

APPLMATH 2026 · INTERNATIONAL WORKSHOP · MESSINA, 10–12 JUNE 2026

Smarter Waste, Better Living

An AI-informed decision-making framework for Messina's sustainable future

Carlotta D'Alessandro¹, Antonio Licastro¹, Andrea Morana¹, Katarzyna Szopik-Depczyńska², Giuseppe Ioppolo¹

¹Department of Economics, University of Messina, Italy

*²Department of Corporate Management, Institute of Management,
University of Szczecin, Poland*

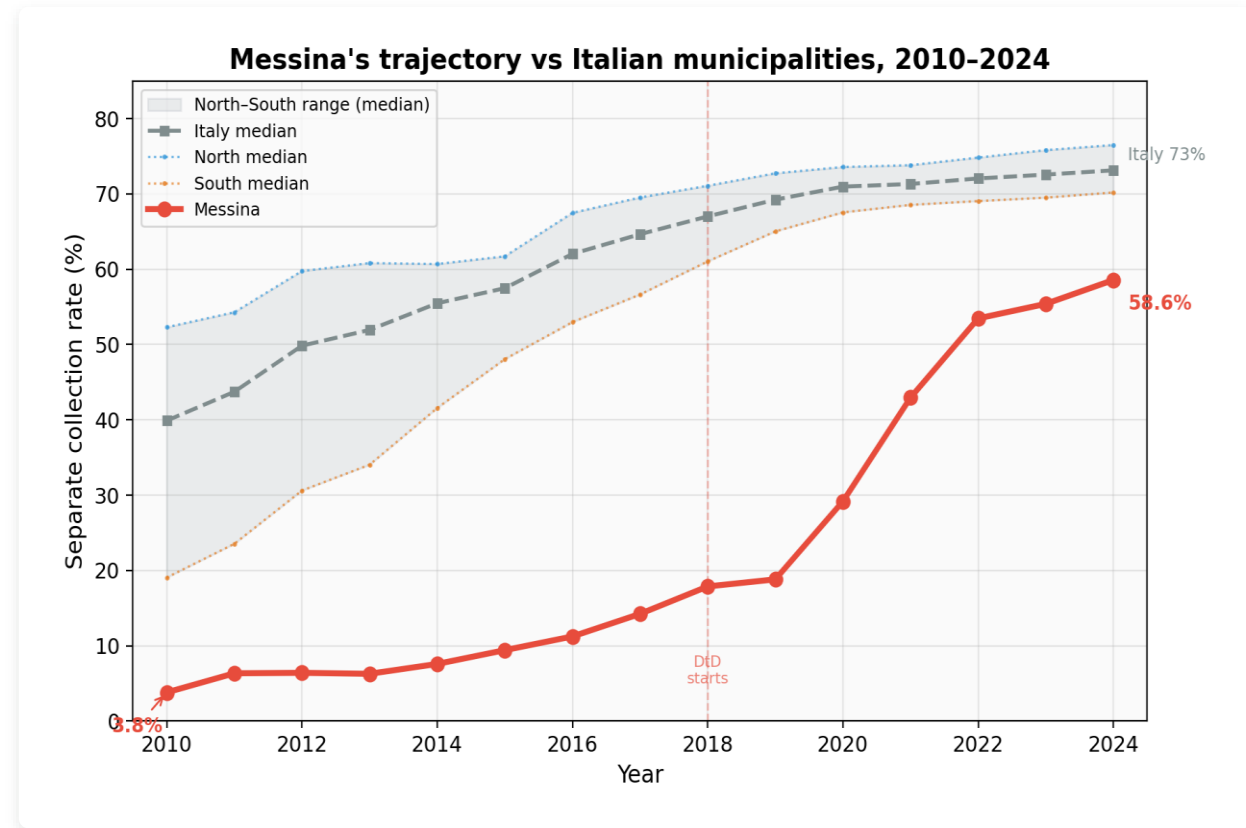
THE STARTING POINT

A remarkable rise

In fourteen years Messina's recycling rate rose from 3.8% to 58.6%, after citywide door-to-door collection began in 2018. The city now ranks **first in Southern Italy** and sixth nationally among cities above 200,000 (ISPRA 2024).



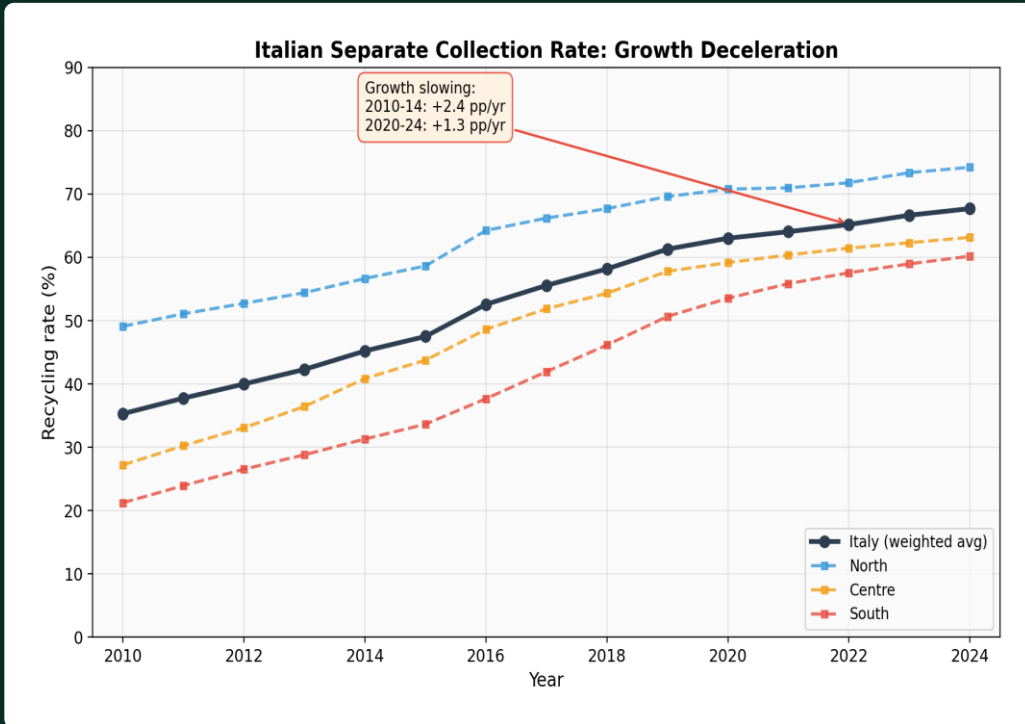
Door-to-door collection began in 2018.



Messina (red) vs Italian median and North-South range, 2010-2024. Source: ISPRA.

■ BUT WILL IT LAST?

Growth is decelerating, in Italy and worldwide



Italian separate collection rate (weighted average), 2010–2024.
Source: authors' analysis of ISPRA Catasto Nazionale Rifiuti, 114,871 municipal observations.

A WORLDWIDE PATTERN

Year-over-year gains have halved since 2016. Germany (~67%), Wales (~65%), Taiwan (~59%), USA (~32%) - all hit ceilings.

Sources: Germany: Umweltbundesamt, recycling indicator, 67.2% in 2023. Wales: Williams & Phillips (2022) Recycling 7(4):46, 65.4% in 2020/21. Taiwan: EPA/MOENV, general waste recycling 58.8% in 2020. USA: Oh & Kim (2025) Sustainability 17(24):11335, 32.1% since 2018 (US EPA).

PAYT tariff works - but then it plateaus

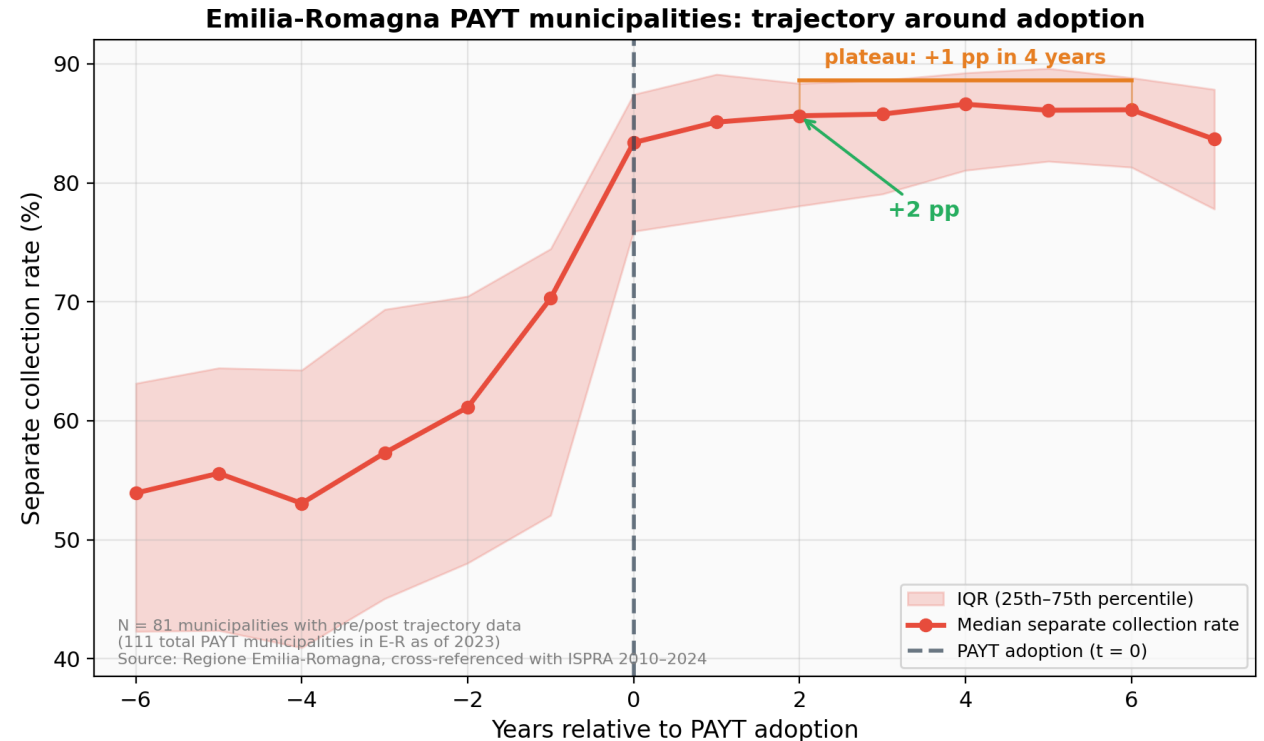
Emilia-Romagna tracks all 111 municipalities that adopted PAYT, with exact activation dates. We cross-referenced those with pre/post data against ISPRA production records (2010–2024) to build before/after trajectories aligned to the year of adoption.

-22%
National per-capita cost
€166.6 vs €214 national avg

+2 pp
then plateau
111 Emilia-Romagna PAYT towns

81.2%
average recycling
In PAYT towns vs 66.8% national

PAYT's primary effect is economic: households that sort more pay less. The Emilia-Romagna panel (111 PAYT municipalities as of 2023) shows a +2 pp increment at adoption, but then a plateau. PAYT is effective, but not sufficient.



Coordination vs. automation

Two ways AI can enter waste management. One has the potential to improve citizens/municipalities cooperation.



AI-COORDINATION

Sensors, real-time feedback, tracked drop-points.

- **Makes behaviour observable** → activates social norms
- Reduces net cost of cooperation below the social-pressure threshold



AI-AUTOMATION

Optical sorting, automated material recovery.

- Cuts household sorting effort
- Behaviour stays invisible
- Crowds out perceived responsibility (*moral hazard*)

■ OBSERVABILITY: THE KEY CONCEPT

Why identical incentives produce different results

The core issue is observability: whether the cost of waste and the benefit of recycling are visible to the citizen at the moment of the decision. A flat tariff hides the cost; PAYT makes it visible; AI-coordination makes behaviour observable to the community.



LOW VISIBILITY

$\sigma \approx 0.3$

Chetty et al. (2009): when a tax is hidden at checkout, the behavioural response is ~30% of the visible case.



HIGH VISIBILITY

$\sigma \approx 0.8$

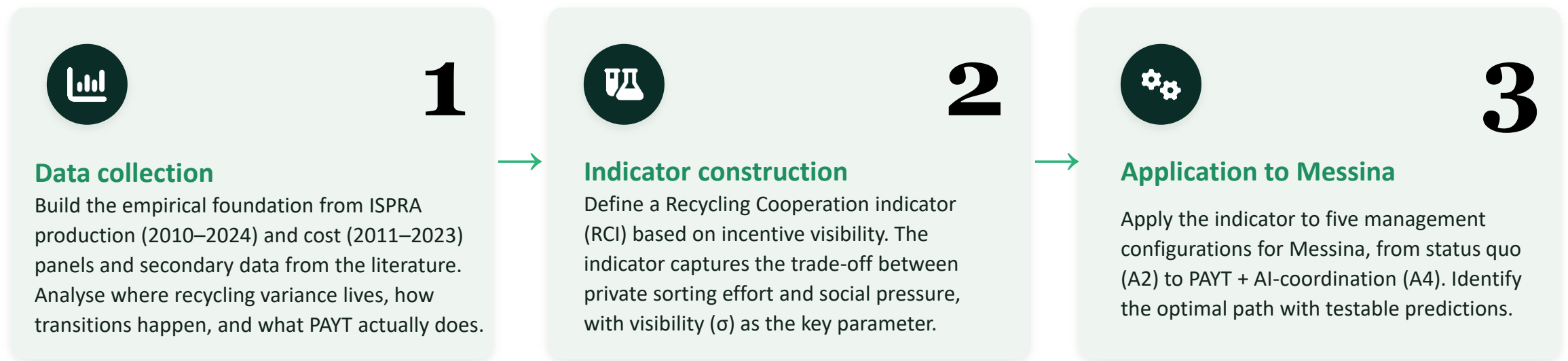
Tiefenbeck et al. (2019): real-time feedback on resource use recovers most of the response (-22% consumption).

The Research Question

Given the observed deceleration in recycling growth, what combination of tariff design (PAYT) and technology (AI-coordination vs automation) can sustain Messina's trajectory — and push beyond the possible ceiling that comparable cities seem to have hit?

Three phases

From data collection, through indicator construction, to scenario analysis applied to Messina.



Data 114,871 production obs (2010–2024) · 57,888 cost obs (2011–2023) · 1,488 PAYT municipalities (ISPRA census) · 111 Emilia-Romagna communes with adoption dates.

A cost–benefit threshold for cooperation



NUMERATOR

net private sorting effort

Private sorting effort (c_u)
minus perceived environmental
benefit (b)
minus visibility \times PAYT saving ($\sigma \times i$)



DENOMINATOR

external pressure

Social norm pressure (s)
plus deterrence / expected fine (d)
Both rise when behaviour is
observable

THE RECYCLING COOPERATION INDICATOR

$$\text{RCI} = (c_u - b - \sigma i) / (s + d)$$

*When $\text{RCI} < 1$, social pressure exceeds the net sorting effort:
cooperation can sustain itself.*

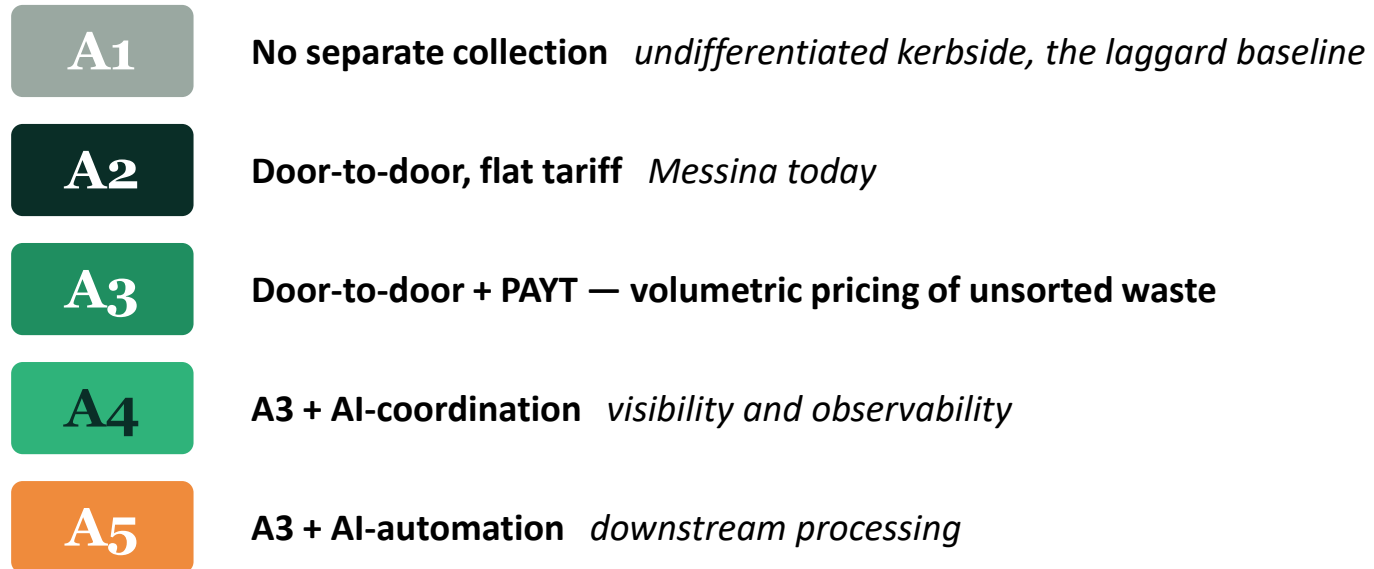
$\text{RCI} > 1 \rightarrow$ cooperation trap (pressure insufficient)

$\text{RCI} < 1 \rightarrow$ self-sustaining cooperation

σ is the key lever: raising visibility shrinks the numerator and, by making behaviour observable, grows the denominator.

Five management configurations

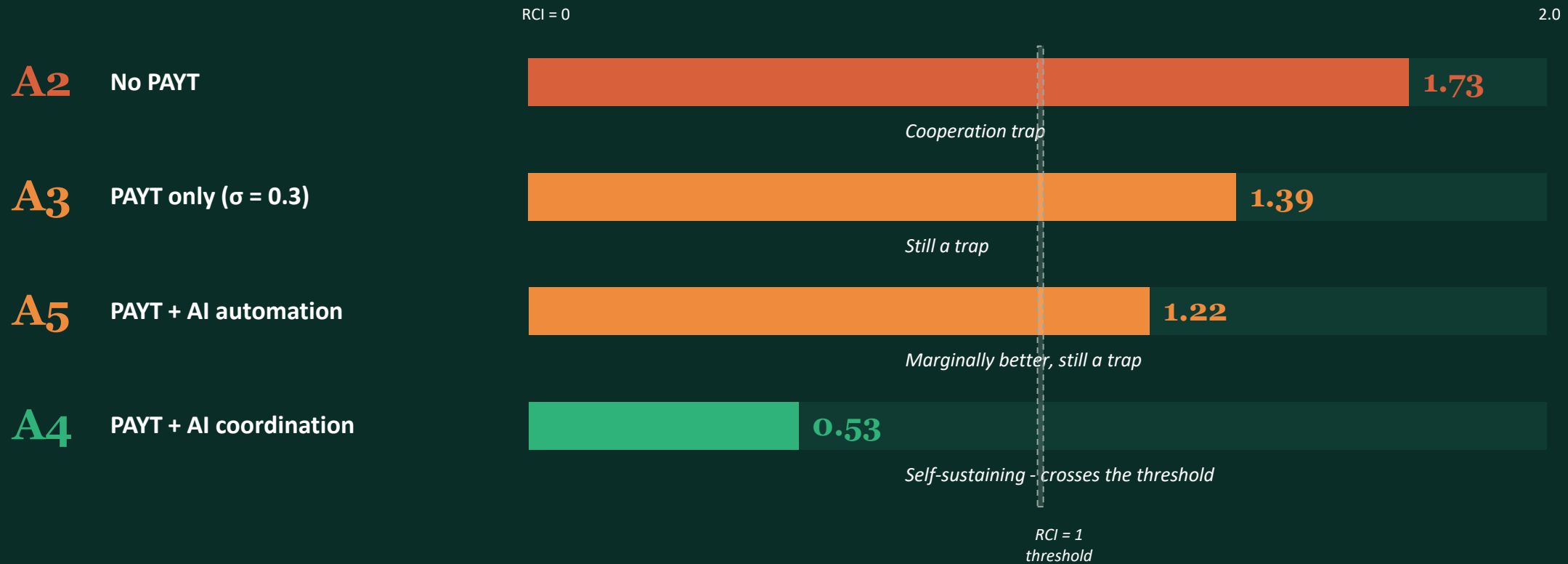
Each adds one institutional or technological layer. We evaluate all five with the recycling cooperation index.



■ APPLICATION TO MESSINA

Applying the indicator to Messina's five scenarios

Recycling Cooperation indicator (RCI) for each configuration, calibrated on Messina's costs (ISPRA 2024) and literature parameters. The RCI = 1 line separates traps (right) from sustainable outcomes (left).



A5 improves on A3 but does not cross RCI = 1: automation helps marginally, coordination transforms the outcome. Note: parameter values are illustrative, calibrated from the literature (Chetty 2009, Tiefenbeck 2019, Ferreira & Marques 2015). Future studies are needed to estimate precise values for Messina, but the qualitative ordering of configurations is robust. a. The qualitative ordering is robust; exact values carry uncertainty.

■ WHAT MESSINA SHOULD DO

A staged path: $A2 \rightarrow A3 \rightarrow A4$

Messina runs A2 today (door-to-door, flat tariff, RCI = 1.73). The indicator identifies A3 as the necessary step and A4 as the configuration that sustains cooperation (RCI = 0.53).



PAYT is used by ~14% of Italian municipalities. In the Messina province, 15 small comuni are piloting PAYT under a PNRR-funded project (SRR Messina Provincia, 2024). The city of Messina has not yet adopted PAYT.

■ LIMITATIONS

An indicator prediction, not yet validated

The link from AI-coordination to sustained cooperation is an indicator-based prediction calibrated from the literature. Direct empirical validation in the waste sector is outstanding.

Parameters from the literature, not measured locally

The private sorting effort c_u and other parameters are derived from the empirical literature, not measured in Messina. The indicator is also static: it identifies sustainable configurations but does not predict transition dynamics.

AI paradigms treated as mutually exclusive

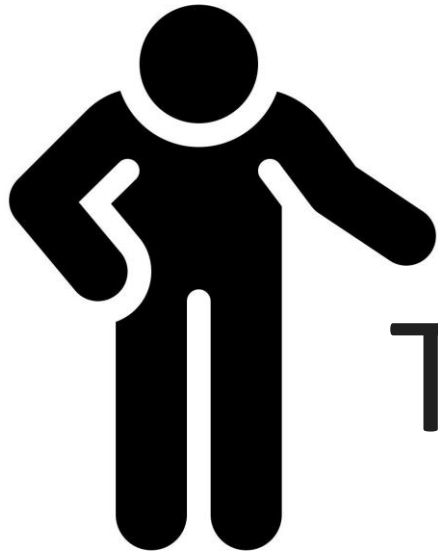
The model evaluates AI-coordination and AI-automation as separate configurations (A4 vs A5), not as complementary layers. In practice, a municipality could deploy both. Future work should explore hybrid configurations and their interaction effects on observability.

No causal estimate from national data

ISPRA's main panel does not record collection method or PAYT adoption, so causal identification from the national data is not possible.

No municipal budget constraint

The indicator models the citizen's decision but does not account for municipal budget constraints. Future work should identify the technology cost threshold beyond which improving the recycling rate is no longer economically sustainable for the municipality.



Thank you



carlotta.dalessandro@unime.it