana (2017-2018), 48-50% of the disposed MSW in Astana city was classified as organic, 30% as recyclables, 10% refuse-derived fuel (RDF) and the rest being other fractions (Abylkhani et al., 2019).

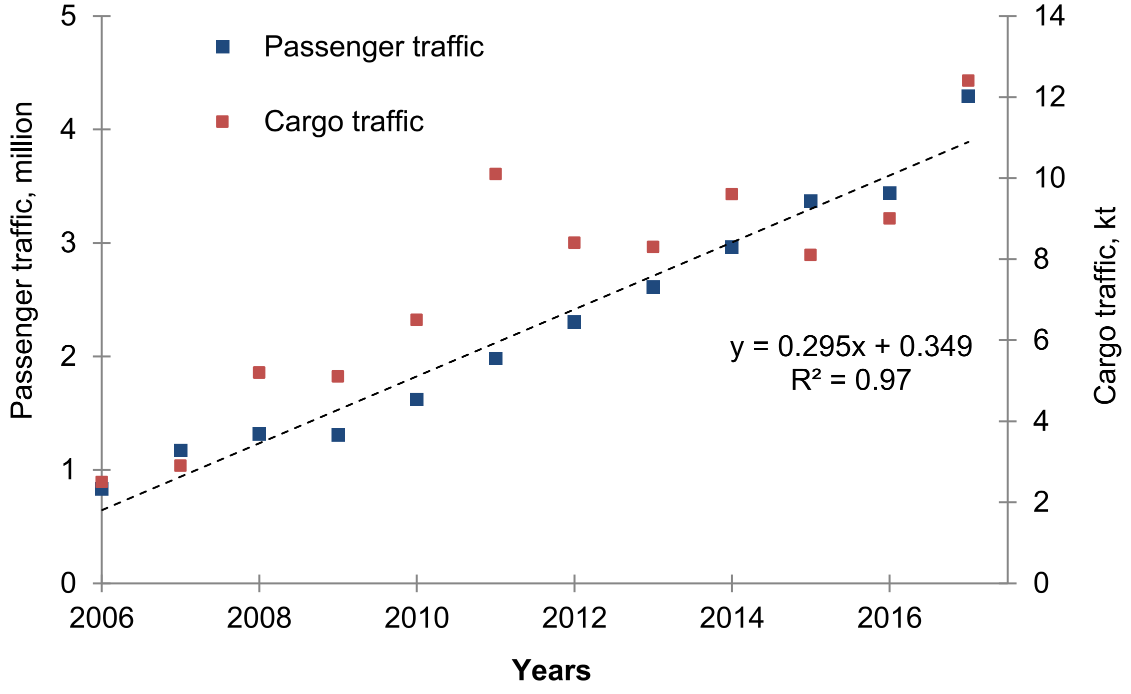

Figure 2 Dynamics of passenger and cargo traffic at Astana International Airport during 2006-2017 (AIA, 2018a).

Currently, Astana International Airport serves nearly 160 flights per day including both landing and take-off flights (AIA, 2018a). According to the latest data, the passenger traffic growth rate via Astana International Airport in the first half of 2018 has increased by 11% in comparison to the same period for 2017 (AIA, 2018b). Figure 2 shows the dynamics of passenger and cargo traffic for the period of 2006-2017. The total passenger traffic of Astana International Airport numbered around 4.3 million in 2017 (AIA, 2018a). As reported by the civil aviation committee, 29% of the total passenger traffic in Kazakhstan came from Astana International Airport (CAC, 2017). As seen in Figure 2, the passenger traffic has more than quadrupled over the period of 2006-2017 (AIA, 2018a). The passenger traffic curve over this period was linear. It should also be noted that there is a high probability of an increase in passenger traffic in the near future due to the steady growth in recent years, as indicated by the statistical data on the demographics and economics of the Astana city residents. In 2017, more than 1031 t of MSW from Astana International Airport was disposed at the MSW landfill[1]. MSW generation is also likely to increase in line with a stable increase of the passenger traffic, as seen in Figure 2. Based on the statistical data of the sorting plant in Astana, the solid waste from the Astana International Airport is delivered approximately 15 to 16 times per month with an average weight of around 6 tonnes. Separate statistics are also available for construction and demolition waste (CDW) that is also being disposed at a separate cell of the current MSW landfill. However, the CDW is excluded from this study and focuses on municipal solid waste only.

2.5 Proposed waste management scenarios

In this study, four scenarios of MSW utilization are compared in terms of CO_2 emissions savings. The scenarios examined are illustrated in Table 3. The quantities and composition of MSW were used as input data to the tool for calculations of GHG emissions. The first scenario illustrates the current situation for waste management in Astana International Airport. As noted above, roughly 10% of Astana MSW is recycled and the remaining 90% is disposed at the sanitary landfills (Urcha, 2018; Abylkhani et al., 2019; Inglezakis et al., 2018). In addition, MSW generated at Astana International Airport is transported to the city MSW landfill side where it merges with the city MSW stream and is treated by a similar mechanical separation process. Thus, MSW stream from airport was proposed to model the current situation (10% as recyclable and 90%

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being landfilled), see Figure 3. The second scenario assumes an improved scheme for MSW management, where recyclable fraction of MSW such as glass, plastics, paper and metals are separated at the source including composting of the organic fraction. These values are in general agreement with the recent results obtained from MSW sampling campaigns made in Astana city (Abylkhani et al., 2018). According to the MSW composition of the city, the potential fractions of recyclables account roughly for 30%. A similar scenario was proposed by Milutinovic et al., (2017) in a study on environmental assessment of MSW management for the city of Niš in Serbia. The third scenario assumes an energy recovery option by introducing an incineration technology to utilize all MSW generated at the airport. This scenario is justified by the high content of paper and plastic fractions in the MSW streams of Astana International Airport and the intention of Astana municipality to build a waste to energy plant in the future. However, in this particular scenario an assumption was made that the WtE is to be built close to the Astana International Airport and thus the transportation costs are not taken into account. The fourth scenario introduces a combination of scenarios 2 and 3. In this scenario, it is assumed that the source separation of recyclables such as plastics, papers, metals, glass was taking place, along with sorting and composting of organic waste and waste to energy option. Thus, the produced MSW in this scenario is roughly divided into 29% of recyclables and the remaining 79% is sent to incineration plant for energy recovery.

Table 3. Description of waste treatment scenarios

Description	**Share**

Scenario 1	Existing situation	10%-recyclables; 90%-disposal in landfill;
Scenario 2	Introduction of waste separation • Source separation and recycling of plastics, paper, metals, glass; • Source separation and composting of organic fraction	29%-recyclables; 71%-disposal in landfill
Scenario 3	Energy recovery from solid waste • Waste to energy (WtE) of total produced waste	100% of waste to be sent to a WtE plant (incineration)
Scenario 4	Introduction of waste separation and thermal utilisation • Source separation and recycling of plastics, paper, metals, glass; • Source separation and composting of organics; • Waste to energy of total produced waste	Combination of waste management scenarios 2 and 3; 29%-recyclables; 71%-disposal in WtE plant

3 Results and Discussion

This section presents the passenger traffic and MSW generation and composition at Astana International Airport during 2017-2018. The composition of the airport solid waste is discussed and compared with the MSW composition obtained from Astana city. Finally, the four possible scenarios for GHG emissions are investigated and discussed in detail.

3.1 Monthly dynamics of the passenger traffic in 2017 and 2018

According to the data obtained from the marketing department of Astana International Airport, the total passenger traffic has increased from 4.3 million in 2017 to 4.6 million in 2018 (Marketing Department, 2018). Monthly statistical information for the passenger traffic for 2017 and 2018 is presented in Figure 3. Despite fluctuations between summer and winter periods, a gradual increase of MSW generation can be observed. The initial decrease of passenger traffic from 271 000 to 237 000 in 2017 and from 316 000 to 293 000 can be explained by the occurrence of winter holidays which typically start from roughly 15th of December to 10th of January. The passenger traffic then gradually increases and reaches a peak of 515 000 in 2017 and 508 000 in 2018 during the summer periods. It can be seen that the monthly dynamic of passenger traffic increased from 2017 to 2018, except for the summer period, especially in July and August. These similar values for the passenger traffic between 2017 and 2018 can be explained by added extra passengers due to the fact that there was an EXPO event in the summer of 2017.

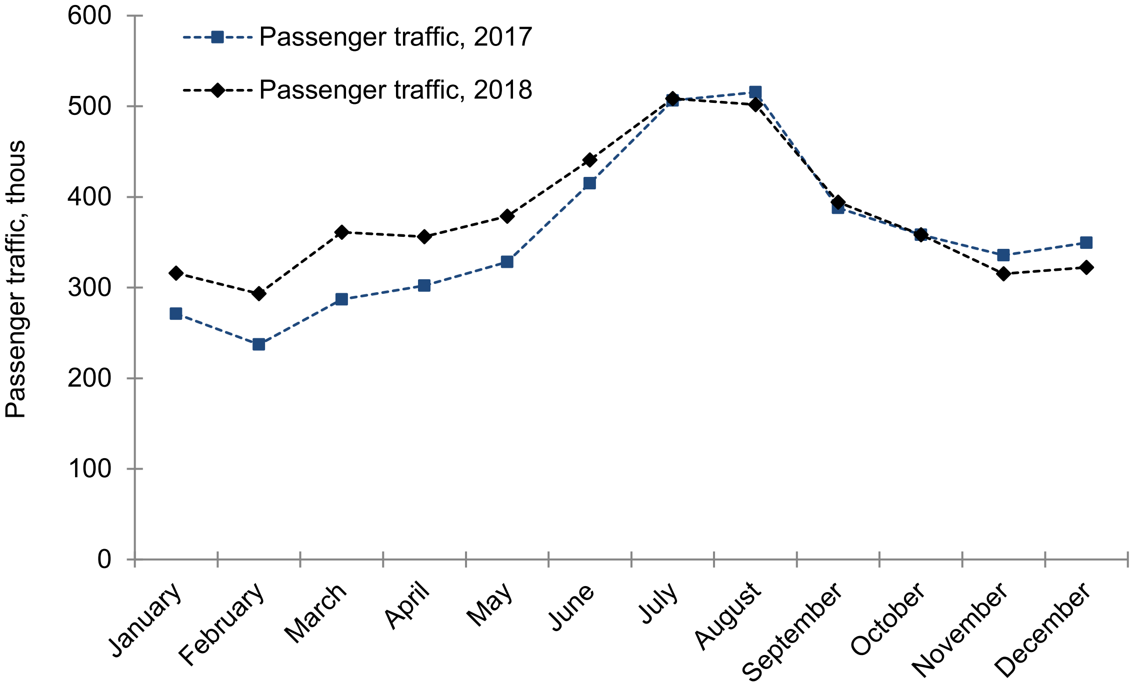


Figure 3 Monthly dynamics of the passenger traffic during 2017 and 2018

3.2 MSW generation at Astana International Airport

As noted above, the total MSW generation from Astana International Airport in 2017 was 1031 t. Solid waste generation per passenger based on quantities delivered to the MBT plant is shown in Figure 4.

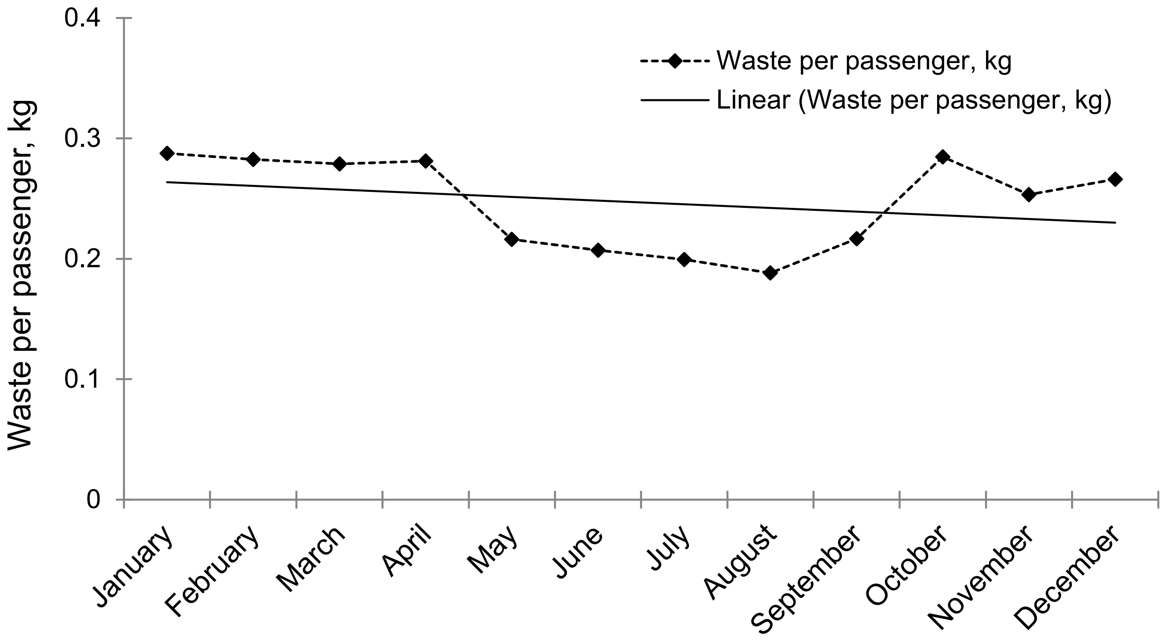


Figure 4. Dynamics of waste per passenger in 2017

The monthly passenger traffic and the total MSW weight in 2017 provided a value of around 0.24 kg of MSW per passenger (MBT data, 2017). This value is comparable with data from smaller airports such as Aberdeen International and Edinburgh Airports during 1998-2001 (Pitt and Smith, 2003). The waste per passenger in Aberdeen International Airport was 0.24 kg in 1998/1999 and 0.26 kg in 2000/2001, while the values in Edinburgh airport were 0.22 kg in 1998/1999 and 0.21 kg in 2000/2001. According to Miedico (2018), the waste per passenger at Naples International was 0.14 kg which is found to be 1.7 times smaller than the data obtained at Astana International Airport (Miedico, 2018). The waste per passenger of Kansai International Airport was 0.43 kg in 2015 which is notably higher than the value of Astana International Airport. It should be noted that the waste per passenger value of Kansai International Airport has been decreasing gradually from 0.71 kg to around 0.43 kg between 2002 and 2015

(Baxter et al., 2018). The compositional analysis of solid waste was conducted based on 27 flights of 4 different airlines in Larnaca's International Airport (LIA) in Cyprus (Tofalli et al., 2017). The results of this study demonstrate the difficulties in implementing waste minimization practices during the flights due to the limited time for most flights in Europe which typically do not take more than 3 h. In addition, waste prevention practices were also limited by available space within the aircraft and the strict safety rules at airports.

3.3 MSW composition

Table 4 shows the gross MSW composition for Astana International Airport obtained from the first and second sampling campaigns at the landfill. The recyclable fractions such as paper, plastic, metals and glass collected at the first step sorting amounted to around 54%. This value is comparable with the data reported by Hong Kong International Airport in which the recyclable fraction was 53.8% in 2013 (HKIA, 2015/2016). The first step of MSW separation at Astana International Airport (Sampling-I) could result in a rapid effect in terms of GHG emission savings. Further, it is worth mentioning that Astana International Airport has its own boilers for district heating of buildings (AIA webpage). In this regard, separation of combustible fraction such as refuse-derived fuel (RDF) for district heating represents another attractive solution, as it has been successfully implemented at Munich and Kansai International Airports (Baxter et al., 2014; KIA, 2016; Munich Airport, 2013).

Table 4 Solid waste composition in Astana International Airport and Astana city (Abylkhani et al., 2018)

Component	Airport Sampling-I[1] %	Airport Sampling-II %	Astana city[2] %
Paper	30.0	44.7	12.5
Plastic	17.2	30.5	15.4
Fe Metals	1.4	0.4	2.0
Non-Fe Metals	2.2	7.3	0.7
Glass	3.1	2.8	6.2
Wood	0.0	0	0.8
Textile and Leather	0.3	0.3	3.4
WEEE	1.0	0.4	0.6
C&D	0.0	0.2	0.9
Organics	4.7	5.2	47.2
Fine fraction			3.4
Cabin specific waste	4.0	6.5	
Hygiene Waste/Diapers	7.2	0.5	6.2
Rest	28.9	1.2	0.8
TOTAL Sample	100	100	100

[1] - Sampling-I/Sampling-II means first and second sampling campaigns of airport MSW; [2] - Average of 4 seasonal sampling campaigns during 2017-2018

According to the studies of Pitt and Smith (2003) and Jones (1996), about 45 to 60% of the produced waste in airports comes from the aircraft themselves rather than being produced within the airport. In addition, the composition of MSW from the residential region of Astana city was provided for comparison. As expected, the recyclables such as paper, plastic and glass fractions found are different than those observed in airport waste. The paper fraction of airport MSW was found to be in the range of 30 to 45%, while this fraction from city waste was roughly 12.5%. The plastics fraction showed a more or less comparable trend while the glass fraction of the airport waste is one-half that this observed in the city waste. This difference is probably due to the high rate of paper and plastic in packaging of fast food or other travel items typically needed for passengers at international airports. In addition to food packaging, Baxter et al. (2018a) noted that the paper waste also consists entirely of newspapers, magazines, documents and computer printouts in most international airports. Another obvious difference was seen in the organic fraction of MSW. As expected, the organic fraction at Astana International Airport was around 5% in contrast to 47% in city waste (Abylkhani et al., 2018). It should be noted that according to the information obtained from marketing department of Astana International Airport, cabin waste including recyclables and organic waste is outsourced by private company. In addition, both cabin waste of international and domestic flights are the collected at the Astana International Airport Furthermore, this collected cabin waste is merged with the general airport waste and transported to the city landfill for disposal. These observations on the quantity of organic waste can be explained by the duration of passenger stay and the existence of residents at the airports in dedicated apartments. Moreover, as it was discussed by Kilkiș and Kilkiș (2017) that onboard MSW separation scheme reduces the amount of general waste. A comparison of the percentage of organic fraction in the airport waste produced in selected airports is provided in Figure 6. The organic fractions from Munich, Copenhagen, and Hong Kong International Airports were 11%, 18% and 35%

respectively in recent years,. This trend for organic waste at international airports can be linked with the conclusion drawn by Castillo-Manzano et al., (2018), namely passengers tend to consume more goods where there are malls and shops. Castillo-Manzano and López-Valpuesta (2013) also pointed out that passenger behavior is even more obvious when cheaper food chain options are offered at the airport areas such McDonalds and Burger King. As can be seen, organic waste at international airports increases along with the increasing presence of such food chains. The percentages of organic waste vs. passenger traffic are illustrated in Figure 5.

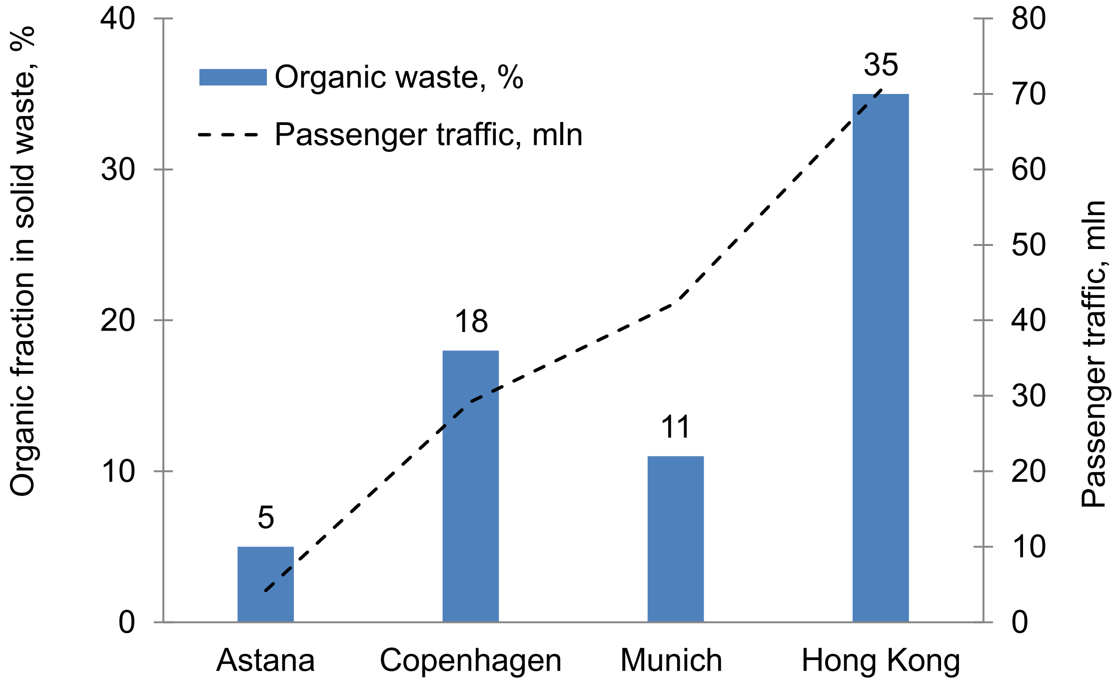


Figure 5 Percentage of organic waste vs. passenger traffic (Copenhagen Airport, 2017; Munich Airport, 2016; HKIA, 2016/17).

3.4 Greenhouse gas emissions

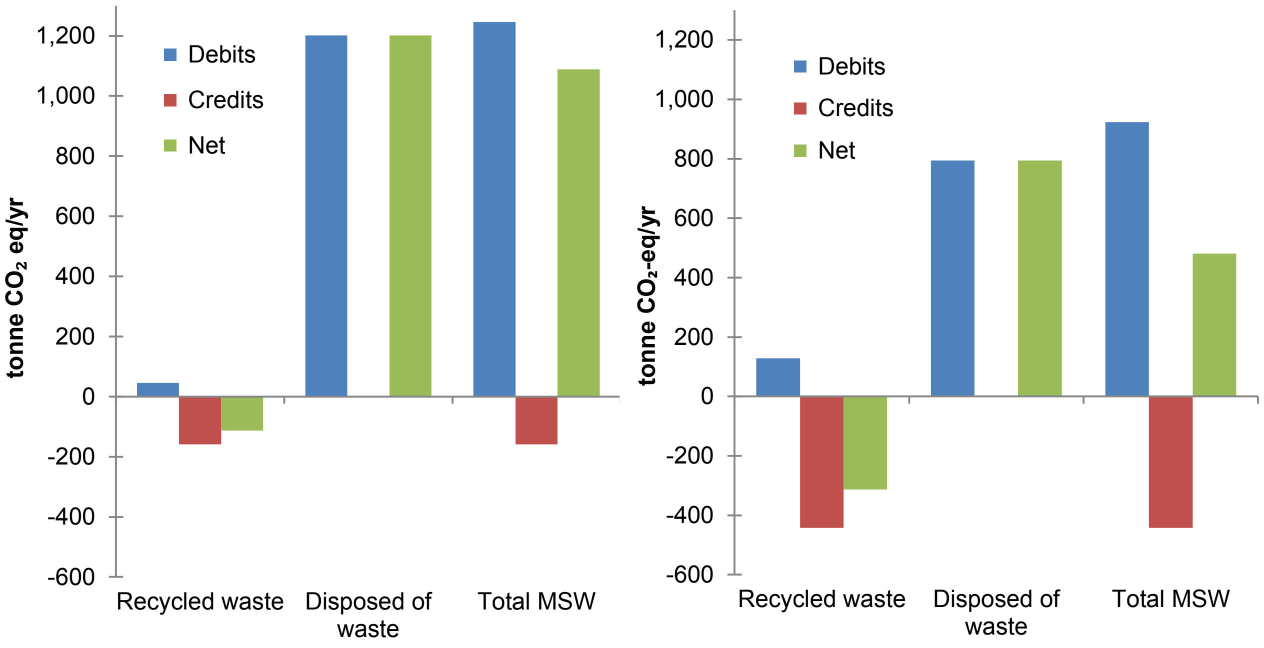
As mentioned above, the model is based on a simplified Life Cycle Assessment (LCA) method and thus cannot not directly compared to more elaborated multi-criteria analysis models presented elsewhere (Stefanovic et al. 2016; Mulitinovic et al., 2017; Inglezakis et al., 2018). Figure7 (a, b, c and d) illustrates the calculated GHG emissions for the scenarios that were described in Table 3. GHG emissions for recycled, disposed waste in landfill and for total treated MSW waste were plotted separately. GHG emissions were presented for actual GHG emissions (noted as debit), for avoided GHG emissions (noted as avoided) and net GHG emissions.

Scenario 1 describes an existing situation where 90% of MSW is landfilled and around 10% is recycled. The calculated GHG emissions due to the 90% of MSW landfilled was 1247 t CO_2 eq/year, while avoided emissions was only 158 t CO_2 eq/year. As a result, the net GHG emissions of the total MSW was 1088 t CO_2 eq/year in scenario 1. An implementation of the recycling scheme, with a reasonable recycling rate of 29% in scenario 2, could reduce the net GHG emissions further to 607 t CO_2 eq/year. As a result, the difference in GHG emissions between the recycled and disposed MSW was 481 t CO_2 eq/year. In scenario 3, it is assumed that 100% of generated MSW at Astana International Airport is to be incinerated. Thus, the net GHG emissions and avoided net GHG emissions were 535 and 563 t CO_2 eq/year, respectively, see Figure 6 (c). The GHG effect of this scenario resulted in -28 t CO_2 eq/year. Thus, in contrast to scenarios 1 and 2, scenario 3 demonstates significant environmental benefits in terms of emissions.

An aggregate scenario 4 was proposed, which combines scenarios 2 and 3, see Figure 6 (d). In this scenario, it is assumed that 29% of MSW was recycled and the remaining 71% of MSW was disposed in an incineration plant. An estimated net GHG effect was found to be significantly lower in comparison to scenarios 1 and 2, where landfilling and a small portion of recyclables were considered. It is apparent that the existing situation taking place in Astana International Airport, as dealt with in scenario 1, produces the worst environmental performance due to the lack of waste management practices. Scenarios 3 and 4 were found to be the most environmentally sustainable since 100% or 71% of the produced MSW was considered to be treated in the incineration facilities, respectively. Table 5, provides the summary of GHG emissions values for each scenario.

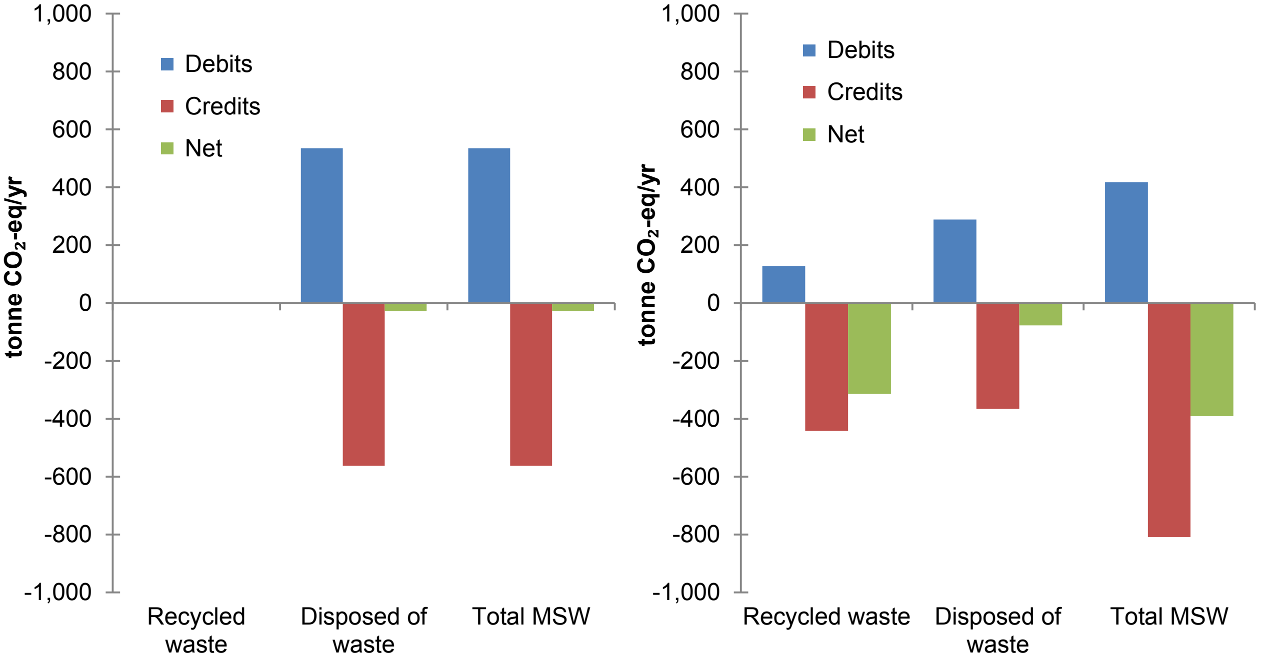
Table 5. The net GHG emissions (t CO_2 eq/year)

GHG emissions	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Recycled waste	-113	-314	0	-314
Disposed of waste	1201	794	-28	-77
Total MSW	1088	481	-28	-391



(a) GHG emissions for scenario 1

(b) GHG emissions for scenario 2



(c) GHG gas emissions for scenario 3

(d) GHG emissions for scenario 4

Figure 6 (a,b,c,d). GHG emissions for four scenarios

3.5 Cost analysis of the scenarios

The cost analysis of MSW dosposal from the Astana International Airport is based on the cost of each technology considered in the scenarios. The costs of the MSW disposal that includes separation and landfilling were provided from the sorting plant operator. According to the sorting plant operator, the cost of treatment at the sorting plant was approximately 5.4 €/t[1]. Other costs of technologies for MSW disposal such as incineration and composting were taken from available references (ECDG Environment, 2010; GEA, 2015; GIZ, 2017). It should be highlighted that the transportation cost of MSW from the airport to the disposal location was excluded from calculations in all scenarios.

3.5.1 Scenario 1 - Existing MSW scheme

As expected, scenario 1 has the lowest disposal cost due to the relatively low tariff (tipping fee) given by the MSW sorting plant which includes both cost of separation and landfilling. It should be noted here that norms (tarrifs) for accummulation of MSW is set by the local municipality and split into residential buildings (apartments) and private houses. The norms of MSW for latest residential group is found to be higher than the residents living the apartments. Thus, the centralized transportation of MSW within the city is served by private companies under the approved tariffs. Since, the tariff takes into account a social aspects of residents such as number of family member, income level, this tariffs are normally set at lower cost which could affect to the quality of the service. However, some private organizations such as airports do not operate beyond this tariffs and contract directly with MSW sorting plant with self delivery. Considering that the generation of MSW in Astana International Airport is roughtly transported each two days, the cost of this scenario is expected to be low. The only factor that can cause to the cost is a gradual increase of passenger traffic which consequently will increase the amount of MSW generated at the airport.

3.5.2 Scenario 2 - MSW recycling, composting and WtE

In scenario 2, it is assumed that around 24 t of generated MSW which consist of mainly organic waste will be composted at a price of 40 €/t. The cost of composting technology per tonne of organic waste can be found elsewhere (ECDG Environment, 2010; GEA, 2015). The remaining 727 t was assumed to be disposed at the MSW landfill. Additionally, further treatment was considered in this scenario by separating the MSW stream into recyclables. Thus, 278 t out of 727 t were separated as recyclables at the mechanical sorting plant of Astana landfill. The current tariff set by MSW sorting plant of Astana was used as the cost of MSW recycling and disposal at the landfill. As a result, the separation of MSW several streams into composting, recycling and landfilling, the cost of scenario 2 increased from 5546 € to 6377 €.

3.5.3 Scenario 3 Incineration of produced MSW

In scenario 3, all the generated MSW is assumed to be incinerated at a WtE plant. Typical cost of MSW incineration is around 65 €/t (GIZ, 2017; DEC, 2013) and the total cost will be roughly 70 000 €. It should be noted that this cost in scenario 3 could vary slightly due to the external costs associated with heat and power generation and environmental costs (Holmgren and Amiri, 2007). In addition, there are also external costs based on the monetary valuation of damages caused by the pollutants from waste to energy plants (Holmgren and Amiri, 2007).

3.5.4 Scenario 4 MSW recycling, composting and WtE

Similarly to in scenario 3, 24 t will be composted in this scenario, 278 t will be separated and collected as recyclables and 727 t will be incinerated at WtE plant. As a result, the cost of this scenario found to be lower than scenario 3.

3.5.5 Summary of cost analysis for scenarios

Figure 8 provides the plot of the costs versus GHG emissions of scenarios. Interestingly, the GHG emissions decreased linearly as the waste management options became more complex. However, the cost of MSW disposal among the scenarios was found to be non-linear. Generally speaking, gradual introduction of the waste management practices noted in scenarios could represent a better step in terms of cutting the cost of MSW and GHG emissions. The construction of composting and incineration plants are scheduled in the near future. Table 6 provides the mass balance and estimated costs of MSW disposal for each scenario.

Table 6 Mass balance of MSW and cost estimation of the scenarios

MSW disposal options	**Mass Balance of each scenario**			
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
Landfilling	929	727	0	0
Composting	0	24	0	24
Recycling	100	278	0	278
Incineration	0	0	1030	727
Total MSW (t)	**1029**	**1029**	**1029**	**1029**
	Cost of scenarios			
Landfilling	5007	3918	0	0
Composting	0	960	0	960
Recycling	539	1498	0	1498
Incineration	0	0	66950	47255
Total cost (€)	**5,546**	**6,377**	**66,950**	**49,713**

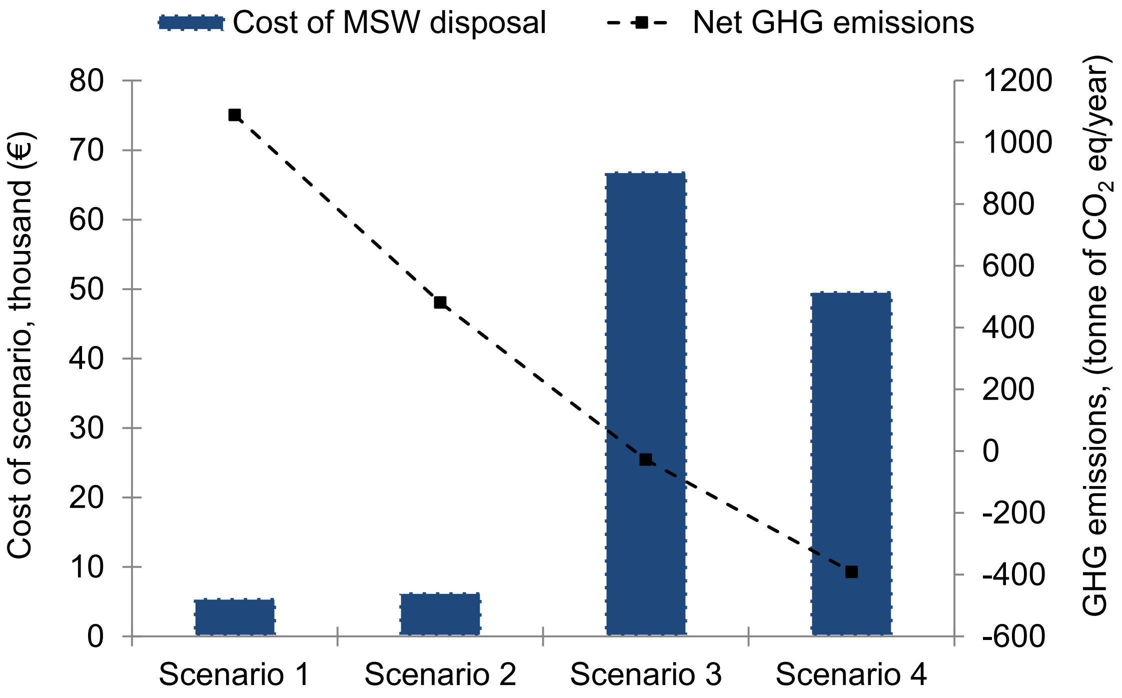


Figure 7. Illustration of GHG emissions vs. the cost

It should be highlighted that the annual quantity of MSW produced at the Astana International Airport (1030 t) does not justify the construction of any onsite waste treatment facilities at present. At the same time, sending the waste to external waste treatment plants such as incineration as in scenario 3 is found to be the most expensive option. However, such decisions must also be taken after consideration of environmental, technical and social parameters. It is clear that, without setting strict environmental policies and waste management strategy, landfilling will remain as the most economic option for MSW disposal.

4 Conclusions

Solid waste metabolism in airports exhibits several differences compared to this of a city as for instance the significant differences in the composition and thus in the ways waste should be managed. Case studies on solid waste management in airports are useful for the development of sustainable airports and the overall management of solid waste in the area where they are located. The simplified life cycle analysis presented in this paper is a useful tool for the estimation of environmental impact of airport solid waste and the methodology described can be used for other airports by adapting the scenarios to the local conditions.

Astana International Airport has become one of the main international gateways for communication within the region and the rest of the world. The MSW generation and relevant environmental implications are likely to increase due to the continuous gradual increase of the passenger traffic rate and continuous expansion of Astana International Airport. In this regard, the following key conclusions can be drawn from this work:

- The MSW composition of Astana International Airport has a high content of recyclable fraction (54%) of high calorific value materials.
- The observed value of recyclables was found within the range in comparison to other international airports;
- The composition of MSW such as organic fraction does not vary with the seasons and found around 5%;
- The current waste management practices at the Astana International Airport showed the highest GHG emissions in comparison to the proposed alternative scenarios
- As expected, the cost of the existing MSW disposal method is found to be the lowest in comparison to other scenarios.

The outcomes of this work is useful for the authority of Astana International Airport as well as city municipality for waste management planning. The introduction of waste management elements proposed in scenarios 3 and 4 would place Astana International Airport in the category of sustainable airports in the region. However, it should be highlighted that at this stage, that integration of MSW stream with city MSW stream is feasible due to the low quantity of waste generation. Taking into account the remarkable achievements of some of international airports in terms of sustainability rankings, the authors believe that Astana International Airport could follow these examples as a benchmark and set the sustainability strategy by gradually improving the MSW management schemes based on the above discussed scenarios. In the future, this work will be continued with a detailed analysis CO_2 emissions by aircraft emissions, cost sensitivity analysis of technologies and GHG emissions due to the transportation.

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References

Abeyratne, R., 2001. Ethical and moral considerations of airline management. J. Air Transp. Manag. 7, 339–348. https://doi.org/10.1016/S0969-6997(01)00019-9.

Abylkhani, B., Aiymbetov, B., Yagofarova, A., Tokmurzin, D., Venetis, C., Poulopoulos, S., Sarbassov, Y, Inglezakis, VJ., 2019. Seasonal characterization of municipal solid waste from Astana city, Kazakhstan; composition and thermal properties of combustible fraction. Waste Manag. Res. 37, 1271-1281. https://doi.org/10.1177/0734242X19875503 (accepted on 20 August 2019).

ACI Policy Handbook, 2018, 9th Edition. https://aci.aero/Media/2259c3f4-8016-442f-8c7a-138ebb1eb0c/JWWLuQ/About%20ACI/Policies%20and%20Practices/2018/ACI_Policy_Handbook_Jan_2018_FINAL.pdf (accessed 05 January 2019).

AIA, 2018a, Official webpage of Astana International Airport. http://astanaairport.kz/news/2018/28 (accessed 15 September 2018).

AIA, 2018b. Official webpage of Astana International Airport webpage. http://astanaairport.kz/pages/structural_subdivisions (Accessed 05 November 2018).

ASTM D 5231-92 (Reapproved 2003): Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste.

Baxter, G., Srisaeng, P., Wild, G., 2018. An Assessment of Airport Sustainability, Part1-Waste Management at Copenhagen Airport. Resources. 7, 21. https://doi.org/10.3390/resources7010021.

Baxter, G., Srisaeng, P., Wild, G., 2018. Sustainable Airport Waste Management: The case of Kansai International Airport, Recycling. 3, 1-22. https://doi:10.3390/recycling3010006.

Baxter, G., Wild, G., Sabatini, R., 2014. A sustainable approach design and operations: Case study of Munich Airport, Engineering Australia convention, 25-27 November, Melbourne;

Boons, F., Van Buuren, A., Teisman, G., 2010. Governance of sustainability at airports: Moving beyond the debate between growth and noise. Nat. Resour. Forum. 34(4), 303–313. https://doi.org/10.1111/j.1477-8947.2010.01314.x.

Brussels Airport, Environmental Report 2017. https://www.brusselsairport.be/uploads/media/default/0001/16/a92280c1acc7cff0e19a019e2efc49f61b61614e.pdf (accessed 21 November 2018).

CAC, Civil aviation committee report, 2017. http://aviation.mid.gov.kz/en/node/9657 (accessed 15 September 2018).

Carvalho, I.D.C., Calijuri, M.L., Assemany, P.P., Freitas, M.S., Moreira, N.R.F., Santiago, A.F., Batalha de Souza, M.H., 2013. Sustainable airport environments: a review of water conservation practices in airports, Resour. Conserv. Recycl. 74. 27–36. http://dx.doi.org/10.1016/j.resconrec.2013.02.016.

Castillo-Manzano J.I., López-Valpuesta, L., Sánchez-Braza, A., 2018. When the mall is in the airport: Measuring the effect of the airport mall on passengers’ consumer behaviour, J. Air Transport. Manag. 72, 32-38. https://doi.org/10.1016/j.jairtraman.2018.07.003.

Castillo-Manzano, J.I., López-Valpuesta, L., 2013. Analysing passenger behaviour towards the catering industry: implications for airport management. Int. J. Hosp. Manag. 35, 258–260. https://doi.org/10.1016/j.ijhm.2013.06.010.

Copenhagen Airports, Looking Back Moving Forward, Group annual report, 2017. https://cph-prod-cdn.azureedge.net/495d3d/globalassets/8.-om-cph/6.-investor/arsrapporter/en/group-annual-report-2017.pdf (accessed 21 November 2018).

DEC, 2013. Department of Environment and Conservation. Waste technologies: waste to energy facilities, A report for the Strategic Waste Infrastructure Planning (SWIP) Working Group, commissioned by the Government of Western Australia. May 2013. Project number: 0038022. Available at: http://www.wasteauthority.wa.gov.au/media/files/documents/SWIP_Waste_to_Energy_Review.pdf (accessed 25 December 2018).

ECDG, 2010. European Commission DG Environment, Final Report. Assessment of the options to improve the management of bio-waste in the European Union, Annex E, 2010, Eunomia Research & Consulting. Arcadis Project number:-11/004759. Available at: http://ec.europa.eu/environment/waste/compost/pdf/ia_biowaste%20-%20final%20report.pdf (accessed 01 November 2019).

GA, Gatwick Airport, 2017. Performance report, 10 Decade of change. https://www.gatwickairport.com/globalassets/business--community/new-community--

sustainability/sustainability/decade-of-change-2017-report-low-res.pdf (accessed 25 December 2018).

GEA, 2015. German Environmental Agency. Best Practice Municipal Waste Management, Information pool on approaches towards a sustainable design of municipal waste management and supporting technologies and equipment. https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2018-05-30_texte_40-2018-municipal-waste-management_en.pdf (accessed 20 November 2018).

Geneva Airport, Sustainability report 2016-2018. Available at: http://www.gva.ch/en/Portaldata/1/Resources/fichiers/institutionnels/environnement/Rapport-developpement_durable_ENG.pdf (accessed 05 October 2018).

GIZ, 2017. Deutsche Gesellschaft für Internationale Zusammenarbeit. Waste to Energy Options in Municipal Solid Waste Management, A guide for decision makers in developing and emerging countries. Available at: https://www.giz.de/en/downloads/GIZ_WasteToEnergy_Guidelines_2017.pdf (accessed 01 December 2018).

HKIA, 2015/2016. Hong Kong International Airport, Building our shared future, Sustainability report 2015/2016. http://www.hongkongairport.com/iwov-resources/html/sustainability_report/eng/SR1516/pdf/AAHK_full.pdf (accessed 01 December 2018).

HKIA, 2016/2017. Hong Kong International Airport, Sustainability report 2016/17-Highlights. http://www.hongkongairport.com/iwov-resources/html/sustainability_report/eng/SR1617/assets/doc/HKIA_SR201617_En.pdf (accessed 02 September 2018).

HKIA, Hong Kong International Airport, https://www.hongkongairport.com/en/sustainability/environment/waste.page (accessed 02 September 2018).

Holmgren, K., Amiri, S., 2007. Internalising external costs of electricity and heat production in a municipal energy system, Energy Policy 35, 5242-5253. https://doi.org/10.1016/j.enpol.2007.04.026.

IFC WBG, 2012. International Finance Corporation, WorldBank Group, Municipal Solid Waste Management : Opportunities for Russia-Summary of key findings. Available at: https://www.ifc.org/wps/wcm/connect/06d5e7fc-5268-4142-a9bd-31e4a050cdc9/PublicationRussiaRREP-SolidWasteMngmt-2012-en.pdf?MOD=AJPERES&CVID=jwzKQBD (accessed 05 October 2018).

IFEU 2016, Tool for Calculating Greenhouse Gases (GHG) in Solid Waste Management (SWM). https://www.ifeu.de/en/project/tool-for-calculating-greenhouse-gases-ghg-in-solid-waste-management-swm/ (accessed 07 November 2018).

Inglezakis, V.J., Moustakas, K., Khamitova, G., Tokmurzin, D., Sarbassov, Y., Rakhmatulina, R., Serik, B., Abikak, Y., Poulopoulos, S.G., 2018. Current Municipal Solid Waste Management in the cities of Astana and Almaty of Kazakhstan and Evaluation of Alternative Management Scenarios, Clean Technol. Environ Policy. 20(3), 503–516. https://doi.org/10.1007/s10098-018-1502-x.

Inglezakis, VJ., Amzebek, A., Kuspangaliyeva, B., Sarbassov, Y., Balbayeva, G., Yerkinova, A., Poulopoulos, SG., 2018. Treatment of municipal solid waste landfill leachate by use of combined biological, physical and photochemical processes. Desalin and Water Treat. 112, 218-231. https://doi.org/10.5004/dwt.2018.22252.

International Civil Aviation Organization (ICAO), 2002, Civil Aviation Statistics of the World. Doc 9180. Montreal.

International Civil Aviation Organization (ICAO), 2016. On board a sustainable future: 2016 environmental report. Available at: http://www.icao.int/environmental-protection/Documents/ICAO%20Environmental%20Report%202016.pdf (accessed 25 November 2019).

International Civil Aviation Organization (ICAO), Waste Management at Airports, Eco Airport Toolkit. Available at: https://www.icao.int/environmental-protection/Documents/Waste_Management_at_Airports_booklet.pdf (accessed 16 August 2018).

IPCC, 2006a, IPCC, Guidelines for National Greenhouse Gas Inventories, Overview. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/0_Overview/V0_1_Overview.pdf. (accessed 27 October 2018).

IPCC, 2006b, IPCC, Guidelines for National Greenhouse Gas Inventories, Volume 2, Chapter 2: Stationary Combustion. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf. (accessed 27 October 2018).

IPCC, 2006c, IPCC, Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 4: Biological Treatment of Solid Waste**.** https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_4_Ch4_Bio_Treat.pdf (accessed 28 October 2018).

Johnke, B., 2002. Emissions from waste incineration, Background paper. IPCC expert meetings on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/5_3_Waste_Incineration.pdf (accessed 30 October 2018).

Jones, P., 1996. Waste management and airports. In: Pedoe, N., Raper, D., Holden, J. (Eds.), Environmental Management at Airports—Liabilities, Social Responsibilities Conference, Manchester Airport, 1995. Thomas Telford, London.

KIA, 2016. Kansai International Airport, Smart Island Report, 2016. Available at: http://www.kansai-airports.co.jp/en/efforts/environment/kix/smart-island/file/smart_rprt16.pdf (accessed 27 October 2018).

KIA, Kansai International Airport, http://www.kansai-airports.co.jp/en/company-profile/about-airports/kix.html (accessed 01 November 2018).

Kilkiș, Ș., Kilkiș, Ș., 2016. Benchmarking airports based on a sustainability ranking index. J.Clean. Prod. 130, 248-259. https://doi.org/10.1016/j.jclepro.2015.09.031.

Kilkiș, Ș., Kilkiș, Ș., 2017. Benchmarking aircraft metobolism based on a Sustainable Airline Index. J. Clean. Prod. 167,1068-1083. https://doi.org/10.1016/j.jclepro.2017.03.183.

Koç, S., Durmaz, V., 2015. Airport Corporate Sustainability: An analysis of indicators reported in the sustainability practices. Procedia-Social and Behavioral Sciences 181, 158-170. https://doi.org/10.1016/j.sbspro.2015.04.877.

Lam C.M., Yu, I.K.M., Medel, F., Tsang, D.C.W., Hsu, S.C., 2018. Life-cycle cost-benefit analysis on sustainable food waste management: The case of Hong Kong International Airport, J. Clean. Prod. 187, 751-762. https://doi.org/10.1016/j.jclepro.2018.03.160.

Li, X.D, Poon, C.S., Lee, S.C., Chung, S.S., Luk, F., 2003. Waste reduction and recycling strategies for the in-flight services in the airline industry. Resour. Conserv. Recycl. 37, 87-99. https://doi.org/10.1016/S0921-3449(02)00074-5.

Marketing Department of Astana International Airport, 2018.

Mayer, R., Ryley, T., Gillingwater, D., 2015. Eco-positioning of airlines: Perception versus actual performance. J. Air Transp. Manag. 44-45, 82-89. https://doi.org/10.1016/j.jairtraman.2015.03.003.

MBT data, 2017 (Mechanical Biological Treatment) plant data from 2017. Data on MSW weights was obtained by personal communication.

Miedico, M., 2018. Sustainable growth management at Naples International Airport, Italy. WIT Transactions on Ecology and the Environment. 215, 233-240. www.witpress.com, ISSN 1743-3541. doi:10.2495/EID180211.

Milutinović, B., Stefanović, G., Đekić, PS., Mijailović, I., Tomić, M., 2017. Environmental assessment of waste management scenarios with energy recovery using life cycle assessment and multi-criteria analysis. Energy 137, 917-926. https://doi.org/10.1016/j.energy.2017.02.167.

Monsalud, A., Ho, D., Rakas, J., 2016. Greenhouse gas emissions mitigation strategies within the airport sustainability evaluation process, Sustain Cities Soc. 14, 414–424. http://dx.doi.org/10.1016/j.scs.2014.08.003.

Munich Airport Publications, More winners: Integrated report, 2015. Available at: https://www.munich-airport.com/publications-2044662 (accessed 05 October 2018).

Munich Airport Publications, Perspectives: Integrated Report, 2013. Available at: https://www.munich-airport.com/_b/0000000000000001983430bb593a8d53/ib2013-en.pdf (accessed 14 October 2018).

Munich Airport Publications, Thinking ahead: Integrated report, 2016. https://www.munich-airport.com/publications-2044662 (accessed 05 October 2018).

NSC, National Statistical Committee, 2018. http://stat.gov.kz/ (accessed 15 November 2018).

Official news on passenger traffic at Astana International Airport in 2017 (in Russian). https://express-k.kz/news/sotsium_lenta/aeroport_astany_v_2017g_uvelichil_passazhiropotok_na_25-115181 (accessed 27 November 2018).

Pitt, M., Smith, A., 2003. An assessment of waste management efficiency at BAA airports, Constr. Manag and Econ. 21, 421-431. https://doi.org/10.1080/0144619032000089599.

Pitt, M., Smith, A., 2003. Waste management efficiency at UK airports. J. Air Transp. Manag. 9, 103–111. https://doi.org/10.1016/S0969-6997(02)00063-7.

Prognoz Study, 2008. Resource savings and CO_2 reduction potentials in waste management in Europe and the possible contribution to the CO_2 reduction target in 2020. October 2008. Available at: https://www.prognos.com/uploads/tx_atwpubdb/2008_Prognos_summary_CO2_reduction_potentials_01.pdf (accessed 05 November 2018).

Renou, S., Givaudan, J.G., Poulain, S., Dirassouyan, F., Moulin, P., 2008. Landfill leachate treatment: Review and opportunity, J. Hazard. Mater. 150, 468–493. https://doi.org/10.1016/j.jhazmat.2007.09.077.

SAGA, 2013. Sustainable aviation guidance alliance. Available at: http://www.airportsustainability.org/. (accessed 15 September 2019)

Stefanovic, G., Milutinovic, B., Vucicevic, B., Dencic-Mihajlov, K., Turanjanin, V., 2016. A comparison of the Analytic Hierarchy Process and the Analysis and Synthesis of Parameters under Information Deficiency method for assessing the sustainability of waste management scenarios, J. Clean. Prod. 130, 155-165. http://dx.doi.org/10.1016/j.jclepro.2015.12.050.

Tofalli, N., Loizia, P., Zorpas, A.A., 2017. Passengers waste production during flights, Environ Sci. Pollut Res. 25, 35764-35775. https://doi.org/10.1007/s11356-017-0800-x.

Upham, P., Thomas, C., Gillingwater, D., Raper, D., 2003. Environmental capacity and airport operations: current issues and future prospocts. J. Air Transp. Manag. 9. 145-151. https://doi.org/10.1016/S0969-6997(02)00078-9.

Urcha, S., 2018. Municipal solid waste prospects in Astana city, Presented at: *“Green Energy and Municipal Solid Waste Workshop”,* 12th September 2018, Nazarbayev University, Astana (*In Russian*); https://nur.nu.edu.kz/handle/123456789/3529 (accessed 01 December 2018).

US Federal Aviation Administration, 2013. Recycling, Reuse and Waste Reduction at Airports: A Synthesis Document. https://www.faa.gov/airports/resources/publications/reports/environmental/media/RecyclingSynthesis2013.pdf (accessed 20 August 2018).

You, S., Wang, W., Dai, Y., Tong, Y.W., Wang, C-H., 2016. Comparison of the co-gasification of sewage sludge and food wastes and cost-benefit analysis of gasification- and incineration-based waste treatment schemes, Bioresour. Technol. 218, 595-605. https://doi.org/10.1016/j.biortech.2016.07.017.