Modeling U.S. Municipal Waste Management Based on Per Capita Generation and Disposal Trends

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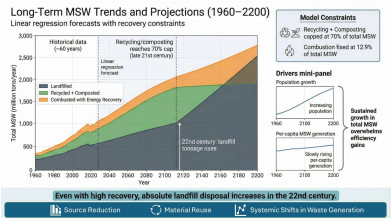
Abstract

Over the past six decades, rapid population growth and shifting consumption patterns in the United States have significantly reshaped municipal solid waste (MSW) management, with population nearly doubling and MSW generation more than tripling between 1960 and 2018, driving higher per capita waste outputs and intensifying environmental pressures as economic development and urbanization expand both household and commercial waste streams. This study responds to the need to understand how long-term demographic and behavioral trends affect landfill reliance, recycling capacity, and sustainability outcomes by quantitatively examining nearly sixty years of national MSW data to evaluate relationships between population growth, total MSW volumes, per capita generation, recycling and landfill shares, and energy recovery through combustion. Using these historical data, this study develops linear regression models to forecast major waste streams through the year 2200, while imposing explicit constraints primarily capping the recycling and composting rate at 70% and fixing the combustion rate at 12.9% of total MSW generation, to keep long-term projections within plausible technological and policy limits. The analysis suggests that resource recovery efforts continue to improve, with recycling and composting eventually reaching the 70 percent cap by the late 21st century, indicating substantial gains in diversion efficiency and processing capacity; however, the sustained linear growth in total MSW generation, driven largely by population expansion and rising per capita consumption, ultimately overwhelms these efficiency gains. The major finding is that even under optimistic recovery assumptions, the absolute tonnage of waste requiring landfill disposal is projected to rise sharply in the 22nd century, underscoring that improved management efficiency alone is insufficient and highlighting the critical importance of strategies that directly reduce waste generation through source reduction, material reuse, and systemic shifts in production and consumption.

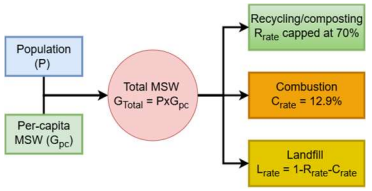


Methodology

Historical MSW Trends in the United States (1960–2018):

- **Population Growth:** Steady, consistent linear increase over 58 years.
- **Total MSW Generated:** Strong long-term rise; per-capita generation stabilized after early 2000s with a spike in 2018.
- **Recycling & Composting:** Increased nearly 10-fold, from ~6% (1960) to 38% (2018), showing major growth in resource recovery.
- **Combustion (Energy Recovery):** Rapid expansion in the 1980s; stable since 2000 at ~12–14% of total MSW.
- **Landfilling:** Share of total MSW dropped from ~94% (1960) to ~50% (2018), despite increases in absolute tonnage until the 2010s.

Area	Assumption	Impact
Long-Term Drivers	Current political, economic, and technological conditions remain unchanged through 2200.	High uncertainty; major disruptions or innovations could shift trends.
Population Growth	Population follows a constant linear growth rate based on 1960–2018 data..	Ignores future demographic or policy changes affecting growth.
Combustion Rate Cap	Combustion fixed at 12.9%, matching 2008–2018 average.	Assumes no major expansion or phase-out of waste-to-energy capacity.
Recycling Rate Cap	Recovery capped at 70% maximum efficiency.	Prevents unrealistic projections above 100% due to material limits.
Landfill Minimum	Landfilled rate cannot drop below 0%.	Ensures model stability and avoids negative waste values.
Per Capita Generation	Per-capita MSW grows slowly and linearly.	Assumes consumption increases outweigh lightweighting and efficiency gains.

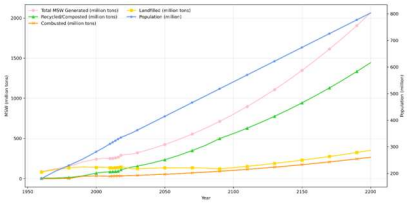


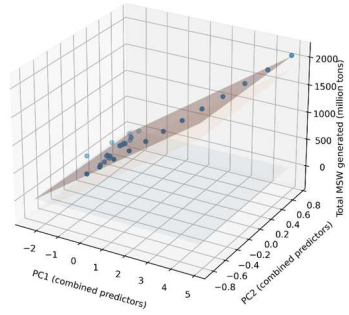
Results and Discussion

Historical vs. Forecasted MSW Trends (1960–2200):

Historical data show a major decline in landfilling share, dropping from ~94% in 1960 to ~50% in 2018 as recycling, composting, and energy recovery increased.

- Forecasted trends indicate total MSW generation will continue rising, exceeding 2 billion tons by 2200, driven by population growth and long-term consumption patterns.
- Even with recycling and composting reaching an assumed upper limit of ~70%, absolute waste volumes continue to grow throughout the forecast period.
- Projected landfilled tonnage increases substantially, reaching ~353 million tons by 2200, more than double the 2018 value, despite improvements in recovery rates.
- Combustion with energy recovery remains stable in both historical and forecasted periods, maintaining a consistent share of the MSW stream.
- Overall results show that efficiency gains in waste management are outweighed by long-term increases in total waste generation, leading to rising landfill demand over time.





PCA–MSW Response Surface:

- PC1 and PC2 summarize the dominant variation in the predictor dataset, allowing complex inputs to be visualized in two dimensions.
- Total MSW generation increases consistently along the direction of the fitted response plane, indicating strong linear relationships with the principal components.
- Data points closely aligned with the plane show observations well-explained by the PC-based regression model.
- Points above or below the plane indicate deviations from linearity, suggesting additional factors or nonlinear effects not captured by PC1 and PC2 alone.
- The combined PCA–regression approach highlights how underlying predictor patterns translate into long-term trends in MSW generation.

CONCLUSIONS

- Landfilling fell from 93.6% (82.5M tons) in 1960 to ~50% (146M tons) in 2018.
- Recovery methods rose from 6.4% to 38.2%, and combustion stabilized near 11.8%.
- Total MSW tripled to 292M tons as population grew from 180M to 335M; per-capita waste increased 69% to 1.85 tons/person/year.
- Forecasts show total MSW reaching ~2.06B tons by 2200, even with recovery capped at 70% and combustion near 13%.
- Landfilled waste is projected to rise to ~353M tons by 2200, 2.4× the 2018 value.
- Per-capita MSW remains 2.0–2.5 tons/year, and per-capita landfilling stays above 0.3 tons/year.
- Overall, total waste growth outpaces gains in recycling, composting, and energy recovery, driving long-term increases in landfill demand.

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