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Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
Università degli Studi di Messina

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H-SMA-CE: a decision support system for circular economy transition

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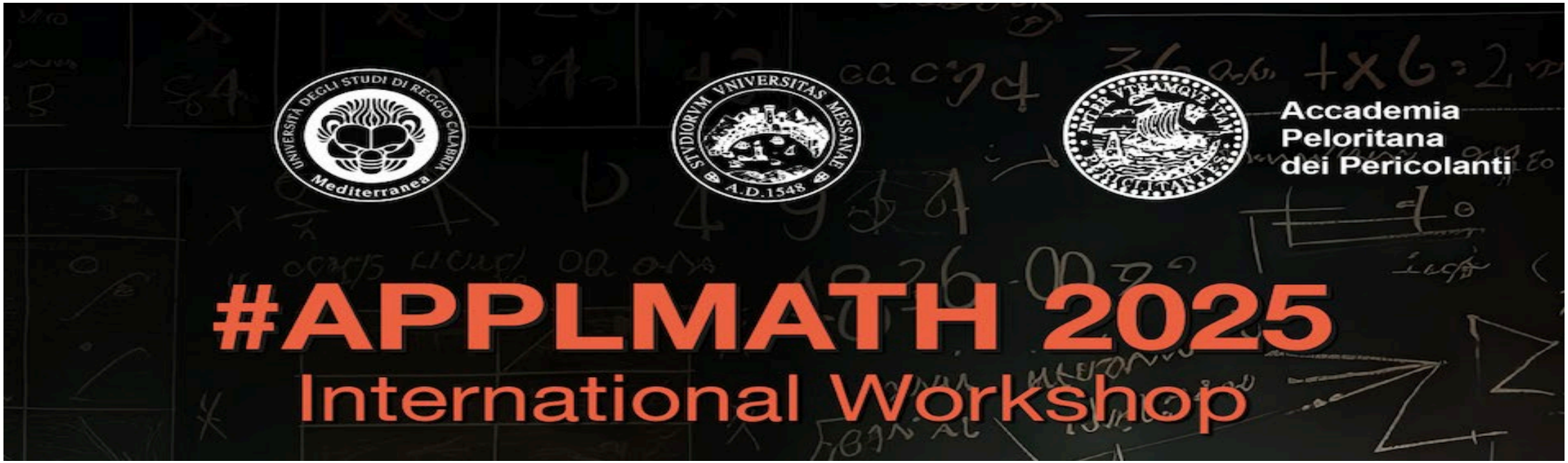

A Multi-Criteria Decision-Making Analysis of Waste Management Practices in Historical Small Towns: The Taurasi Case Study

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THE CHALLENGE

Historical Small Towns (HSTs) Face Unique Waste Management Challenges

- **54% of Italian territory**, 16% of population
- Narrow medieval streets limit vehicle access

- Heritage preservation requirements restrict infrastructure
- Limited financial resources and administrative capacity

- Demographic decline and aging population
- **Need:** Balanced approach between sustainability and heritage preservation

CASE STUDY: TAURASI

- **Location:** Campania region, Southern Italy (398m elevation)
- **Population:** 2,092 inhabitants (declining -1.36% annually)
- **Economy:** Wine production (Taurasi DOCG)
- **Waste generation:** 742.82 tons/year
- **Differentiation rate:** 67.77%
- **Key fraction:** Organic waste = 259.62 tons (51.6% of differentiated)

Taurasi

RESEARCH OBJECTIVES

Developing a Decision Support Framework

Primary goal: Optimize waste management for HSTs

Research questions:

- ✓ What criteria capture HST-specific waste management needs?
- ✓ How do different alternatives perform in Taurasi's context?
- ✓ What implementation pathways balance all objectives?

Approach: Multi-Criteria Decision Making (MCDM)

METHODOLOGY OVERVIEW

Two-Stage MCDM Approach

Stage 1: AHP (Analytic Hierarchy Process)

- Determine criteria weights through stakeholder input
- Pairwise comparisons using Saaty's 1-9 scale
- Consistency checks (CR < 0.1)

Stage 2: TOPSIS

- Evaluate alternatives against weighted criteria
- Identify ideal positive and negative solutions
- Rank alternatives by proximity to ideal

MATHEMATICAL FRAMEWORK AND ALTERNATIVES EVALUATED

Priority Vector Calculation

- $w_i = \Sigma(m_{ij})/n$

Where m_{ij} = normalized comparison matrix elements

Consistency validation

Consistency Index: $CI = (\lambda_{max} - n)/(n - 1)$

Consistency Ratio: $CR = CI/RI < 0.10$

$CR < 0.10$

λ_{max} = principal eigenvalue

Four Waste Management Approaches

S1: Enhanced Organic Management

- Community-scale composting
- Targets 259.62 tons organic fraction

S2: Viticultural Waste Valorization

- Focus on wine production residues
- Aligns with local economy

S3: Collection System Adaptation

- Small vehicles for narrow streets
- Minimal infrastructure changes

S4: Inter-municipal Collaboration

- Share resources across towns
- Achieve economies of scale

CRITERIA HIERARCHY

Four Main Dimensions with Sub-criteria

Environmental (32%)

- Resource recovery potential
- Emissions reduction
- Environmental impact

Economic (30%)

- Implementation costs
- Operational costs
- Revenue potential

Heritage Compatibility (23%)

- Visual impact on landscape
- Compatibility with town character
- Cultural integration

Social (15%)

- Community acceptance
- Convenience for residents
- Educational value

Criteria Weights from AHP Analysis

Table 1. *AHP-Derived Criteria Weights for Waste Management Evaluation in Taurasi*

Main Criteria	Weight	Sub-criteria	Local Weight	Global Weight
Environmental	0.32	Resource recovery potential	0.45	0.144
		Emissions reduction	0.30	0.096
		Environmental impact	0.25	0.080
Economic	0.30	Implementation costs	0.40	0.120
		Operational costs	0.38	0.114
		Revenue potential	0.22	0.066
Heritage Compatibility	0.23	Visual impact on historical landscape	0.46	0.106
		Compatibility with town character	0.34	0.078
		Cultural integration	0.20	0.046
Social	0.15	Community acceptance	0.42	0.063
		Convenience for residents	0.38	0.057
		Educational value	0.20	0.030

PERFORMANCE MATRIX

Key Performance Scores (0-1 scale)

Table 2. *Normalized Performance Matrix of Waste Management Alternatives*

Criteria	Enhanced Organic Management	Viticultural Waste Valorization	Collection System Adaptation	Inter-municipal Collaboration
Resource recovery potential	0.842	0.758	0.412	0.683
Emissions reduction	0.736	0.627	0.493	0.574
Environmental impact	0.779	0.694	0.625	0.592
Implementation costs	0.487	0.452	0.823	0.438
Operational costs	0.603	0.554	0.831	0.471
Revenue potential	0.721	0.847	0.318	0.682
Visual impact	0.461	0.524	0.856	0.598
Compatibility with town	0.512	0.659	0.786	0.598
Cultural integration	0.642	0.827	0.529	0.602
Community acceptance	0.695	0.752	0.641	0.524
Convenience for residents	0.581	0.549	0.807	0.529
Educational value	0.771	0.854	0.492	0.613

Note: Higher scores indicate better performance. For cost criteria, higher scores indicate lower costs.

TOPSIS RESULTS

Table 3. *TOPSIS Analysis Results and Final Rankings*

Alternative	Distance to Positive Ideal	Distance to Negative Ideal	Proximity Coefficient	Rank
Enhanced Organic Management	0.142	0.327	0.697	1
Viticultural Waste Valorization	0.168	0.303	0.643	2
Collection System Adaptation	0.281	0.205	0.422	4
Inter-municipal Collaboration	0.233	0.236	0.503	3

SENSITIVITY ANALYSIS

Table 4. *Sensitivity Analysis Results for Different Weighting Scenarios*

Scenario	Environmental	Economic	Heritage	Social	Ranking
Base Case	0.32	0.30	0.23	0.15	EOM > VWV > IMC > CSA
Environmental Focus	0.50	0.20	0.15	0.15	EOM > VWV > IMC > CSA
Economic Focus	0.20	0.50	0.15	0.15	CSA > EOM > VWV > IMC
Heritage Focus	0.20	0.15	0.50	0.15	CSA > VWV > IMC > EOM
Social Focus	0.20	0.20	0.15	0.45	VWV > EOM > CSA > IMC

Note: EOM = Enhanced Organic Management; VWV = Viticultural Waste Valorization; CSA = Collection System Adaptation; IMC = Inter-municipal Collaboration

Key insight: No single "best" solution across all scenarios

INTEGRATION POTENTIAL ANALYSIS

Combining Approaches for Synergy

1. Organic + Viticultural:
- Addresses all organic streams
- Shared infrastructure possible
- Cost: €125,000-175,000

2. Organic + Collection Adaptation:
- Improves efficiency
- Reduces visual impact
- Maintains heritage character

Recommendation: Phased implementation starting with collection adaptation

Table 5. *Integration Potential Analysis of Waste Management Approaches*

Integration Combination	Primary Waste Streams Addressed	Implementation Synergies	Potential Barriers
EOM + VWV	Household organic waste (259.62 tons); Viticultural residues	Shared processing infrastructure; Complementary feedstock characteristics	Implementation cost accumulation (€125,000-€175,000); Governance complexity
EOM + CSA	Household organic waste; General municipal waste	Enhanced collection efficiency for organic fraction; Reduced visual impact	Limited revenue generation potential; Incomplete viticultural waste coverage
VWV + CSA	Viticultural residues; General municipal waste	Cultural heritage reinforcement; Lower combined implementation costs	Fragmented implementation responsibility; Limited household organic fraction management
EOM + IMC	Household organic waste; Regional organic streams	Enhanced economies of scale; Implementation cost distribution	Reduced local control; Increased stakeholder coordination requirements
Comprehensive Integration	All municipal and agricultural waste streams	Complete waste stream coverage; Maximized resource recovery	High initial complexity; Substantial governance coordination requirements

CRITICAL TENSIONS REVEALED

Trade-offs Between Objectives

Finding: Need integrated approaches, not single solutions

Environmental vs. Heritage:

•Best resource recovery = highest visual impact

•Minimal heritage impact = lowest recovery

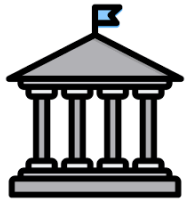
Economic vs. Environmental:

• Cheapest options limit circular economy potential

• Environmental optimization requires investment

PRACTICAL IMPLICATIONS

Guidance for Stakeholders



❖ For Municipalities:

- Start with low-impact adjustments
- Build toward integrated system
- Engage wine producers early

❖ For Waste Companies:

- Invest in smaller, heritage-friendly vehicles
- Design aesthetically integrated infrastructure

❖ For Heritage Authorities:

- Circular economy can enhance cultural identity
- Support approaches aligned with local traditions

KEY CONTRIBUTIONS

➢ **Methodological:**

1. MCDM framework adapted for HST contexts
2. Integration of heritage criteria in waste decisions

➢ **For Waste Companies:**

1. No one-size-fits-all solution for HSTs
2. Integration better than single approaches
3. Local identity strengthens sustainability

➢ **For Heritage Authorities:**

1. Compare across multiple HSTs
2. Longitudinal implementation studies

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