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ORIGINAL PAPER

# Current municipal solid waste management in the cities of Astana and Almaty of Kazakhstan and evaluation of alternative management scenarios

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## Abstract

The present paper provides a detailed analysis of the current situation on municipal solid waste (MSW) management in Kazakhstan with focus on the two major cities, Astana and Almaty, the current and former capital of the country. Untill recently, ninety-seven percent of the MSW was disposed in open dumps and substandard authorized landfills. Ninety-three percent of the 4530 municipal waste disposal landfills were not permitted, while from the 307 authorized waste disposal facilities, only the one in the city of Astana was designed in accordance with international standards (2015). Core legislation, current management policy, existing and planned facilities and infrastructure, as well as solid waste quantity and composition are discussed. The analysis is complemented by the implementation of a decision support software tool, which provides insights in waste management needs and evaluates the alternative waste management plans. Six alternative scenarios were evaluated, and the results obtained demonstrate that the optimum scenario is separation at source for both biowaste, which is composted and packaging waste processed via the materials recovery facility. Regarding the residual waste, the optimum scenario for Astana is mechanical biological treatment (MBT)-composting-recyclables and waste-to-energy for the refuse-derived fuel (RDF). For Almaty, 80% of the waste should be processed through MBT-composting-recyclables, and 20% via incineration and RDF. The results obtained can contribute to solid waste management planning in Kazakhstan and other Central Asian countries.


**Keywords** Municipal solid waste · Decision support software tool · Almaty · Astana · Kazakhstan

## Introduction

Population increase combined with consumption-based modern life style is constantly increasing the pressure on Earth through elevated consumption of natural resources and increased release of all forms of waste (Kim 2002). Municipal solid waste (MSW) is an inevitable by-product of human daily life and its proper management and treatment is the starting point toward an environmentally healthy urban life. According to the Intergovernmental Panel on Climate Change, MSW refers to waste streams that are generated in urban areas which are collected and treated by, or for, municipalities or other local authorities (IPCC 2006). Despite the efforts made for the last 20 years, MSW generation and management remains an urgent global problem, especially if the concentration of population and activities in large urban centers are considered. Although the generation of MSW in developing countries has been consistently rising over the years and the composition of waste has similar characteristics, the exact quantity varies among different countries depending on the average standard of living and various climate and cultural, industrial, infrastructural and legal factors (Khajuria et al. 2010). MSW disposal in most

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developing countries around the world poses major environmental and public health problems (de Sousa Jabbour et al. 2014). Insufficient MSW management contributes to the anthropogenic emission of methane, a powerful greenhouse gas, released due to the anaerobic decomposition of the organic fraction in landfills (Aleluia and Ferrão 2016). Landfilling is still the dominant disposal route around the globe (Khan et al. 2016).

The available peer-reviewed literature on solid waste management for the Central Asia region in the English language is rare; the papers of Vermenicheva et al. (1999) on Kazakhstan, Sim et al. (2013) on Kirgizstan, and some data in the review paper of Karak et al. (2012) are exceptions. According to the existing literature, a well-organized collection and reprocessing industry for secondary raw materials was developed in the former Soviet Union, but disappeared after the collapse of the union in the early ‘90 s. Since then, little priority has been given to environmental protection (Sim et al. 2013). Kazakhstan is a country with huge oil, gas and minerals resources which drive its rapid economic development. Astana is a new city with the target to become the main urban center in the country. The population increased from 281,000 to 600,00 within year 1999–2007 and to the current population of 872,619, which makes it the second-largest city in Kazakhstan after Almaty (NSC 2016). Many environmental stresses and risks are expected to take place, especially if the public environmental awareness is not increased and the public authorities are not sensitive to the degradation of environmental quality. It is also noteworthy that there are not any extensive programs in Kazakh cities for integrated waste management or even for recycling MSW. There is not any relevant available information in the literature to be used, and collecting such data is a challenging task.

Focusing on waste management in Kazakhstan, it is in its infancy and the majority of MSW is disposed of in open dumps, while only a small portion is led to engineered landfills (Orazbayev et al. 2013). Outside big cities, typically only about one-quarter of the population has access to MSW collection services, and 97% of MSW is taken to uncontrolled dumps and substandard authorized landfills without any processing or recycling. More than 93% of the 4530 municipal waste disposal landfills in the country are not permitted, while from the 307 authorized waste disposal facilities, only the one in the city of Astana is designed following international standards (Concept 2013). There has been little incentive for local authorities and business in the waste disposal sector to increase added value recovery through recycling, composting, or recovering energy from urban waste, with recycled volumes, reported to be less than 5% of total MSW volume (Concept 2013). The country has currently no waste-to-energy (WtE) plants, such as centralized incineration or biological plants, and the production of green energy from MSW is not established. An exception is the city of Aktau where a pilot unit equipped with a mechanical–biological treatment plant (MBT) and WtE facility has been planned, but not realized until now (MEWR 2014). It is evident that Kazakhstan needs to develop a new integrated waste management system taking into account recent reforms in the institutional and legal framework.

One common method for the evaluation of solid waste management plans is the development of scenarios aiming to describe alternative options in order to provide support in both decision making and selection of the best alternatives (Deus et al. 2017). Scenarios must take into account the basic dimensions of sustainability to select and evaluate technology alternatives, and decision making should consider environmental, technical, and economic aspects (Garrido-Baserba et al. 2016). Every waste management scenario has to be also developed according to the needs of the respective region where it will be applied (Mancini et al. 2017). However, there are some common elements that do not depend on the region. Such elements include the characteristics of the waste treatment technologies that will be integrated into the management system (Chen et al. 2011). Competent authorities and stakeholders should be able to identify how these technologies can be applied in technically and financially feasible terms, satisfying the legislative restrictions and prerequisites (Ghinea et al. 2012). They should examine them as standalone units in order to comprehend their environmental impacts, advantages and disadvantages. In that context, a decision support software (DSS) tool is applied in the two biggest cities of Kazakhstan, namely Astana and Almaty, for examining and comparing the application of different solid waste treatment options.

Given the complexity of waste management, multi-criteria decision-making models have become important, as they can deal with problems involving multiple dimensions and conflicting criteria (Khan et al. 2016). The tools based on multi-criteria analysis are considered by many experts as superior to other alternatives like life-cycle assessment, which mostly focuses on environmental aspects, and cost–benefit analysis, which is based on the maximization of economic efficiency (Coelho et al. 2017). Life-cycle and economic assessments are carried out separately, most often employing different system boundaries and assumptions (Martinez-Sanchez et al. 2015). Multi-criteria analysis considers all three pillars of sustainability, i.e., economic, social, and environmental criteria (Coelho et al. 2017). A DSS tool is a computer-based software that helps the user in organizational decision-making activities. Its history dates back to 1965, when the necessity for building large-scale information systems appeared (Vinodh et al. 2014). Coelho et al. (2017) presented an in-depth review of the multi-criteria decision-making applications used in MSW management.

The main purpose of the present paper is to provide information and examine the current MSW management in Astana and Almaty, the two most important cities in Kazakhstan. Reliable data on MSW generation and composition are included and discussed along with core legislation, current management policy, and existing and planned facilities and infrastructure. The analysis is supported by a multi-criteria analysis of future alternative management scenarios conducted by means of a DSS tool, which provides viable waste management plans and insights in waste management needs. The information provided and the DSS tool analysis constitute an original contribution in the case of Kazakhstan, and the major findings obtained can be useful in developing sustainable waste management plans in the country. The research therefore represents an original contribution to the literature on solid waste management in Central Asia.

## Assessment of the current situation of municipal waste management in Kazakhstan

### Municipal waste quantity, composition and treatment facilities

The total volume of MSW in Kazakhstan is about 100 Mt, and the annual waste generation is 5–6 Mt, a figure that is expected to rise to 8 Mt by 2025. Table 1 presents the solid waste amounts directed to landfills and the relevant waste generation norms for 16 major cities of Kazakhstan.

Astana is the capital city of the Republic of Kazakhstan with a population of 872,619 (NSC 2016). Waste management problems in Astana can be well understood in the light of rapid urbanization. As the economic situation improves, with Astana constituting approximately 8.5% of the total GDP (equal to US$ 151.67 billion in 2011), the concern for waste management rises since a stronger economy often leads to an increased waste production due to a higher purchasing capacity. According to the latest data (2013), about 1118 t of MSW are generated every day in Astana, and the collection capacity is approximately 600–800 t (MRD 2012). Waste generation rates are 507 kg/ca/y or 1.39 kg/ca/d, while waste collection rates are 365 kg/ca/y or 1 kg/ca/d (72% collection efficiency). In 2012, the experimental studies performed on waste generation in Astana led to the establishment of new norms on waste generation, namely 2.16 $m^3$/ca/y for people living in apartment houses and 2.33 $m^3$/ca/y for people living in private houses (MRD 2012). The density of the waste was found to be 157 kg/$m^3$. Based on that data, the waste generation is lower, at 353 kg/ca/y or 0.968 kg/ca/d. As analyzed in more detail elsewhere (Inglezakis et al. 2014), there are differences between the statistical data (based on waste collected) and actual data (normative, based on waste generated, experimentally measured) due to several factors, such as lack of weighing equipment in landfills, low collection rates by organized systems, disposal at illegal dumps, and the booming of construction activity in the city that produces large amounts of construction and demolition waste while commuting workers are not officially registered as citizens of Astana. The norms refer to household waste, and it is well known that the differences between MSW and household waste could be considerable; 1.04 and 0.88 kg/ca/d in Korea (Zhang et al. 2010). For Astana, the value of 1.39 kg/ca/d is used in the DSS tool.

**Table 1** Waste generation and disposal in selected Kazakh cities (MEWR 2014)

| City | Population at the end of 2012 | Solid waste amount disposed in landfills in 2012 (t) | Waste generation norms ($m^3$/ca/y) |
|---|---|---|---|
| Astana | 778,198 | 326,400 | 2.16 |
| Almaty | 1,475,429 | 549,120 | 2.55 |
| Aktau | 180,885 | 109,700 | 2.0 |
| Aktobe | 420,567 | 360,600 | 0.47 |
| Atyrau | 272,071 | 44,070 | 0.56 |
| Karaganda | 478,952 | 132,850 | 1.87 |
| Kostanay | 219,224 | 152,730 | 1.17 |
| Uralsk | 271,361 | 108,500 | 2.3 |
| Shymkent | 662,100 | 64,550 | 1.7 |
| Pavlodar | 342,435 | 94,470 | 1.30 |
| Kokshetau | 152,006 | 57,700 | 1.16 |
| Ust-Kamenogorsk | 309,500 | 45,600 | 1.98 |
| Taldykorgan | 156,162 | 17,000 | 2.77 |
| Taraz | 343,275 | 34,960 | 0.54 |
| Kyzylorda | 253,960 | 36,100 | 1.7 |
| Petropavlovsk | 206,043 | 62,000 | 2.07 |

Almaty was the capital of Kazakhstan until 1998 and continues today as the major commercial and cultural center of Kazakhstan, as well as its biggest population center. The current population is 1,703,482, and according to data provided by competent authorities and stakeholders, the MSW collected in Almaty in 2014 was 612,300–672,693 t (ASD 2013), which gives an average of 1760 t/d or 1.03 kg/ca/d (MHI 2014). The official norm for Almaty is higher than Astana, estimated at 2.55 $m^3$/ca/y for people living in apartment houses and 2.9 $m^3$/ca/y for people living in private houses resulting in 1.17 kg/ca/d. This value is used in the DSS tool and as expected, it is higher than the one calculated by use of the amount of collected waste.

The waste generation rates presented above for Astana and Almaty are in general agreement with those reported for other cities in developing countries, for example, 1.62 kg/ca/d in Kuala Lumpur (2009) (Saeed et al. 2009), 1.12 kg/ca/d in Bangkok (2016) (Sukholthaman and Sharp 2016), 1.01 kg/ca/d in Kuwait city (2009–2013) (Al-Jarallah and Aleisa 2014), 1.26 kg/ca/d in Bahrain (2005) and 1.3 kg/ca/d in Qatar (2005) (Alhumoud 2005), 1.11 kg/ca/d in Shanghai, 1.08 kg/ca/d in Chongqing, 1.17 kg/ca/d in Hangzhou, and 1.33 kg/ca/d in Hong Kong (2006–2009) (Zhang et al. 2010).

According to the latest projections, the generation of MSW in the period of 2011–2025 in urban areas is likely to grow by more than 50% along with growth in prosperity (Concept 2013). The annual waste growth rate is expected to be 3.33%, higher than in other developing countries in Asia, e.g., 2% for Malaysia (Moh and Manaf 2014). Due to the absence of reliable data, the annual waste generation growth in this study is set equal to the annual population growth, under the assumption of constant waste generation rate per capita for the following years. According to NSC (2016) population data for the decade 2005–2015, the average annual population growth in Astana and Almaty is 4.72 and 3.14%. These rates are high, indicating an urbanization trend. Taking into account that Astana is the new capital, this rate is expected to be higher over the following years. For projection purposes the values of 5 and 3.14% for the annual waste growth will be used for Astana and Almaty. The forecast of the Ministry of Environment and Water Resources (2014) on waste generation was based on three different rates, 1, 3 and 5%.

MSW composition varies depending on weather conditions and season. In Fall, the amount of food waste increases markedly, which is associated with an increased consumption of fruits and vegetables from population, while in Summer and Spring the amount of small dropouts (street debris) grows. The composition of MSW has also changed significantly over time. The proportion of plastic materials and paper has increased recently, whereas coal and slag have almost disappeared after the transition to centralized heating (MRD 2012). The composition of MSW in Astana and Almaty is presented in Table 2 and is derived from several sources. An average of these values will be used in the DSS tool.

In order to calculate the prognosis of packing waste generated, the proportion and composition of packaging waste in municipal waste is required. According to available data for European countries, an average of about 35% of MSW is packaging waste with great variations from one country to another, while 60% of the quantity of packaging waste is from population and 40% from industry, commerce and institutions. Data on packaging waste are presented in Table 3 for Romania (Ambăruş et al. 2012), Wales (Burnley et al. 2007), Turkey (Han et al. 2010), Portugal (Magrinho and Semiao 2008), and Greece (MEE 2015).

As expected, the composition of packaging waste differs by region; in the absence of local data, the average of MSW is used in the DSS tool. Based on the preceding analysis, the data used in the DSS tool are presented in Table 4.

For Astana, the collected waste is processed in the MBT plant or directed to the landfill. The waste-processing complex named LLP « Altyn-TET » started its operation in the end of 2012 (MRD 2012). The projected capacity of the complex is 250,000–300,000 t/y, i.e., 685–822 t/d. The complex was foreseen to recover 20% of the incoming waste, so the remaining 80% of waste is briquetted (compacted)

**Table 2** MSW composition in Kazakhstan (Vermenicheva et al. 1999; MRD 2012; MEWR 2014)

| MSW composition (% wt) | Kazakhstan (1999) | Kazakhstan (2014)[a] | Astana (2012–2014) | Almaty (2014) |
|---|---|---|---|---|
| Food wastes | 24.0–40.0 | 37.0 | 27.2–28.0 | 26.8–30.7 |
| Landscaping wastes | – | 3.0 | 1.5–4.1 | 3.0–6.9 |
| Paper and cardboard | 22.9–40.0 | 25.0 | 9.4–13.0 | 15.5–28.5 |
| Plastic | 1.0–2.0 | 15.0 | 12.4–18.5 | 6.9–15.3 |
| Glass | 2.7–4.0 | 6.0 | 14.5–15.2 | 3.7–9.8 |
| Metals | 1.5–5.0 | 3.0 | 0.9–1 | 2.8–3.3 |
| Textile | 4.0–7.3 | 6.0 | 3.3–9.5 | 2.7–3.5 |
| Others | 25.6–25.9 | 5.0 | 14.1–27.5 | 17.3–23.3 |

[a] Average of the 9 regions

**Table 3** Percentage of material type of packaging waste in mixed municipal or household (*) waste

| | Greece | Romania* (2006) | Turkey Istanbul (2007) | Wales (2007) | Wales* (2007) | Portugal Lisboa (2008) | Average |
|---|---|---|---|---|---|---|---|
| Paper/cardboard | 6.3 | 3.2 | 13.0 | 5.1 | 6.1 | 7.1 | 6.8 |
| Glass | 1.9 | 3.0 | 4.7 | 5.3 | 6.7 | 5.5 | 4.5 |
| Metal | 2.0 | 1.3 | 1.4 | 2.0 | 3.0 | 1.3 | 2.2 |
| Plastic | 3.4 | 7.1 | 12.5 | 4.5 | 4.4 | 8.8 | 6.8 |
| Wood | 0.8 | – | – | – | – | 0.4 | 0.6 |
| Total (% in mixed waste) | 14.4 | 14.6 | 31.6 | 16.9 | 20.2 | 23.1 | 20.9 |

**Table 4** Input data regarding waste composition (%)

| Type | Astana | Almaty |
|---|---|---|
| Organics | 27.6 | 28.8 |
| Garden | 2.8 | 5 |
| Paper/cardboard (packaging) | 6.8 | 6.8 |
| Paper/cardboard (other) | 4.4 | 15.2 |
| Wood (packaging) | 0.6 | 0.6 |
| Wood (other) | 0.0 | 0.0 |
| Glass (packaging) | 4.5 | 4.5 |
| Glass (other) | 10.4 | 2.3 |
| Metal (packaging) | 0.0 | 2.2 |
| Metal (other) | 1.0 | 0.9 |
| Plastic (packaging) | 6.8 | 6.8 |
| Plastic (other) | 8.7 | 4.3 |
| Other | 26.4 | 22.6 |

and disposed in the landfill. The facility accepts mixed solid waste and proceeds to separating out the recyclable materials. The recyclables are separated, and the remainder is compacted and disposed in the landfill. The compaction of the remaining waste allows the decreasing of the area required for the landfill. In March 2013, the waste acceptance capacity of the plant was about 300–380 t/d. Only about 6% of the incoming waste is recycled (paper, plastic, glass and metal), while the rest is briquetted and disposed. The recycling rate is much lower than the potential of the waste (46.9%) due to low market demand. The recovered materials are about 0.3% by volume metal, 2% plastic, 3.1% paper and cardboard, and 0.6% other material. According to planning, the waste acceptance capacity of the plant will be increased to 600–800 t/d. The treatment of separated recyclable materials will also take place in the same facility. The feasibility of implementation of the biogas plant (anaerobic digestion) for organic waste treatment in the current operating facility is under consideration. Such an implementation will allow the increase of the percentage of waste recovery to 50% and generate power at the same time. It is also important to mention that the plan is to implement the separation-at-source system in the country in the near future. Concerning the final disposal, the operating section of solid waste landfill is 12 ha and has a capacity of 2.8 Mt of MSW. However, the landfill is already almost completely filled and an expansion was planned for the second half of 2016. The new landfill is built using modern technologies, including a system for the collection and utilization of generated methane, rainwater collection, wastewater treatment and drainage systems. The area of the new landfill is 50.4 ha, and it will consist of 4 cells. The projected capacity of the first cell is 2 Mt of MSW with a projected life of 6 years.

In Almaty, the waste is collected by 73 private companies, with the company "Tartyp" covering 70% of population. The first MSW processing plant in Kazakhstan was opened in December 2007 in Almaty with the support of local municipality. Vtorma-Ecology Plant covered 90% of the city's utilization of MSW. Due to economic crisis in Kazakhstan in 2008, the price of recyclables had fallen by 1.5–3 times, and the plant was not able to cover its costs and pay the loans, and as a consequence it was closed in October 2010. Today, there are no waste recycling facilities in the city and all waste is disposed in landfills. There were six landfills near Almaty in 2009, but now there is only one active landfill with an area of 44 ha, where most of the waste is disposed. As a result, in Almaty, 3 Mt of MSW have been disposed in total in the landfill. Valuables are salvaged, recycled, and then sold to Russia, China, etc., at an estimated rate of 1.5 t/d (MHI 2014).

The data in Table 5 are used in the DSS tool.

## Overview of the waste management legislative framework and strategy in Kazakhstan

Waste management in Kazakhstan is regulated by the Environmental Code of the Republic of Kazakhstan and relevant amendments as of 2009, and a number of other orders and resolutions relevant to Sanitary Rules like the Order of the Ministry of Health of the Republic of Kazakhstan No 555 (2010) on the approval of Sanitary Rules, and the Resolution No 291 of the Government of the Republic of Kazakhstan (2012) on the approval of the Sanitary Rules. The Program of Modernization of Municipal Solid Waste

**Table 5** DSS input data

| Parameter | Astana | Almaty |
|---|---|---|
| Waste generation per capita (kg/ca/d) | 1.39 | 1.17 |
| Annual waste generation growth (%) | 5.00% | 3.14% |
| Equivalent population[1] | 872,619 | 1,703,482 |
| Population reference year | 2016 | 2016 |
| Planning period (y) | 20 | 20 |
| Plastics price[2] (€/t) | 300 | 300 |
| Ferrous metals price[2] (€/t) | 40 | 40 |
| Aluminum[2] (€/t) | 833 | 833 |
| Glass[2] (€/t) | 23 | 23 |
| Paper[2] (€/t) | 21 | 21 |
| Electricity[3] (€/MWh) | 85 (biogas)<br>0 (incineration) | 85 (biogas)<br>0 (incineration) |
| MBT capacity (t/y) | 124,100 | 0 |

[1]NSC data (2016)

[2]Average market data fluctuate and the values reported in the table are averages subject to large deviation

[3]Three different green feed-in tariffs are set in Kazakhstan: solar, wind and biogas. The price in the table is for biogas (2014) while there is no incineration WtE feed-in tariff

Management for the years 2014–2050 was issued by the Ministry of Environment and Water Resources (2014). The program is based on the act No 577 (2013) entitled "Concept of transition of Kazakhstan to a Green Economy," and the act No 750 (2013), which is the action plan of the Government of Republic of Kazakhstan to implement this concept. The Program of Modernization of Municipal Solid Waste Management for the years 2014–2050 is considered as one of the priority areas for implementation of the Green Economy Program. This program aims to increase efficiency, reliability, environmental and social acceptability of MSW collection, transportation, processing and disposal services. According to the program, several measures must be taken (MEWR 2014):

- Set the target for MSW recycling up to 40% by 2030 and 50% by 2050; and storage of residual MSW volumes at environmentally friendly and sanitary landfills with their share to increase to 100% by 2050, so that all landfills in the country comply with the most up-to-date environmental and sanitary requirements;
- Introduce a household waste separation program for consumers;
- Define a tariff calculation methodology, which will cover operational costs and investments with a certain rate of return taking into account the profit generated from recycled materials;
- Implement the principles of a manufacturer's extended liability to cover a part of the costs for the collection and disposal of packaging, electronic and electric equipment, transport vehicles, batteries, furniture and other used goods;
- Develop a mechanism to attract investments, e.g., through public–private partnerships in big cities, and at the level of municipalities in small populated centers, using budget resources to develop industry;
- Update MSW recycling and storage standards using new technologies, such as anaerobic digestion, composting and biogas;
- Improve collection, processing and presentation of statistical information to monitor achievements of target indicators in MSW management.

According to the program, the modernization of waste management will be implemented in three stages as follows:

- Stage 1 is a pilot one to be implemented in 2014–2020. It is requested to prepare a regional management program of solid waste and to produce a pilot implementation of the principles and mechanisms of programs.
- Stage 2 is the main implementation stage planned for 2021–2030.
- Stage 3 is the final stage to take place in 2031–2050. The implementation of the program must be completed and the sustainability of the program is evaluated.

All inhabited localities are classified into three large groups, namely (Concept 2013):

- Group A1: Large cities, such as Astana and Almaty, where the population of the city and metropolitan area are more than 200,000 inhabitants.
- Group A2: urban and rural areas with a population less than 200,000, within a radius of 50 km from the regional landfill or processing complex.
- Group B: rural and other communities that do not fall into the above categories.

Each group of localities will have its own program for implementation of waste separation at source. For Astana, Almaty, and other group A localities, the introduction of separate collection of biodegradable (food and green) municipal waste and other recyclables at source is planned to be facilitated by installing separate labeled containers for collection. The government's policy is in principle in line with European Union policies although the targets' timeline is much different. Taking into account that MSW legislation is under development, the targets set in the DSS tool are derived from the European Union legislation, which is a successful regulatory framework, and can be used as a pilot for the legislation development in Kazakhstan. EU legislation is explicitly mentioned as a good example, and it is analyzed in some detail in the Program of Modernization of Municipal Solid Waste Management for the years 2014–2050 (MEWR 2014). The targets set by the government are shown in Table 6.

## Multi-criteria analysis of MSW management alternatives

The DSS tool for waste management is a computer integrated tool, aiming at supporting the decision-maker throughout the various steps of waste management planning, and allows a thorough understanding of the complex interplay between the numerous factors involved in integrated waste management (Chang et al. 2012). Most existing tools developed for assessing waste management practices incorporate a large number of variables and result in complex solutions, which are often inadequate for practical use (Bani et al. 2009). The DSS tool used in this paper is a user-friendly software equipped with multiple functions (Panagiotidou et al. 2012):

- an automated process tool, identifying and suggesting the most suitable technologies within an integrated waste management framework, and guiding the decision-maker toward formulating appropriate scenarios for waste management planning;
- an analytical tool, evaluating available waste management options through Material Flow Analysis, providing a multidisciplinary comparison (Environmental, Economic, Social, Legislative and Technical) between different waste management technologies;
- a decision support tool, assisting the appropriate authorities to comparatively assess and evaluate the alternative waste management scenarios, based on a predefined set of quantitative and qualitative criteria.

DSS provides solutions that can be considered neither optimal nor absolute, as the solution includes the perceptions of decision-makers. The PROMETHEE II multi-criteria decision-making method and MATLAB graphical user interface environment were used. After developing the Graphical User Interface (GUI), a standalone distributable application (exe) for Windows Operational System is created, using MATLAB Compiler, allowing executions on computers with no MATLAB installed (Panagiotidou et al. 2012). As far as the application of PROMETHEE method in the present case study is concerned, it seems that its major advantage toward other multi-criteria methods lies in its simplicity and the clear and easily obtained information that can be understood by both decision-makers and analysts.

**Table 6** Targets set in the Program of Modernization of MSW Management for the years 2014–2050 (MEWR 2014)

| Target | 2020 (%) | 2030 (%) | 2050 (%) |
|---|---|---|---|
| Coverage of population for solid waste collection[a] | 90 | 100 | 100 |
| Landfills that meet the requirements of sanitary rules | 50 | 95 | 100 |
| Proportion of recycled waste | 10 | 40 | 50 |
| Percentage of collecting biodegradable waste from the public and other manufacturers using separate collection (total biodegradable waste)[a] | 10 | 30 | 80 |
| Percentage of the collection of packaged materials, paper and glass from population and other manufacturers with separate collection (total volume of material in the MSW in total waste categories)[a] | 10 | 50 | 80 |
| The proportion of waste collection of household appliances in population with separate collection (total amount of waste materials in total MSW in this category)[a] | 20 | 70 | 80 |
| Percentage of biodegradable waste placed in landfills MSW (all biodegradable waste) | 90 | 70 | 50 |
| Percentage of biodegradable waste production for “green” energy (total volume collected from biodegradable waste) | 5 | 15 | 30 |
| Percentage of separate collection of hazardous household waste (total amount of waste in this category) | 35 | 65 | 80 |
| Ratio for processing hazardous waste collected by (total amount of waste collected in this category) | 65 | 85 | 100 |
| Percentage of separate collection of bulky, construction and other waste from this category in population (total number of waste in this category) | 35 | 65 | 75 |
| Percentage of recycling household waste collected (amount of separately collected waste in this category) | 50 | 80 | 90 |
| Ratio of disposal from used cars (total number of discarded or unused cars) | 20 | 50 | 70 |
| Percentage of recycling of used tires (from the total the number of discarded or put used car tire) | 50 | 80 | 90 |

The baseline year for setting targets is 2015

[a]Cities and agglomerations with a population of more than 200,000 people

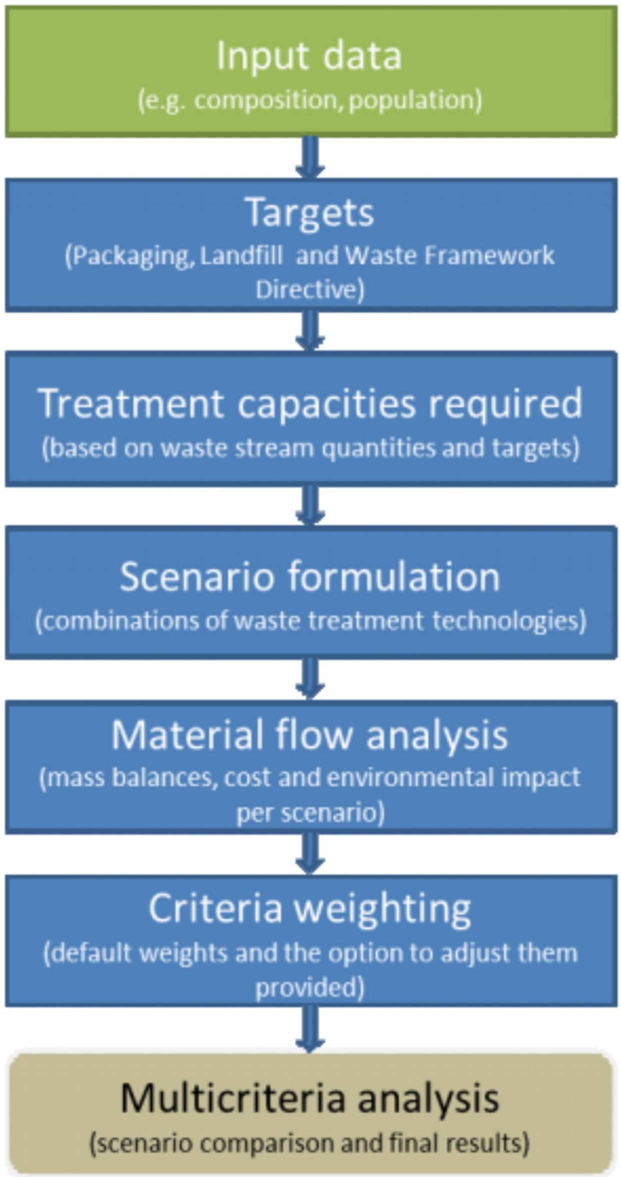



**Fig. 1** Structure of the DSS Tool

## DSS tool methodology outline

The details of the DSS tool are provided by Inglezakis et al. (2016). The DSS tool is divided into different sections, which correspond to the steps during the development of a waste management plan. The structure of the tool is presented in Fig. 1.

The recycling targets and obligations are derived from the existing European Union waste legislative framework and future policy priorities in solid waste management. The baseline for waste management planning through the DSS tool consists of the following three directives: Landfill Directive (1999/31/EC), which sets targets for the year 2020 for biodegradable municipal waste (BMW), Packaging Directive (1994/62/EC), which sets targets for packaging waste recycled, and the Waste Framework Directive (2008/98/EC), which sets a recycling target for 2020. The relevant analysis on these targets for Astana is provided elsewhere (Inglezakis et al. 2014). For Almaty, these targets are not realistic and the DSS tool evaluation is limited to the comparison of alternative scenarios. The DSS tool includes three main waste streams for waste management planning with corresponding waste treatment facilities (Table 7).

Based on the available best practices and EU legislation targets, the methodology for the formulation of the scenarios is as follow:

1. Obligatory separation at source and recovery of materials (plastic, paper, glass, metal) in a material recovery facility (MRF);
2. Obligatory separation of biowaste at source and treatment in a biological treatment facility; Composting or Anaerobic Digestion (AD);
3. Treatment of the residual waste in one or combination of two of the following options (% capacity of each option is defined by the user):
   - MBT-composting-recyclables
   - MBT-composting-RDF (refuse-derived fuel)

**Table 7** Description of technologies (Panagiotidou et al. 2012)

| Technology index | Technology description | Biowaste | Packaging waste | Residual waste |
|---|---|---|---|---|
| Tech. 1 | Composting | √ | | |
| Tech. 2 | Anaerobic digestion (AD) | √ | | |
| Tech. 3 | Material recovery facility (MRF) | | √ | |
| Tech. 4 | Aerobic mechanical and biological treatment (MBT)-composting-recyclables | | | √ |
| Tech. 5 | Aerobic mechanical and biological treatment (MBT)-composting-RDF | | | √ |
| Tech. 6 | Aerobic mechanical and biological treatment (MBT)-AD-recyclables | | | √ |
| Tech. 7 | Aerobic mechanical and biological treatment (MBT)-AD-RDF | | | √ |
| Tech. 8 | Biodrying | | | √ |
| Tech. 9 | Incineration | | | √ |

- MBT-anaerobic digestion-recyclables
- MBT-anaerobic digestion-RDF
- Biological drying and production of SRF (Solid Recovered Fuel)
- Incineration;

4. Landfilling or incineration (WtE) of the residues RDF and SRF.

The first two steps are obligatory, while several possible scenarios can be formulated by combining the rest of the options. Six main technologies can be applied, which are the basis for the alternative management scenarios. Additional scenarios can be developed by combining certain elements of the main scenarios.

The scenarios can comprised of different technologies for the treatment of waste, and based on economic and technical restrictions, the DSS tool allows or rejects the selection of particular technologies or combination of technologies for the formulation of alternative scenarios. For the purpose of comparative assessment of alternative scenarios, economic, environmental, technical, social and legislative criteria have been developed (Panagiotidou et al. 2012). The tool evaluates the formulated scenarios based on a number of 28 quantitative and qualitative criteria. The user is able to modify the rates of each criterion in order to depict the local needs and priorities regarding waste management. The established set of criteria can be separated to quantitative and qualitative criteria, according to the type of measurement scale used to express the performance of alternatives. For the particular study, each criterion is expressed in its units taking into account that the evaluation of alternatives for each criterion, which represents the qualitative information, is based on the evaluation scale (Hokkanen and Salminen 1997).

The current DSS tool provides default evaluations per technology for each qualitative criterion, which rely on the studies concerning waste management status in south-east European countries, but the user can modify these evaluations by changing the rating/evaluation (0–100) per waste treatment technology. The rating method requires the user to evaluate criteria by a predetermined scale (0–100), with 0 point to represent "very low" performance, while 100 points to represent "very high" performance (Panagiotidou et al. 2012).

As the criteria have been identified and scored, the next step is their weighting. The DSS tool provides default values and the user is allowed to modify them. The values are adjusted for Astana and Almaty based on the local conditions and consultation with local stakeholders. Once the user determines the value (1–100) for a criterion, the DSS tool calculates the corresponding weight in percentage (%), based on normalization of the weights for all criteria so that the sum of weights always remains 100%. After consultation with the local authorities and waste management experts, the proposed weights for all the criteria were derived and are presented in Table 8.

## Results and discussion

After the basic data are defined for the case studies of Astana and Almaty, formulation of alternative scenarios can be performed (Table 9). Scenario 1 is MBT-composting-recyclables (100%), and landfilling of the residual waste is used as baseline due to its simplicity. Taking into account the governmental policy for separation at source, it can be assumed that this base scenario will be soon accompanied by MRF and composting or anaerobic digestion facilities for the treatment of the separated recyclables and biowaste (Fig. 2).

The results of the DSS tool are presented in Figs. 3 and 4. Based on the weights assigned, the proposed optimum scenario for the residual waste in Astana is number 2: MBT-composting-recyclables and waste-to-energy for the RDF produced at the MBT. For Almaty, the optimum scenario is number 6: MBT-composting-recyclables for 80% of the waste and incineration for the rest 20% of the waste and the RDF produced at the MBT.

Scenarios 2 and 6 are close enough in rating for both cities and the optimum scenario selection can be explained by the differences both in the weighting criteria applied (Table 8) and in the existing facilities. Astana has an MBT plant but not for Almaty (Table 5). Scenario 1, which is based on landfilling, is ranked as the third best option—close to the second one—in Astana, while it is only ranked fifth, and actually it exhibits a negative score, in Almaty. The land requirement and visual impact criteria weights are much lower in Astana. These criteria are much more important in Almaty due to the landscape and population size. Scenario 4 is the worst for both cities because of the fact that it relies on anaerobic digestion (AD) for both biowaste and residual waste, a technology which is considerably more expensive than composting. However, when AD is combined with incineration in Scenario 5, it is ranked as the second-best option for Almaty. The results obtained show that the right combination of technologies could be superior to the single technology.

Astana is a new city, and the available data on waste composition and the DSS tool results can be viewed as snapshot of the current situation. The DSS tool can provide useful information on how waste patterns may evolve over time. Its population has increased four times since 1998, although some districts are still under-populated and under-used, there are no signs of them becoming "waste cities," as it has happened in several newly constructed cities in China (He et al. 2016). The present work does not address the construction waste, which constitutes a challenge for a city with such a high growth rate and

**Table 8** Criteria weights for the implementation of the DSS Tool

| Criteria | Almaty | Astana |
|---|---|---|
| Economical criteria | | |
| Capital expenditure (€/t) | 6.45 | 7.34 |
| Operation and maintenance cost (€/t) | 6.45 | 7.34 |
| Revenues from products (€/t) | 5.65 | 6.42 |
| Land requirement ($m^2$/t) | 4.03 | 0.92 |
| Market prospect of products (1–100) | 4.84 | 5.50 |
| Environmental externalities—external costs and benefits (€/t) | 1.61 | 1.83 |
| Environmental criteria | | |
| Greenhouse gas emissions | 4.03 | 4.59 |
| Emissions to air (kg gas eq./t) | 4.03 | 4.59 |
| Conventional fuel savings | 0.81 | 0.92 |
| Wastewater generation (1–100) | 1.61 | 1.83 |
| Water consumption ($m^3$/t) | 1.61 | 2.75 |
| Production of non-hazardous solid waste—residues (% input) | 4.84 | 5.50 |
| Production of hazardous residues (% input) | 3.23 | 3.67 |
| Noise Pollution (1–100) | 4.03 | 0.92 |
| Technical criteria | | |
| Existing experience—reliability (1–100) | 4.03 | 4.59 |
| Adaptability to local conditions (1–100) | 4.03 | 4.59 |
| Flexibility (1–100) | 3.23 | 3.67 |
| Energy consumption (kWh/t) | 4.03 | 4.59 |
| Energy production (kWh/t) | 4.03 | 4.59 |
| Secondary products | 4.03 | 4.59 |
| Correlation with recycling activities (1–100) | 4.84 | 5.50 |
| Social criteria | | |
| Social acceptance (1–100) | 4.03 | 2.75 |
| Visual impact (1–100) | 4.03 | 0.92 |
| Risk perception (1–100) | 4.03 | 2.75 |
| Employment quality (1–100) | 2.42 | 2.75 |
| Potential for the creation of new jobs (1–100) | 4.03 | 4.59 |
| Legislative criteria | | |
| Harmonization with the priorities of the EU legislation (1–100) | 0.00 | 0.00 |
| Contribution to the landfill directive targets (1–100) | 0.00 | 0.00 |
| Sum | 100.00 | 100.00 |

**Table 9** Alternative scenarios formulation

| Scenario | Biowaste | Packaging waste | Technology for Facility 1 | % for Facility 1 | Technology for Facility 2 | % for Facility 2 | RDF/SRF treatment |
|---|---|---|---|---|---|---|---|
| 1 | Composting | MRF | MBT-composting-recyclables | 100 | – | 0 | Landfilling |
| 2 | Composting | MRF | MBT-composting-recyclables | 100 | – | 0 | Waste-to-energy |
| 3 | Composting | MRF | MBT-composting-recyclables | 50 | Incineration | 50 | – |
| 4 | AD | MRF | MBT-AD-recyclables | 100 | – | 0 | Waste-to-energy |
| 5 | AD | MRF | MBT-AD-recyclables | 50 | Incineration | 50 | – |
| 6 | Composting | MRF | MBT-composting-recyclables | 73 | Incineration | 27 | – |

**Fig. 2** Example of an alternative scenario

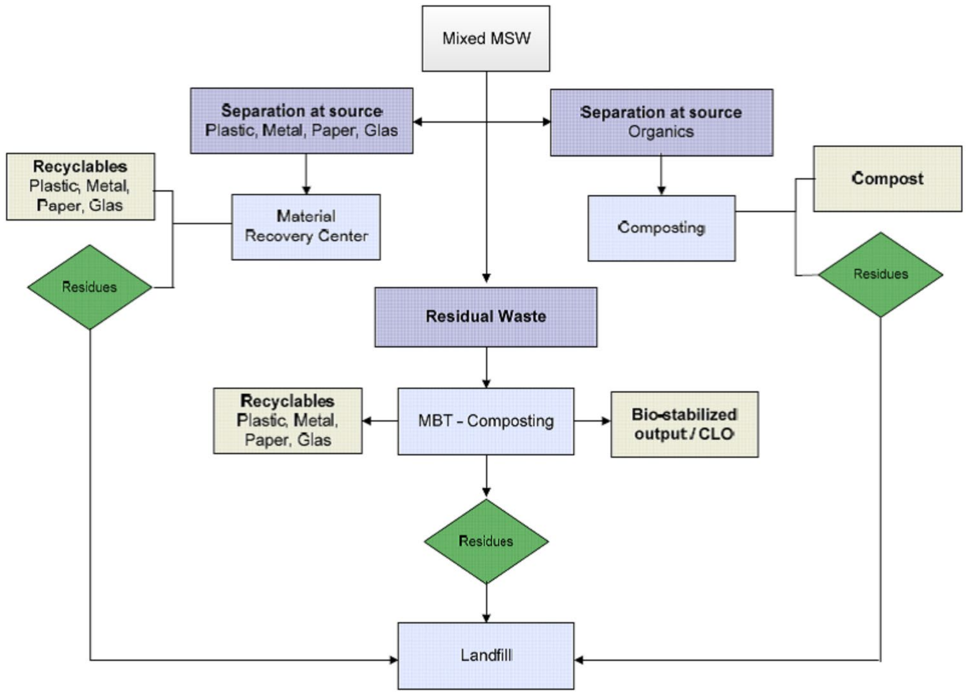



**Fig. 3** Results of the application of the DSS tool for Astana

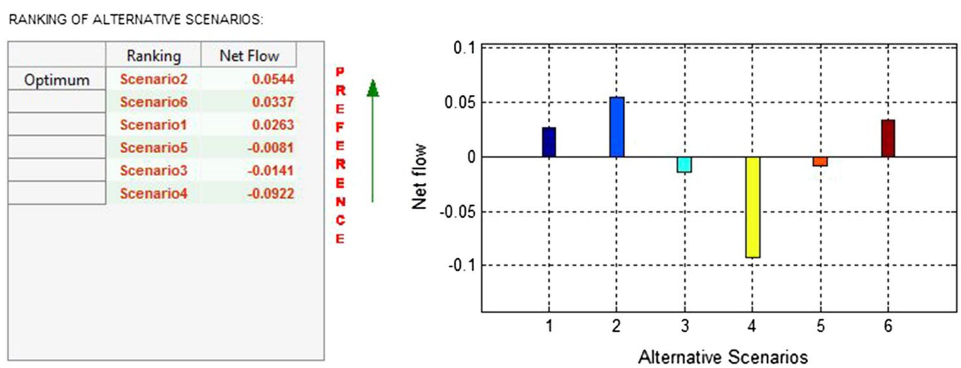
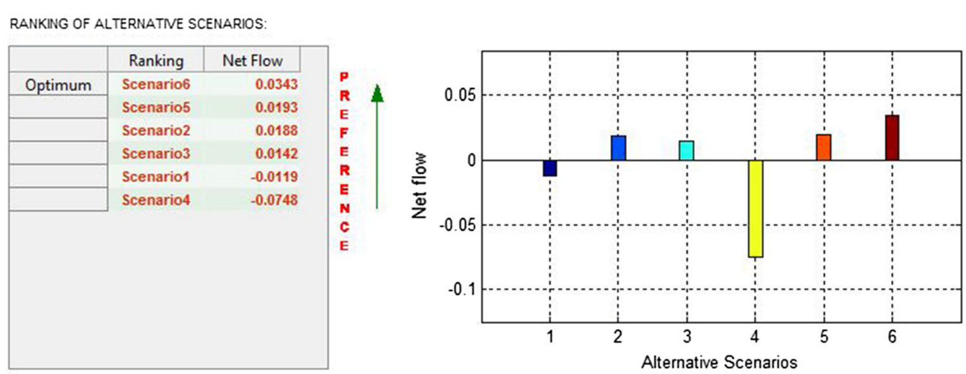



**Fig. 4** Results of the application of the DSS tool for Almaty




construction activity. According to the relevant ministerial decree No. 145 dated 25.11.2014, the category "Other waste" includes only small amount of construction waste from households as well as stones and waste from street cleaning. Thus, construction waste is not included as a separate fraction in Table 4, but it is likely included in the 26.4% of "Other waste." The generation of construction waste per gross residential floor area is around 50 kg/

m$^2$, and construction waste can be as high as 40% of the total urban waste generation when new cities are built, as for example in China (He et al. 2016). The inclusion of construction waste in the total waste amount dilutes the other fractions, and most probably the actual organic waste fraction is bigger.

WtE technologies and incineration are essential components in the proposed scenarios. Converting solid waste-to-energy provides an option not only to produce renewable energy but also to contribute to offsetting greenhouse gas emissions (Khan et al. 2016). The use of WtE technologies depends on several factors, the most crucial being the fraction of the biodegradable organic matter. High fraction of organic waste suggests that biological methods are more appropriate, while thermal combustion technologies are technically and economically challenging to utilize in light of the lower calorific value and higher moisture content (Aleluia and Ferrão 2016). A large number of facilities using WtE technologies are operated, especially in developed countries like Canada (Shareefdeen et al. 2015), USA, UK, Germany, and the Netherlands (Kayakutlu et al. 2017). This option helps in diverting MSW from landfills and offers an alternative renewable source of energy. Its implementation, however, depends on legislation and public acceptance. Social factors are often overlooked, but several studies have highlighted the fact that waste treatment plans and technologies that do not take into account the social aspects are destined to fail (Milutinovic et al. 2016).

Kazakhstan, being in the first steps of developing a modern and efficient waste management planning, must invest in public awareness and education so as to build strong foundations for such a system to succeed. This is vital when it comes to separation at source, which entirely depends on the willingness of the citizens to collaborate with the waste management operators. The country should gradually involve the public in decision making as well. The Aärhus Convention proposed increased levels of public involvement in environmental decision making (Garnett et al. 2017), and public involvement is often argued as necessary, since public support is needed in order to implement crucial elements of the policy.

Composting is an essential technology in both proposed scenarios. Several studies have demonstrated that the composting process is one of the most environmentally friendly technologies for the management of organic solid waste, and it contributes to the recycling of nutrients (Oliveira et al. 2017). Taking into account the immense size and low productivity of lands in Kazakhstan, composting can provide a sustainable fertilizer contributing to this unexploited national capital of the country.

## Conclusions

Kazakhstan is a country with rapid economic development and the environmental stresses and challenges have to be confronted. As far as waste management is concerned, it is in its earliest stages, and significant amounts of metropolitan solid waste are rejected in open dumps. Relevant data on waste management in Kazakhstan are absent in the literature except the paper of Vermenicheva et al. (1999), while the collection of reliable figures and environmental information is a challenging task. In the present paper, data related to waste generated in two main cities of Kazakhstan, Astana and Almaty, were shown with composition details and current management practice. The information presented has been discussed along with environmental policy trends and targets set in the country. A Decision Support Software tool was used to perform a multi-criteria analysis and comparison of future MSW management alternatives for both cities. The application of the DSS tool demonstrated that for both cities the optimum scenarios involve separation at source for biowaste, which is subsequently composted, and packaging waste, which is subsequently processed in MRF installations. For the residual waste, the optimum scenario for Astana is a combination of MBT-composting-recyclables and waste-to-energy for the RDF, while for Almaty it is a combination of MBT-composting-recyclables for 80% of the waste, and incineration for the rest 20% of the waste and the RDF.

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