

Environmental impact assessment of municipal solid waste management and Comparative Life Cycle Assessment of system solution scenarios in Riyadh, Saudi Arabia

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Introduction

Municipal Solid Waste (MSW) management has gained global attention, with the Saudi Arabian government and policymakers increasingly prioritizing waste management practices in the country. The National Centre for Waste Management (MWAN) was established in 2019 to specifically address waste management issues in Saudi Arabia. The country has experienced a significant increase in MSW, reaching approximately 12 million tons per year, attributed to population growth and evolving citizen lifestyles. Riyadh, the capital city, alone generates around 8 million tons of MSW annually, the highest in the country, primarily managed through landfill disposal and incineration.[1]

The current study aims to assess the impact of an MSW management system in Riyadh, Saudi Arabia, under six different scenarios based on the Strategy for 2035 of Riyadh. The system boundaries encompass MSW treatment and disposal through recycling, incineration, composting, and landfilling methods. The study seeks to employ a scientific approach to understand the environmental impacts of products and systems, addressing concerns arising from inefficient systems and economic factors, as well as a lack of technical expertise in biological and/or thermal treatment in Saudi Arabia.

In alignment with KSA's Vision 2030, efforts are directed towards reducing greenhouse gas (GHG) emissions to achieve key environmental performance indicators. Studies have shown that implementing Material Recovery Facilities (MRF) with anaerobic digestion can have a lesser environmental impact when combined with landfilling and composting. The Saudi government is actively promoting stronger recycling and an integrated municipal waste management system to enhance the waste management scenario, including the systematic implementation of waste management strategies such as materials recovery facilities, energy waste systems, and recycling facilities, which can also create local employment opportunities.[2]

The waste management scenario in Saudi Arabia presents significant challenges, with the country producing approximately 53 million tons of waste annually, leading to soil and groundwater contamination. The environmental degradation caused by solid waste in 2021 was estimated at \$1.3 billion, with nearly half of the total waste originating from three major cities: Riyadh, Jeddah, and Dammam. Landfills in Saudi Arabia are approaching their capacity, and the majority of municipal waste is disposed of untreated in landfills or incinerated, with limited recycling. Recycling, reuse, and energy recovery are still in the early stages, with waste sorting and recycling primarily driven by an active informal sector. [3]

Efforts are underway to deploy waste-to-energy technologies in the Kingdom, and the Saudi government is investing in waste management solutions to address the growing challenge of solid waste management. The Saudi government's commitment to divert waste from landfills by 2035 aligns with the Saudi Green Initiative, aiming to divert 94% of waste from landfills. This strategy involves comprehensive and integrated plans to cover all regions of the Kingdom, starting from Riyadh. The government is also considering the imposition of waste management fees as part of the waste management system, demonstrating a serious commitment to improving recycling and waste management in the country.[1]

Material and methods

The LCA methodology is utilized to assess and compare the environmental impact of various waste management scenarios. The end-of-life (EoL) modeling procedure in OpenLCA differs across databases, generally employing two distinct approaches. In this study, the Opposite Direction Approach (ODA) using OpenLCA is utilized, modeled with the Ecoinvent v3.6 dataset and calculated with the ReCiPe 2016 Midpoint (H) method; V1.04/World (2010) H [4].

Table 1. Scenario assumptions

MSW scenarios:	Landfill	WtE (pyrolysis, gasification, anaerobic digestion, incineration, etc)	Recycle	Organic M Treatment
S0: The Royal Commission for Riyadh City (RCRC) Current MSW in Saudi Arabia [5]	100%	0%	0%	0%
S1: The Royal Commission for Riyadh City (RCRC) strategic_2023 [6]	2%	80%	5%	13%
S2: The Royal Commission for Riyadh City (RCRC) strategic_2035 [5]	1%	68%	10%	21%
S3: MWAN: (2025) [7]	9%	7%	42%	42%
S4: (MWAN) The National Centre for Waste Management-strategic master plan_2035 [1]	6%	14%	27%	53%
S5: (SIRC) The Saudi Investment Recycling Company (PIF) 2035 [8]	0%	19%	81%	0%



Figure 1. Municipal solid waste (MSW) management systems based on the proposed scenarios under study in Riyadh. (a) Scenario 0 (S0), (b) scenario 1 (S1), (c) scenario 2 (S2), scenario 3 (S3), scenario 4 (S4), and scenario 5 (S5).

Results and discussion

In order to comprehend the current situation and make recommendations for the future, this study specifically focuses on the municipal solid waste (MSW) in Saudi Arabia. The environmental impact of the defined scenarios is compared for seven impact categories: global warming, ozone formation (human health), fine particulate matter formation, terrestrial acidification, freshwater eutrophication, mineral resource scarcity, and fossil resource scarcity. The results will focus on waste treatment and scenario, and the detailed results for all the impact categories included in the ReCiPe method [4]. Waste treatment will be modeled using secondary data from the Ecoinvent database, as specific data from the type of technology that will be implemented is not available in existing facilities in Riyadh. The MSW generation, electricity mix, population, and electricity consumption for the period 2024–2035 will be calculated based on Riyadh Strategy forecasts and governmental statistics.

Conclusions

The waste management system in Riyadh, Saudi Arabia, primarily relies on landfilling, but in 2024, the city enhanced its Master Strategy across by the National Center for Waste Management (MWAN) to address the increasing waste levels. The strategy includes proposals for waste incineration, material recycling, and biowaste treatment in scenarios to be fulfilled by 2030 and 2035 [1]. While these treatments have higher environmental impacts than landfilling, they offer benefits such as reducing greenhouse gas emissions, generating renewable energy, and recovering material value, aligning with the principles of the circular economy [9]. However, the success of these alternative management systems depends on factors such as households' attitudes towards waste separation, the municipality's collection schemes, and cost allocation. In conclusion, the management of municipal solid waste in Saudi Arabia presents a complex challenge, but the government's initiatives and strategic plans demonstrate a strong commitment to addressing these issues and improving waste management practices in the country.

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