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# Exploring the mitigation of greenhouse gas emissions from the current municipal solid waste system of Kazakhstan: case study of Nur-Sultan city

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**Abstract.** As we move forward, municipal solid waste (MSW) landfills, particularly in developing countries, contribute notably to global greenhouse gas (GHG) emissions. Therefore, the MSW sector plays a key role in planning strategies for developing countries such as Kazakhstan to decrease GHG emissions. With respect to the Paris Agreement, Kazakhstan has set the target of reducing GHG emissions to 15-25% by 2030 compared to the level of 1991, which will undoubtedly require certain measures in the field of MSW management. Several recent articles have been published on the waste management sector of Kazakhstan; however, none have explicitly focused on the impact of greenhouse gas emissions and possible pathways towards sustainable management. Thus, this paper describes the existing MSW system in Nur Sultan city as representative for the rest of the country. The quantitative evaluation of GHG emissions from the existing MSW system in the capital is carried out based on the IPCC methodology using the SWM-GHG calculator developed by the Institute for Energy and Environmental Research (IFEU). An assessment and cost analysis of a set of several suitable MSW management scenarios, such as scenario 1: existing case (15% recycling rate and 85% disposal), scenario 2: 30% recyclable materials, and 70% sanitary landfill with gas collection; scenario 3: 30% recyclable materials and 70% biological stabilization and landfill without gas collection; scenario 4: 30% recyclable materials, 20% composting and 50% waste to be sent to the WtE plant (incineration). The level of GHG emissions decreases with the introduction of more integrated waste management methods, but requires more financial investments. Therefore, Scenario 3 is the most efficient to implement in terms of the combination of cost of €19.4 million/year and magnitude of GHG emissions of 48 kt of $CO_2$ eq/year. The outcomes of this work will help to extrapolate the model to other large cities in Kazakhstan

**Keywords:** MSW, GHG emissions, recycling, landfilling

## 1. Introduction

The strategy for waste management varies worldwide but in particular, the strategy in post-soviet developing countries like Kazakhstan is far different from the European Union [1]. For example, in Kazakhstan the level of MSW landfilling was around 94% and the recycling rate was 6% in 2018 [1], whereas in the EU, these values were close to 39% and 38 %, respectively [2]. In the EU countries as in Sweden, Denmark, Germany, Belgium, Austria, and the Netherlands, solid waste is primarily recycled and reused as secondary raw materials, and if recycling is ineffective or impossible, waste is used as secondary energy resources [3]. However, if these two methods are not feasible, the waste is further classified as suitable for disposal. According to the European Environment Agency, greenhouse gas emissions (GHG) from MSW in the EU decreased by 42% or 107.720 MMT of $CO_2$ equivalent between 1995 and 2017 [4]. The total amount of recycled MSW increased by 13%, and the amount of waste disposed of in landfills decreased by 60% over the same period.

The waste management sector takes fourth place in the list of contributors to the global GHG emission after the energy, industry, and agricultural sectors [5]. The case of the EU emphatically highlights that proper waste management can effectively reduce GHG emissions since MSW contributes for 5% of global GHG emissions [6]. Any method of waste management directly or indirectly contributes to the GHG emissions, yet to different degrees. Thus, implementing an optimal waste management strategy is crucial. For example, the final disposal of solid waste in landfills without gas recovery and open landfills contributes to the largest GHG emissions in the atmosphere compared to other treatment methods, in the form of $CH_4$ and $N_2O$ [7, 8]. Incineration of waste containing fossil carbon like plastics and synthetic fabrics leads to minor GHG emissions. Recycling and biological treatment, on the other hand, such as composting cause moderate GHG emissions.

In terms of local demography, optimal waste management is important in reaching the goals set by the government of Kazakhstan. In 2010, the government of Kazakhstan started a campaign of voluntary commitment to decrease the amount of GHG emission by 15% by 2020 and 25% by 2050 [9]. Furthermore, during the Climate Ambition Summit in 2020, Kazakhstan has committed to reaching carbon neutrality by 2060 [10]. Currently, landfilling is the primary practice for waste management in Kazakhstan. Despite being economically favourable, landfilling possesses environmental disadvantages such as emissions of gases and the generation of leachates. For instance, in 2017, the amount of GHG emissions generated daily in Tehran as a result of incineration accounted for 4499.1 kg eq. $CO_2$ in contrast to landfilling with 92,170.3 kg eq. $CO_2$ [11]. GHG emissions from landfills cannot be suppressed even with advances in technology; however, the release of methane into the atmosphere can be decreased significantly by a collection of methane gas. Friedrich [12] showed that landfilling without gas collection of 156,474 tons of garden waste results in 203,103 tons of $CO_2$-eq. However, landfilling with gas collection yielded negative GHG emissions of -42,886 tonnes $CO_2$-eq.

An available SWM (Solid Waste Management tool)-GHG calculator was used to determine an optimal strategy among recycling, incineration, and integrated approaches for Malaysia. The authors determined an integrated approach with 40% recycling and 31.9% incineration as optimal with about 64% reduction, or 5,803,493 tonnes $CO_2$-eq, in GHG emissions by 2050 [13]. Similarly, the SWM-GHG calculator showed that the recycling approach results in the largest reduction of GHG emissions in Pakistan [14].

In reference to Kazakhstan, there have been several studies including the MSW compositional analysis by Abylkhani [15] and evaluation of alternative management scenarios by Inglezakis and Moustakas [16]. Nur-Sultan, among other cities, is a quickly growing city with a population increase of four-folds in the last 20 years [17]. Although Nur-Sultan has a lower fraction of landfilling as compared to other regions, it is still predominant among other waste treatment techniques [16]. Given such rapid population growth and continuing prevalence of landfilling, improvements in the management of MSW are needed. To this end, we develop four different waste management scenarios and evaluate the optimal using the SWM-GHG approach. The optimal waste management scenario might be sent to consideration by authorities in order to reduce GHG emissions in Nur-Sultan, and further to other regions of Kazakhstan.

## 2. Materials and Methods

### *2.1. The SWM-GHG Calculator*

The SWM-GHG calculator developed by the Institute for Energy and Environmental Research (IFEU) was used in this study to calculate greenhouse gas emissions in Nur-Sultan city and thus evaluate the four waste management scenarios. The four scenarios were chosen according to their suitability for Kazakhstan. The calculator estimates total emitted GHG emissions from a given amount of MSW, with credits: the prevented GHG emissions or savings, mainly due to recycling, and debits: GHG emissions from MSW management activities. The average MSW composition of Nur-Sultan city in 2018 was as follows: 30-32% of recyclable fractions, 8-10% refuse-derived fuel, 45-50% organic waste (depending on the season), and the remaining 10% were observed as a fine fraction [15]. The SWM-GHG calculator was further used for the cost analysis of the waste management scenarios.

### *2.2. Scenarios development*

*2.2.1. Scenario 1: Status Quo scenario - 15% recycling and 85% landfill without gas collection*. The baseline scenario corresponds to the current situation in Nur-Sultan and major cities of the country. Kazakhstan produces 5 million tons of solid waste with an expected increase up to 8 million tons by 2025 [16]. A separate collection was introduced in 94 settlements and sorting in 80 settlements across Kazakhstan out of 204 cities and regions [18]. In 2020 the capital Nur-Sultan had three recycling enterprises [19]. The share of recycled MSW for the 3rd quarter of 2020 was 15.8%.

*2.2.2. Scenario 2: 70% landfilling with gas collection and 30% recycling.* The purpose of scenario 2 is comparison between disposal in landfill without and with gas collection. In 2018, the Ministry of Energy of Kazakhstan developed a concept of transition to the “Green Economy”, according to which the waste recycling should be increased to 40% by 2030, and to 50% by 2050 [20]. However, given the current recycling rate, 40% by 2030 is an overestimate. Therefore, Scenario 2 considers that metals, plastics, paper, and glass are separated and recycled at a 30% rate to closely meet the legislative targets for recycling. According to Yay [21], the biological decomposition of 1 ton of MSW generates 442 m3 of landfill gas containing 55% of methane. The average methane yield is approximately 100 m3/t MSW considering that only a fraction of the waste is converted to methane due to moisture limitation, non-biodegradable fractions, and inaccessible waste [22]. Hence, in development of the second scenario, a gas collection system is implemented.

*2.2.3. Scenario 3: 70% biological stabilisation with landfill and 30% recycling.* Biological stabilisation (BS) of MSW before landfilling reduces methane emission [24]. BS involves collection of MSW in aerated compost heaps with no-to-minimum mechanical pre-treatment, to make it cost-effective. BS takes at least 8 weeks, beyond which the waste is landfilled. Hence, the developed scenario 3 incorporates 70% of the waste subjected to BS and landfill, and the rest recycled. In particular, MBT (Mechanical Biological Treatment: sorting combined with further biological treatment) was selected for BS. Biological stabilization is similar to MBT method but might be more approachable for Kazakhstan due to easier implementation.

*2.2.4. Scenario 4: an integrated approach - 30% recycling, 20% composting, and 50% incineration.* The scenario applies an integrated approach to minimise environmental hazards caused by GHG emissions. The recycling rate was considered at 30%, organic waste was treated by composting, and the combustible MSW undergoes incineration. The scenario is justified by the high content of food waste which is suitable for composting, paper, and plastic fractions to construct a waste-to-energy plant in the future.

## 3. Results and Discussion

### *3.1. Greenhouse gas emissions*
The net GHG emissions, as the difference between actual and avoided GHG emissions, is shown in Figure 1. Scenario 1 revealed that the net GHG emissions is approximately 455 kt of $CO_2$-eq/year, with 552 kt of $CO_2$-eq/year and 97 kt of $CO_2$-eq/year for actual and avoided emissions, respectively. Scenario 2, on the other hand, is able to decrease the net GHG emissions by two times. The result of

the difference between 'disposed of' (the net emissions reduced by disposal techniques, that include collection, processing, removal of damaged or unwanted substances, deposition of waste) and recycled MSW (the net emissions reduced by recycling) is 251 kt of $CO_2$-eq/year. In the case of scenario 3, 30% of all MSW is recycled and 70% is landfilled with the gas collection. These factors result in 196 kt and 244 kt of $CO_2$-eq/year of credits and debits, respectively, indicating a net GHG emissions of 48 kt of $CO_2$-eq/year. While scenario 3 shows less GHG emissions in comparison with scenarios 1 and 2, the net emissions are still positive. The scenario 4 supposes that Nur-Sultan city recycles 30%, composts 20%, and incinerates 45% of all MSW. As it can be seen from the results the net GHG emission is much lower than in the other three cases, while the credits increased by approximately 90 kt of $CO_2$-eq/year. These calculations give the result of negative (−)161 kt of $CO_2$-eq/year of net GHG emissions for scenario 4.

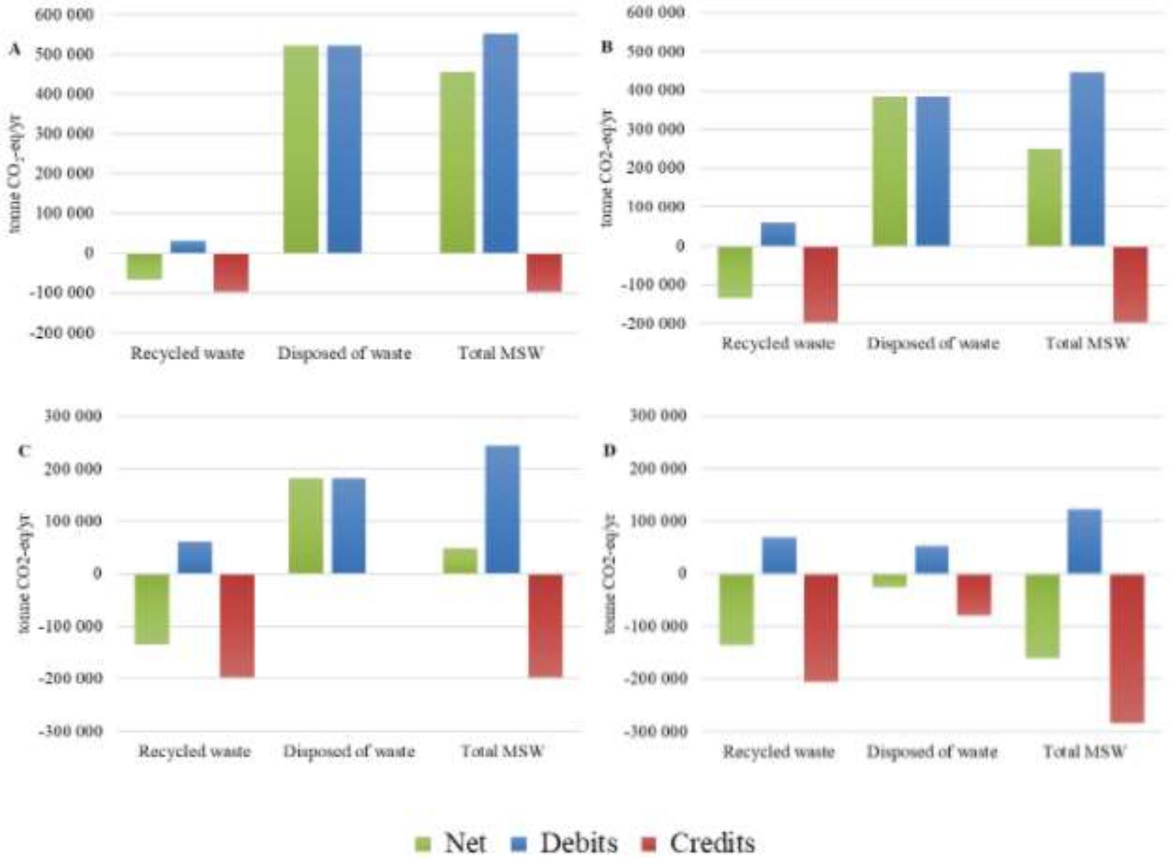


**Figure 1.** GHG emissions for (A) Scenario 1 (B) Scenario 2 (C) Scenario 3 (D) Scenario 4.

### *3.2. Cost analysis*

The cost analysis is further performed to estimate the economic impact of the developed four scenarios; however, it does not include the MSW transportation cost from the collection to the disposal site. The following costs of waste disposal technologies are taken from the literature: 4 €/t for landfilling, 16 €/t for sanitary landfilling with gas collection, 20 €/t for BS, 70 €/t for incineration, and 40 €/t for composting [23, 25, 26]. Scenario 1 has the lowest cost because of the low tipping fee which is charged from the waste sorting plant. In addition, controlled landfill is the cheapest method among all the presented strategies for MSW management with a cost of 4 €/t. In the second scenario, the amount of waste processed has increased up to 132 thousand tons. In addition to the growth in the recycling rate, the method of disposal includes gas collection, which increases the total cost. As a result of these changes in MSW management, the cost of Scenario 2 increased from €1.8 million (Scenario 1) to €5.6 million.

In Scenario 3, the difference in cost is relatively small compared to Scenario 2, mainly due to the unchanged recycling rate of 30%. The only change that contributes to cost is biological stabilisation, which costs 20 €/t, exceeding the cost of sanitary landfill with gas collection by 4 €/t [23], resulting in an increase of €1.2 million. The total waste in the city of Nur-Sultan is 438 thousand tons, in which the organic waste is 206 kt, and the price of composting is 20% of this waste will be composted at a price of 40 €/t [25]. 132 kt are recycled and the remaining 217 kt will be incinerated at the WtE plant. The cost of disposal is determined according to the current tariff in Nur-Sultan, and the typical cost of MSW incineration is 70 €/t [26]. It should be noted that external costs can exist based on a monetary assessment of the damage caused by pollutants from waste to power plants [27]. As a result, the total cost will be €19.4 million/year.

In summary, Figure 2 shows a plot of costs versus the GHG emissions for the four scenarios, which indicates that the GHG emissions are inversely proportional to the level of scenario complexity, while the cost increases proportionally. The introduction of more integrated waste management practices has a more positive effect on the level of GHG emissions but requires more financial contributions. Analysing all scenarios, Scenario 3 is the most efficient for implementation in the near future in terms of the combination of cost and GHG emissions value.

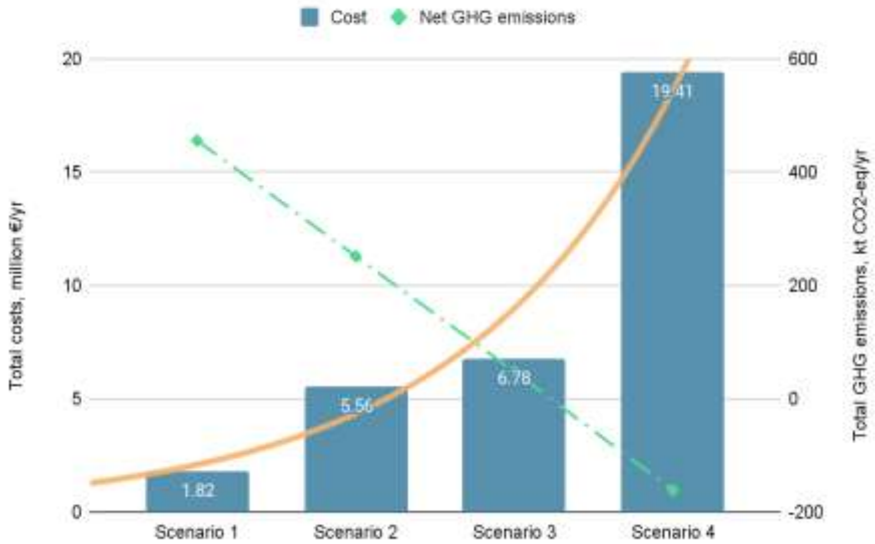


**Figure 2.** A comparison of GHG emissions along with cost for the four developed scenarios.

## 4. Conclusions

The conclusions were drawn from the study:

- The existing MSW management scenario has the highest GHG emissions and the lowest cost.
- An integrated approach has the lowest GHG emissions, with net negative GHG emissions; however, it has high economic cost with at least three times higher than other scenarios.

The results achieved in this paper are significant for the municipalities and especially for waste management planning. The best outcomes from scenarios 3 and 4 can help to organise the sustainable case for the city.

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