MIT Climate & Sustainability Consortium

Short-term and Long-term Efficiency Gains in Reverse Supply Chains

Project Overview

How can we make recycling municipal solid waste less costly for public authorities and profitable for materials recovery facility operators?

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Municipal solid waste (MSW) – which includes everyday items that are thrown away, such as food scraps, clothing, and packaging – recycling in the United States faces systemic inefficiencies. The U.S. only recycles 32% of 292 million annual tons recycled nationally, which is far below the 50% federal target for 2030. While states like California achieve 40-50% recycling rates through policy measures, the lack of a unified federal strategy leaves material recovery facility (MRF) operators struggling with high contamination costs, market volatility, and inadequate infrastructure funding.

To address this challenge, this project, led by MIT Professor Yossi Sheffi (Civil and Environmental Engineering), Principal Research Scientist Matthias Winkenbach (Center for Transportation & Logistics), Research Scientist Milena Janjevic (Center for Transportation & Logistic), and Doctoral Researcher Austin Saragih (Center for Transportation & Logistic), advances a dual solution that includes:

Waste sorting plant.

- **Scalable policy frameworks**, including deposit-refund systems and minimum recycled content mandates. The application of this framework at the federal level would enable meeting the federal target recycling rates.
- **A novel integrated optimization framework,** integrating reverse logistics network design – which is the process of moving products from customers back to retailers or manufacturers – with recycling policy decisions. The application of this approach to Massachusetts shows the potential to increase the recycling rates, while reducing public costs and increasing MRF profits.

This work integrates policy innovation and data-driven logistics to provide actionable pathways for federal adoption, advancing circular economy goals in U.S. waste management.

The project aligns closely with the MCSC's Transportation and Circularity pathways.

Findings & Outcomes

This group analyzed the current municipal solid waste recycling system in the U.S., provided policy options to improve recycling, and developed a new data-driven methodology to enable integrated optimization of policy measures and reverse logistics network.

The team developed an integrated approach to address inefficiencies in municipal solid waste (MSW) recycling by combining policy design, reverse logistics network optimization, and operational planning. Their work bridges gaps in previous research, which often treated these elements independently.

Phase 1: Policy Review

The team conducted a thorough analysis of U.S. recycling policies to identify key levers for increasing recycling rates and estimate the required funding and potential impacts.

Key findings include:

- California's policies, such as mandatory recycling laws (AB 939), container deposit systems (AB 2020), extended producer responsibility (SB 54), and minimum recycled content requirements (AB 793), have enabled the state to achieve a recycling rate of 40-50%, significantly higher than the national average of 32%.
- Federal adoption of similar policies could help bridge the gap toward the national goal of a 50% recycling rate by 2030.
- The lack of a comprehensive federal recycling law and inadequate funding for infrastructure remain critical barriers to scaling these successes nationwide.

Journal Publication: *MIT Science Policy Review*

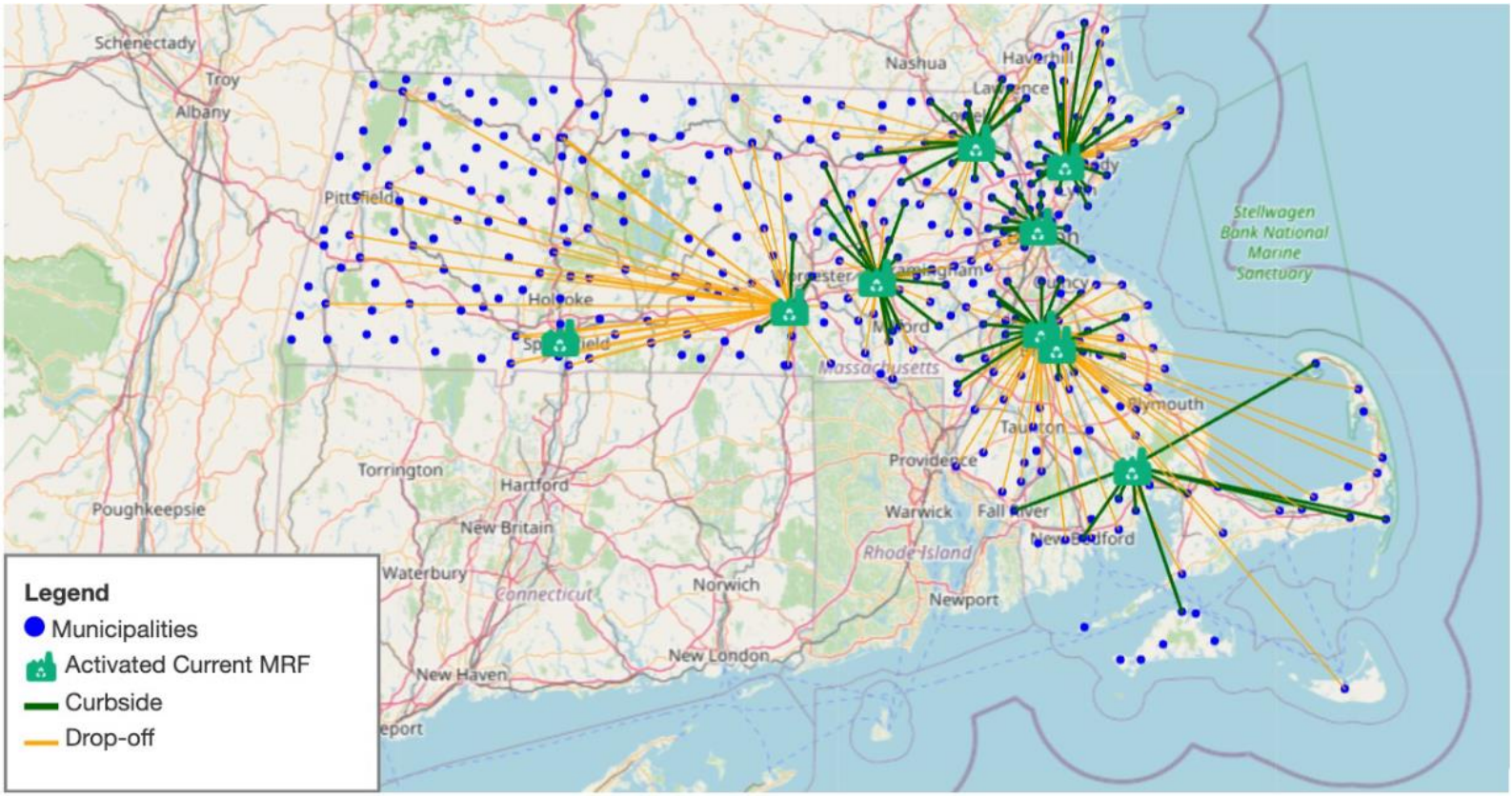
The team's findings were published in *MIT Science Policy Review* in the paper titled "Revitalizing Municipal Solid Waste Recycling: Review of Current U.S. Policies and Potential Directions for the Circular Economy." The paper, co-authored by Austin Iglesias Saragih, Milena Janjevic, and Matthias Winkenbach, outlines policy options for federal adoption, including mandatory recycling laws, deposit-refund systems, and producer responsibility frameworks. It highlights the economic and environmental benefits of aligning federal policies with successful state-level models.

Phase 2: Integrated Optimization of Policy Measures and Reverse Logistics Network Design

The team developed a data-driven optimization framework that integrates policy measures, reverse logistics network design, and tactical and operational planning to improve the MSW system. This method optimizes recycling policies and logistics operations simultaneously, accounting for municipal characteristics and recycling rates to ensure a more efficient and coordinated process. Key outcomes from applying this methodology to Massachusetts include:

- A predicted increase in the overall recycling rate from 13.7% to 18.0%
- A reduction in public sector costs of $17.8M through optimized collection routing and infrastructure investments.

- An increase of $13.3M in MRF profitability.



Reoptimized Recycling Network for Massachusetts

Preprint: *Regress, Reverse, Recycle: Contextual Stochastic Optimization in Waste Logistics Network Design*

The paper introduces a data-driven framework using Post Double Selection with Rigorous Lasso (PDS RLasso) for policy estimation and Empirical Residuals-based Sample Average Approximation (ER-SAA) for network optimization. It demonstrates how targeted policy adjustments can enhance both environmental outcomes and economic viability.

This project demonstrates that harmonizing policy innovation with operational intelligence can transform MSW recycling systems into profitable, scalable models that advance circular economy goals while reducing environmental impacts.

Opportunities for Implementation

Research

- Policy and Network Integration: Further studies are needed to explore how federal recycling policies, such as extended producer responsibility and minimum recyclable content mandates, interact with reverse logistics network design to create solutions for diverse municipalities.

- Behavioral Studies: Future research should investigate how demographic and socioeconomic factors influence recycling behaviors under different policy scenarios, enabling tailored strategies to maximize participation and reduce contamination rates.

Implementation

- Stakeholder Engagement: The study provides a data-driven framework that can be used to enable collaboration with public authorities, MRF operators, and policymakers to co-develop strategies for scaling optimized recycling networks. This could involve aligning incentives for shared infrastructure investments and operational risks between public and private stakeholders.
- Federal Policy Advocacy: The study advocates for a Federal Recycling Act, which could include scaling successful state-level policies like California's mandatory recycling laws, deposit-refund systems, and producer responsibility frameworks to harmonize efforts nationwide.