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From Data Scarcity to Strategic Action: A Managerial Framework for Circular Economy Implementation in Mediterranean Small Towns

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Abstract

Data scarcity hampers the implementation of circular economy (CE) in rural historical small towns (HSTs) where traditional agricultural practices persist outside formal monitoring systems. In this regard, this study proposes and tests an estimation framework to quantify agricultural waste flows and energy recovery potential. The methodology combines waste generation coefficients from peer-reviewed literature with administrative data to generate actionable CE assessments. Application to four Sicilian HSTs within the Local Action Group (LAG) "Terre dell'Etna e dell'Alcantara" exhibits substantial waste generation potential despite their small size. The agricultural enterprises generate an estimated 6930–7130 tons of annual agricultural waste under moderate production scenarios, comprising grape pomace (3250 tons), pruning residues (3030 tons), and mixed processing wastes (650–850 tons). The energy recovery potential ranges from 20–30 TJ through direct combustion to 4.9–8.1 TJ via anaerobic digestion. Sensitivity analysis indicates balanced contributions from all three key parameters (enterprise density, yields, and waste coefficients), each accounting for 31–35% of output variance. The framework provides resource-constrained municipalities with a cost-effective tool for preliminary CE assessment, enabling identification of priority interventions without expensive primary data collection. From a managerial perspective, local administrators can leverage this tool to transform routine administrative data into actionable CE strategies.

Keywords: circular economy; historical small towns; agricultural waste valorization; data-scarce territories; literature-based data; local action group; management



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1. Introduction

The circular economy (CE) paradigm can transform waste management through closed-loop systems that minimize waste while maximizing value retention [1–3]. However, implementing CE principles requires careful consideration of territorial specificities and local contexts, as standardized approaches often fail to address unique regional characteristics [4–8].

Mediterranean agricultural systems have evolved through millennia of human–environment interaction, developing resource-efficient practices adapted to seasonal water

scarcity and specific soil conditions [9–11]. The agricultural sectors present in these territories (viticulture, citrus cultivation, and olive oil production) generate high level of organic residues with valorization potential [12–14]. Yet, paradoxically, the very characteristics that make these systems culturally valuable often impede systematic data collection and monitoring. Small-scale production units, informal processing networks, and traditional waste management practices operate largely outside formal accounting systems [15].

Within these systems, historical small towns (HSTs) represent a particularly challenging context. As a distinctive category of Mediterranean settlements, HSTs are characterized by their medieval origins, preserved architectural heritage, and populations typically under 5000 inhabitants. In Italy, where they are known as “Borghi”, these settlements constitute approximately 70% of the country’s 8000 municipalities [16], forming essential components of the national cultural landscape. These towns, typically developed around castles or noble palaces, maintain their historic town layouts and continue to preserve centuries-old cultural traditions [17]. Despite their small size, HSTs represent significant territorial coverage and face particular challenges in implementing CE principles due to limited institutional capacity and data availability [18].

Indeed, small municipalities lack the financial and technical resources for comprehensive waste characterization studies, leaving significant agricultural and municipal waste unquantified and operating outside official statistics [8,15]. This data gap impedes evidence-based CE planning, as existing indicators require detailed quantitative inputs unavailable in rural contexts, while regional statistics aggregate data at scales too coarse for local decision-making [5,6,19,20]. Beyond data limitations, HSTs face additional implementation barriers: seasonal patterns in resource generation and consumption create temporal mismatches between waste availability and valorization opportunities, while market failures such as the absence of local markets for secondary raw materials limit circular practices [21]. Furthermore, significant demographic challenges affect the potential of CE implementation, with differences in implementation opportunities linked to varying demographics, economic conditions, and local contexts [8]. Geographic isolation and inadequate infrastructure further constrain the economic viability of circular practices, particularly affecting waste collection efficiency in rural environments [15].

To examine these challenges empirically, this study focuses on the territories surrounding Mount Etna in Sicily. The Local Action Group (LAG) “Terre dell’Etna e dell’Alcantara” encompasses 26 municipalities across 965.52 km², with a population of 175,278 inhabitants spanning from the volcanic slopes to the Alcantara valley. This territory exhibits a considerable concentration of agricultural activities, as between 107 (Milo) and 932 (Zafferana Etnea) are registered agricultural enterprises per municipality in the Catania province section alone. Indeed, such enterprise densities in the smallest municipalities far exceed typical rural areas (2–3%), indicating concentrated agricultural activity suitable for collective waste management solutions. For instance, Piedimonte Etneo’s 352 agricultural enterprises in a town of just 3905 inhabitants, when multiplied by typical farm sizes, suggests approximately 700–1000 hectares under cultivation (a remarkable cultivation area per capita for such a small population).

Despite data constraints, emerging valorization research demonstrates the potential value of these waste streams [13,22]. Such valorization pathways can include creating biomaterials, functional ingredients, or energy from agricultural by-products [12]. The wine sector has received attention regarding waste valorization potential, with studies documenting biogas yields, energy content, and biorefinery applications [14,22–24]. Similarly, citrus and olive processing residues show promising characteristics for energy recovery and high-value compound extraction [13,25,26]. However, these studies assume access to primary production data that remains unavailable in many small municipalities. Never-

theless, missing or scattered waste production data [27] impedes both innovation scaling across LAG municipalities and valorization opportunity identification.

While primary data collection remains unfeasible, existing literature provides reliable waste generation coefficients from similar Mediterranean agricultural systems. Indeed, by combining these validated coefficients with readily available administrative data (enterprise registries, territorial profiles), municipalities can generate actionable estimates without expensive field studies. Therefore, the primary research question guiding this investigation asks: How can resource-constrained municipalities systematically estimate agricultural waste flows and energy recovery potential using only routine administrative data and literature-based coefficients?

This overarching question encompasses certain specific dimensions requiring investigation. First, how can waste generation coefficients from existing studies be appropriately transferred to contexts with similar agricultural systems but different scales and management practices? Second, what uncertainty ranges should accompany such estimations, and how can these be communicated to support informed decision-making? Third, which sectoral variations in waste generation patterns emerge across Mediterranean agricultural systems, and how do these influence valorization priorities?

From a managerial perspective, the research shows how local administrators can leverage existing administrative data, such as enterprise registries, population statistics, and territorial characterizations, combined with literature-based coefficients to generate concrete waste estimates. The methodology proposed offers a cost-effective approach to preliminary CE assessment, enabling municipalities to identify priority intervention areas and justify investments in more detailed studies. This contribution directly addresses re-cent calls for accessible assessment tools suitable for varied institutional capacities [6,8,19,20].

Additionally, the theoretical implications extend beyond immediate practical applications, as this research contributes to expanding CE frameworks beyond their urban-industrial origins. Furthermore, the focus on HSTs in volcanic territories highlights how CE implementation must address local volcanic and farming conditions alongside environmental objectives.

Finally, while this study focuses specifically on HSTs, these settlements exist within broader rural territories. In this manuscript, “territory” refers to the larger LAG administrative area encompassing multiple municipalities, while “HSTs” denotes the specific small municipalities selected for detailed analysis. All HSTs are rural settlements, but not all rural areas qualify as HSTs due to the specific criteria of historical heritage and population size.

2. Materials and Methods

This framework functions as a screening tool for preliminary assessment. Just as environmental impact assessments begin with screening before detailed analysis, this methodology enables municipalities to determine whether agricultural waste valorization merits further investigation. Figure 1 illustrates this systematic process.

Waste generation coefficients were extracted from peer-reviewed literature focusing on Mediterranean agricultural systems published between 2013 and 2024. This systematic review encompassed three primary agricultural sectors dominant in the study territory: viticulture, citrus cultivation, and olive oil production. Table 1 synthesizes the selected coefficients, representing consensus values from multiple studies while acknowledging inherent variability in agricultural systems. These coefficients align with recent assessments, confirming citrus processing waste at 50–60% of fruit weight [28] and winery waste at 20–30% of total production [24].

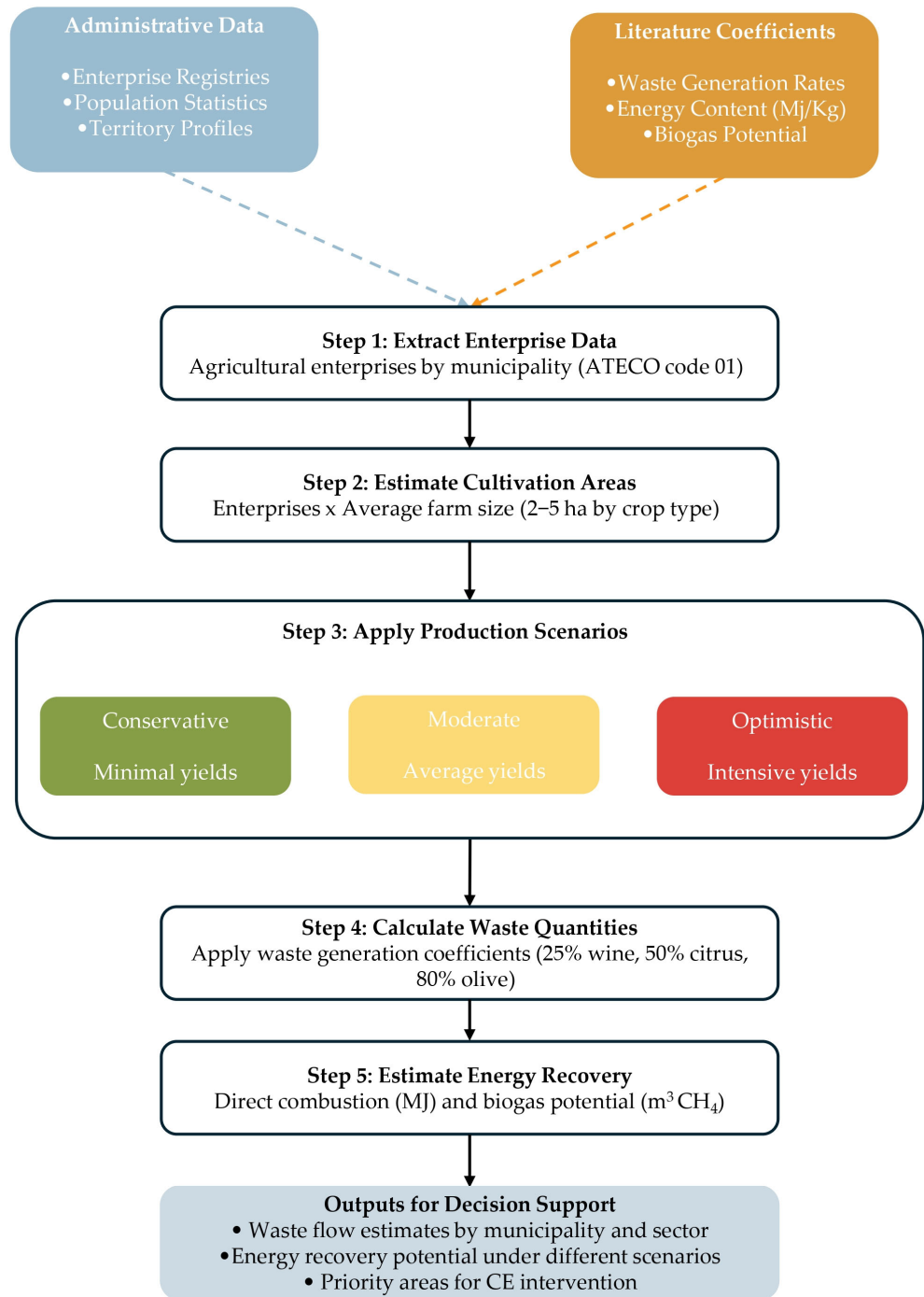


Figure 1. Literature-based CE assessment framework for data-constrained territories. Source: Authors.

The LAG Terre dell’Etna e dell’Alcantara territory can be classified into three typologies shaped by altitudinal gradients: coastal areas (0–300 m) predominantly cultivating citrus; mid-elevation zones (300–800 m) supporting mixed agricultural systems; and upper volcanic slopes (>800 m) specializing in viticulture. The characterization of HSTs within this territory requires consideration of multiple typological dimensions beyond simple altitudinal positioning. Indeed, Italian “Borghi” lack standardized national classification frameworks, with planning practices employing context-specific typologies based on geographic, functional, and economic characteristics instead. The analysis of territorial planning documents and stakeholder consultations additionally led to distinguishing municipalities by their geographic–functional attributes (coastal urban centers versus inland

rural settlements), geographic–morphological positioning (volcanic mountain areas versus river valleys), and economic development trajectories (agricultural production supply chains, nature tourism, and cultural heritage valorization).

Table 1. Agricultural waste generation coefficients and energy recovery potential for Mediterranean production systems. Source: Authors.

Crop Type	Waste Fraction	Generation Rate	Moisture Content	Energy Content (LHV)	Biogas Potential	Key References
Wine	Grape pomace	25% of grape weight	50–65%	9–11 MJ/kg	150–250 L CH ₄ /kg VS	[14,22]
	Pruning residues	2.1 t/ha/year (dry)	44%	18.0 MJ/kg	-	[29]
	Wine lees	1.6–6 kg/hL wine	92–96%	-	300–450 L CH ₄ /kg VS	[30]
Citrus	Processing waste (peels, pulp)	50% of fruit weight	80–90%	3–5 MJ/kg	210–640 L CH ₄ /kg VS *	[31,32]
	Pruning residues	0.65–4.40 t/ha/year (dry) **	35%	15.6 MJ/kg	-	[33]
Olive	Pomace (2-phase)	80–87% of olive weight	60–70%	8–10 MJ/kg	98–188 L CH ₄ /kg VS	[10,26]
	Pruning residues	1.3–3.0 t/ha/year (dry)	40%	15.6–19.8 MJ/kg	-	[11]

* After limonene removal pretreatment; VS = volatile solids. ** From mechanical pruning systems.

From this broader territorial context, four HSTs were selected as detailed case studies based on three criteria: population under 5000 inhabitants, agricultural enterprise density exceeding 8%, and representation of different agricultural typologies. The selected municipalities share characteristics as inland settlements on volcanic slopes with economies anchored in traditional agricultural production and emerging tourism activities, while maintaining distinct profiles across geographic, historical, and economic dimensions (Table 2).

Table 2. Agricultural characterization of HSTs within the territory of the LAG Terre dell’Etna e dell’Alcantara. Source: Authors.

Municipality	Population	Elevation (m)	Geographic Type ^a	Historical–Cultural Type	Agricultural Enterprises (ATECO 01)	Enterprise Density (%) ^b	Dominant Products	Key Characteristics
Castiglione di Sicilia	2889	621	Hill Village	Medieval	360	12.5	Etna DOC wines	Mountain viticulture with wine tourism; Castle of Lauria, Cuba Bizantina (7–8th century); Regional Enoteca; Wine Fest
Piedimonte Etneo	3905	350	Hill Village	Agrarian–Historical	352	9.0	Etna DOC wines, hazelnuts	Agricultural diversification and export orientation; ancient palmenti; Wine train departure point
Sant’Alfio	1510	530	Hill Village	Religious–Cultural	121	8.0	Cherries (DOP), chestnuts, hazelnuts	Traditional polyculture; Cammino dei Tre Santi Martiri pilgrimage route; Cherry Festival; agritourism potential
Milo	1023	720	Hill Village	Specialized Viticultural	107	10.5	Etna DOC Bianco wines	High-altitude viticulture specialization; smallest municipality; ViniMilo festival; high naturalistic value

^a Geographic classification follows ISTAT altimetric standards [34] for central–southern Italy where hill zones are characterized by elevations below 700 m above sea level. ^b Enterprise density calculated as percentage of agricultural enterprises (ATECO code 01) relative to the total population. All municipalities fall within the territory of the LAG “Terre dell’Etna e dell’Alcantara” and were selected based on the following: (i) population under 5000 inhabitants, (ii) agricultural enterprise density exceeding 8%, and (iii) representation of different agricultural typologies.

According to the National Statistics Institute (ISTAT), altimetric classifications for central–southern Italy, settlements between 200 and 700 m fall within the hill village category [34], though this geographic dimension intersects with different historical–cultural identities and economic specialization patterns that shape CE implementation potential.

Consultation of the enterprise registry data reveals concentrated agricultural activity in these HSTs. The four selected municipalities report a combined total of 940 agricultural enterprises, classified under ATECO code 01 (ATECO stands for “Attività Economiche”), representing a remarkable density considering their collective population of just 9327 inhabitants. This concentration ranges from 107 enterprises in Milo (population: 1023) to 360 in Castiglione di Sicilia (population: 2889), far exceeding typical rural densities of 2–3%.

The estimation framework proceeds through five systematic steps. First, administrative data from ATECO enterprise registries, population statistics, and territorial characterizations are extracted for each municipality. Second, cultivation areas are estimated through multiplication of enterprise counts by typical farm sizes: 1.5–2.0 hectares for specialized viticulture, 2.0–3.0 hectares for mixed farming, and 3.0–5.0 hectares for citrus operations. These ranges reflect typical holdings in volcanic territories where terrain constraints limit farm consolidation. Third, three production scenarios capture management intensity variations across the study area (Table 3). While actual farm sizes remain unknown without detailed parcel data, the assumed ranges (1.5–3.0 hectares) reflect typical Mediterranean small-holdings constrained by volcanic terrain and fragmented ownership patterns (personal communication, GAL technical advisor).

Table 3. Production yield scenarios for Mediterranean agricultural systems in volcanic territories. Source: Authors.

Scenario	Management Intensity	Wine Grapes (t/ha)	Citrus (t/ha)	Olives (t/ha)	Rationale
Conservative	Extensive/abandoned terraces	5–8	10–15	2–3	Minimal inputs, aging farmers, depopulation effects
Moderate	Average Mediterranean	10–12	15–20	4–6	Typical management, established literature values
Optimistic	Intensive cultivation	12–15	20–30	6–10	Modern practices, irrigation, technical support

Note: Yield ranges calibrated using Mediterranean literature values [11,13,33], adjusted for volcanic soil constraints typical of Etna agriculture.

The fourth step applies waste generation coefficients from Table 1 to production estimates, calculating ranges for each waste fraction. For instance, Castiglione di Sicilia’s 360 agricultural enterprises, assuming 2 hectares average for Etna DOC (Denominazione di Origine Controllata) specialization, implies approximately 720 hectares under cultivation. Under moderate yield scenarios, this generates 1800 tons of grape pomace annually ($10 \text{ t/ha} \times 720 \text{ ha} \times 0.25$), with biogas potential of 270,000–450,000 $\text{m}^3 \text{ CH}_4$, plus 1512 tons of pruning residues offering additional energy recovery through direct combustion. The final step computes energy recovery potential using lower heating values for direct combustion and biochemical methane potential for anaerobic digestion, incorporating moisture content effects on conversion efficiency.

Recognizing the uncertainty inherent in literature-based approaches, sensitivity and uncertainty analysis examines how variations in key parameters affect outcomes. The uncertainty analysis followed approaches for data-scarce contexts [35], employing interval arithmetic [36] to propagate parameter ranges through the multiplicative model and establish bounds on waste generation estimates. Three key parameters introduce uncertainty: enterprise-to-hectare conversion factors varying $\pm 50\%$ from baseline values based on regional farm size heterogeneity, yield estimates spanning conservative to optimistic scenarios derived from the Mediterranean literature, and waste generation coefficients

encompassing the full range documented in peer-reviewed studies (Table 1). Sensitivity analysis subsequently quantified each parameter's contribution to output variance through systematic one-at-a-time variation, following screening design principles appropriate for models with multiple parameters [37]. Regardless of its computational simplicity, this approach appears suitable for preliminary assessments where the objective is identifying relative parameter importance rather than precise uncertainty quantification [38].

Furthermore, this framework necessarily simplifies complex agricultural realities. Key assumptions include the prevalence of dominant crop types in polyculture systems, the applicability of average coefficients across local variations, active status of all registered enterprises, and technical feasibility of waste collection regardless of terrain constraints. These simplifications remain acceptable for strategic planning purposes, where the objective is identifying CE opportunities requiring detailed feasibility studies rather than providing engineering-level specifications.

3. Results

The application of the estimation framework to the four HSTs implies substantial agricultural waste generation potential despite their small populations. The agricultural enterprises distributed across these municipalities translate into an estimated 1680–2520 hectares under cultivation, depending on assumed farm sizes and crop distributions. This concentration of agricultural activities, representing approximately 18–27% of the combined municipal territories, generates diverse waste streams suitable for CE interventions.

These estimates serve as a pre-feasibility tool, enabling resource-constrained municipalities to (1) identify the scale of opportunity, (2) justify funding for detailed studies, and (3) prioritize which waste streams to investigate further.

Table 4 presents the estimated cultivation areas and resulting waste generation under moderate production scenarios. Castiglione di Sicilia emerges as the largest waste generator, with its 360 viticulture-focused enterprises producing an estimated 1800 tons of grape pomace annually, accompanied by 1512 tons of pruning residues. Piedimonte Etneo's mixed agricultural system, dominated by viticulture (60%) and hazelnut cultivation (40%), generates approximately 1260 tons of grape pomace and 250 tons of hazelnut shells and pruning materials. Sant'Alfio's traditional polyculture, encompassing cherries, chestnuts, and mixed crops, produces more diverse but smaller waste streams, totaling approximately 800 tons annually. Milo, despite being the smallest municipality, concentrates exclusively on high-altitude viticulture, generating 400 tons of grape pomace and 336 tons of pruning residues from its specialized Etna DOC Bianco production.

Table 4. Estimated cultivation areas and waste generation under moderate production scenarios. Source: Authors.

Municipality	Agricultural Enterprises	Estimated Area (ha)	Primary Waste Streams	Annual Waste (tons)
Castiglione di Sicilia	360	720 (viticulture)	Grape pomace	1800
			Pruning residues	1512
Piedimonte Etneo	352	420 (viticulture)	Grape pomace	1050
		280 (mixed/hazelnuts)	Pruning residues	882
Sant'Alfio	121	300–400 (polyculture)	Hazelnut waste	250
			Mixed fruit waste	400–500
Milo	107	160 (viticulture)	Pruning residues	300–400
			Grape pomace	400
			Pruning residues	336

The energy recovery potential from these waste streams varies significantly by valorization pathway and waste characteristics. Biogas generation through anaerobic digestion

offers substantial potential, particularly for high-moisture pomace and processing wastes. Under moderate scenarios, the combined grape pomace from viticulture-focused municipalities could yield 487,500–812,500 m³ of methane annually, representing 4.9–8.1 TJ of energy content. Direct combustion of pruning residues, after accounting for collection efficiencies and moisture content, could provide an additional 15–20 TJ annually across the four municipalities.

Uncertainty analysis highlights variation in waste generation estimates (Table 5). Conservative scenarios, reflecting extensive management practices typical of aging farming populations and abandoned terraces, reduce total waste generation by 40–50% compared to moderate estimates. These scenarios particularly affect mountain municipalities such as Milo and the upper-elevation areas of Castiglione di Sicilia, where terrain constraints and demographic challenges limit intensive cultivation. Conversely, optimistic scenarios, assuming modern management practices and full utilization of registered enterprises, increase waste generation by 25–50%, with the largest increases in mixed agricultural zones where intensification potential remains highest.

Table 5. Uncertainty analysis showing waste generation bounds for conservative, moderate, and optimistic parameter combinations (tons/year). Source: Authors.

Municipality	Conservative	Moderate	Optimistic	Coefficient of Variation
Castiglione di Sicilia	1850–2220	3312	4140–4968	32%
Piedimonte Etneo	1190–1428	2182	2728–3273	31%
Sant’Alfio	440–528	700–900	1050–1260	35%
Milo	441–529	736	920–1104	28%
Total	3921–4705	6930–7130	8838–10,605	31%

Sensitivity analysis, meanwhile, examined how individual parameters influence results by varying each within its uncertainty range while holding others constant (Table 6). The analysis presented balanced contributions across all three parameters. Enterprise-to-hectare conversion factors account for 35.1% of output variance, reflecting uncertainty in estimating farm sizes from enterprise counts alone. Mediterranean small-scale agriculture involves complex arrangements of owned, rented, and informally managed plots ranging from intensive sub-hectare parcels to extensive multi-hectare holdings. A $\pm 50\%$ variation in assumed farm size produces waste estimates from 3515 to 10,545 tons annually. Yield assumptions account for 33.4% of the variance, with management intensity, irrigation availability, and farmer demographics creating productivity differences that translate to waste generation, ranging from 3921 tons (conservative) to 10,605 tons (optimistic). Waste generation coefficients account for 31.5% of variance, reflecting substantial variability in literature values. Wine lees range from 1.6 to 6 kg/hL, citrus pruning residues from 0.65 to 4.40 t/ha/year, and other fractions show similarly wide ranges, resulting in total waste estimates ranging from 4900 to 11,200 tons. Such results indicate that future research should adopt comprehensive data collection strategies rather than prioritizing any single parameter.

Aggregating results across the four municipalities led to a combined annual waste generation potential of 6930–7130 tons under moderate scenarios, comprising approximately 3250 tons of grape pomace, 3030 tons of pruning residues, and 650–850 tons of mixed processing wastes. This waste stream concentration in just four small municipalities with 9327 inhabitants demonstrates the remarkable agricultural intensity of these HSTs. The theoretical energy recovery potential ranges from 20–30 TJ annually through direct combustion to 4.9–8.1 TJ through biogas generation, though actual recovery would depend on collection logistics, processing infrastructure, and economic feasibility.

Table 6. Sensitivity analysis of key parameters affecting waste generation estimates. Source: Authors.

Parameter Tested	Baseline Value	Variation Range	Total Waste Generation Range (tons/year)	Impact (% Change)	Variance Contribution
Enterprise-to-hectare conversion	2.0 ha (viticulture), 3.5 ha (mixed)	±50%	3515–10,545	−50% to +50%	35.1%
Yield scenarios	Moderate (10–12 t/ha grapes)	Conservative to Optimistic	3921–10,605	−44% to +51%	33.4%
Waste generation coefficients	Table 1 values	Literature Min–Max	4900–11,200	−30% to +59%	31.5%

The geographic concentration of waste generation creates both opportunities and challenges for CE implementation. The proximity of Castiglione di Sicilia and Milo along the northern slopes of Etna, combined with their viticulture specialization, suggests potential for shared processing facilities. Similarly, Piedimonte Etneo and Sant’Alfio’s location in the eastern foothills could support joint collection systems for mixed agricultural wastes. However, the mountainous terrain and distributed nature of agricultural holdings pose significant logistical challenges, particularly for pruning residue collection where transportation costs can exceed valorization benefits.

4. Discussion

The 6930–7130 tons of annual agricultural waste identified in just four small municipalities challenges conventional assumptions about minimum viable scales for CE interventions. The quantified waste generation from four municipalities with a small number of inhabitants provides specific data on CE intervention potential at small scales. While urban–industrial applications typically focus on larger population centers, the exceptional agricultural density in these HSTs results in waste concentrations that warrant consideration for valorization strategies. As Mihai and Grozavu [15] noted, rural waste flows often escape official statistics. In agricultural contexts, Spinelli et al. [35] note that residue management has traditionally been viewed as a disposal problem rather than a revenue opportunity, indicating the systematic undervaluation of these resources. It should be noted that such output is not a waste management plan but rather actionable intelligence for decision-making. A municipality learning that it generates 1800 tons of grape pomace annually can now approach investors, apply for feasibility study grants, or engage technology providers, actions that would be impossible without baseline quantification.

However, translating theoretical potential into practical implementation faces significant barriers. Unlike industrial systems, where production units are clearly defined, Mediterranean small-scale agriculture often involves complex arrangements of owned, rented, and informally managed plots. This complexity suggests that enterprise counts, while readily available from administrative registries, provide only approximate indicators of actual cultivation intensity.

The seasonal concentration of waste generation creates additional implementation challenges. Large quantities of grape pomace are produced during short harvesting periods, increasing the concentration per area [39], while collection costs require site-specific assessment. The seasonal availability of waste demands careful handling and treatment to achieve economic feasibility [40]. Storage presents critical challenges, as different preservation methods significantly affect residue quality and subsequent valorization options. This seasonal timing requires planning to match processing capacity with harvest periods.

Resource constraints manifest at multiple levels in HSTs. Municipalities lack technical expertise and funding for waste characterization studies [15], while individual processors such as small olive mills cannot afford appropriate treatment facilities [26]. These limita-

tions compound into ongoing institutional capacity gaps that hinder independent project development [41].

Despite these constraints, there are instances of successful Mediterranean projects, provided the key conditions are met. Cáceres et al. [42] showed that wineries can cover up to 45% of their energy needs through grape pomace valorization using biogas and micro-turbine systems. Da Ros et al. [30] demonstrated successful anaerobic co-digestion of winery wastewater sludge and wine lees at pilot scale. In Almería, self-management of tomato crop waste through composting generated additional profit compared to external waste management [43]. These examples indicate that environmental and economic benefits are achievable, though the Ellen MacArthur Foundation [21] emphasizes that CE implementation requires patient capital and supportive policy frameworks.

The balanced variance contributions (31–35% each) across enterprise-to-hectare conversion, yield assumptions, and waste coefficients suggest that uncertainty reduction requires comprehensive approaches. This finding challenges assumptions that waste generation coefficients would dominate uncertainty in literature-based assessments. Instead, equal attention to improving farm size estimates, yield data, and waste coefficients will be necessary for more precise future assessments.

The regulatory framework for agricultural waste valorization in EU contexts creates additional complexity. The EU Landfill Directive discourages the landfilling of organic waste, while new recycling targets mandate ambitious recovery rates [15]. The classification of agricultural residues within waste legislation affects valorization pathways, with small municipalities often struggling to navigate regulatory requirements. This regulatory complexity affects innovative valorization approaches that fall between traditional waste management categories.

Within this regulatory context, technology selection emerges as a critical decision point given the scale and characteristics of available waste streams. Small-scale anaerobic digestion systems have proven technically feasible for various agricultural residues [30,40]. For solid residues, Christoforou and Fokaides [24] review multiple thermochemical and biochemical pathways, including pelletizing, torrefaction, and gasification. Essential oil extraction from citrus peels offers high-value applications, though optimization remains necessary for local conditions [31]. The match between technology scale and available feedstock quantities remains crucial for project success.

Market development for CE products remains challenging in rural contexts. While demand exists for renewable energy and organic amendments, establishing reliable market channels for small-scale operations faces obstacles. Consumer willingness to pay premiums for sustainably produced agricultural products varies significantly based on product attributes and consumer characteristics [44]. Mechanical pruning in citrus orchards, despite its costs, can achieve extra profits through improved efficiency and residue valorization [33]. However, realizing these benefits requires overcoming market access barriers typical of rural areas.

The implications of this research extend beyond the specific case study territory, as HSTs throughout the Mediterranean face similar combinations of agricultural intensity, demographic challenges, and institutional constraints. The methodology developed here offers a replicable approach for initial CE assessment using readily available administrative data. While the specific waste generation coefficients reflect Mediterranean agricultural systems, the framework's structure adapts to different crop types and territorial contexts. Additionally, while established frameworks [21,45,46] provide strategic guidance across multiple dimensions, they typically assume the availability of baseline data, which does not exist in many HSTs. The proposed methodology addresses this specific limitation by providing a way to estimate waste quantities when primary data collection is unfeasible,

thus enabling the application of broader frameworks in data-scarce contexts. Rather than competing with existing frameworks, this approach provides the quantitative inputs they require but cannot generate in resource-constrained settings.

Climate change considerations add urgency to CE implementation in these territories. Water scarcity and extreme weather events affect traditional waste management practices, while circular approaches that recover water and nutrients from agricultural waste could enhance territorial resilience. The waste management of orange peel shows different environmental impacts through many pathways, with anaerobic digestion and nutrient recovery offering climate benefits [47]. The estimation approach presented here enables policymakers to identify and prioritize CE interventions that simultaneously address waste management and climate adaptation needs. For instance, quantified agricultural residues can be evaluated not only for energy potential but also for their contribution to soil carbon storage and improved water retention. While comprehensive climate vulnerability assessments may exceed local technical capacity, this waste quantification methodology provides actionable data that allows municipalities to select CE pathways offering the greatest co-benefits for territorial resilience. However, implementation requires overcoming the technical, economic, and institutional barriers highlighted throughout this analysis.

The social dimensions of CE implementation in HSTs warrant greater attention. Participatory mapping methods that capture stakeholder relationships demonstrate the importance of including multiple perspectives in rural development planning [48]. LAGs provide institutional frameworks for participatory planning, though effectiveness varies considerably across contexts. The LEADER program emphasizes the need to actively include marginalized groups in rural development initiatives [41], recognizing that social innovation is essential for equitable outcomes.

Beyond formal governance structures, CE implementation increasingly involves social innovations that leverage collaborative networks and community resources. These include repairing and reusing resources at various levels as part of rural enterprise development strategies [48], sharing machinery to reduce installation costs [49], and community-based composting initiatives that embody the regenerative principles of the circular economy [21]. Such bottom-up innovations build on existing social capital while creating new collaborative networks that are essential for resource circulation [41]. Education and environmental awareness campaigns prove necessary to combat traditional disposal practices and foster the adoption of the circular economy [15].

CE initiatives must address equity concerns to ensure community-wide benefits. Without inclusive governance, benefits may concentrate among those with existing economic capacity and technical knowledge. Gender considerations also matter, as programs targeting rural women's livelihoods show potential for integrating social and environmental objectives. Local stakeholders themselves prioritize social actions such as knowledge sharing and networking as essential for sustainable transitions [49], recognizing that technical solutions alone cannot ensure equitable implementation. For the waste valorization initiatives identified through this quantification approach, municipalities need accessible participation methods, fair benefit sharing, and training for smaller producers to avoid reinforcing existing inequalities within HST communities.

The transition toward CE in HSTs requires the strategic sequencing of interventions. This study aimed to show that even small municipalities can identify substantial waste valorization opportunities using readily available data, which is often assumed impossible without expensive studies. For practitioners, this means starting with waste quantification using the proposed approach, then prioritizing technologies matched to local waste volumes and seasonal patterns, while simultaneously building institutional partnerships through existing structures such as LAGs. Rather than waiting for perfect conditions, HSTs

can begin their circular transition by leveraging their unique advantages: concentrated agricultural activities, strong social networks, and cultural heritage that can differentiate circular products in premium markets. The path forward lies not in replicating urban–industrial CE models, but in developing place-based approaches that transform territorial constraints into design parameters for locally appropriate solutions.

5. Conclusions

This study shows that the literature and administrative data, together, may help to quantify agricultural waste flows and energy recovery potential in data-constrained HSTs. The application to four Sicilian municipalities led to certain CE opportunities that were previously hidden by the absence of systematic monitoring. The estimated 6930–7130 tons of annual agricultural waste challenges assumptions about minimum scales for CE interventions and validates the importance of examining concentrated agricultural activities in small territorial contexts.

The key findings highlight both opportunities and challenges for CE implementation in HSTs. First, the high concentration of agricultural enterprises in these small municipalities generates waste concentrations comparable to much larger settlements, with 3250 tons of grape pomace alone potentially yielding 4.9–8.1 TJ through biogas production. Second, the methodology allowed to use readily available administrative data into potential estimates despite the absence of detailed production statistics. Third, sensitivity analysis indicated that no single factor dominates uncertainty, and that comprehensive data collection approaches will be more effective than targeted efforts. Fourth, geographic concentration patterns create both economies of scale for collective processing and logistical challenges that can affect economic viability.

Furthermore, the framework provides practitioners with a cost-effective tool for preliminary CE assessment, enabling municipalities to identify priority intervention areas and justify investments in feasibility studies. The approach democratizes CE planning, making it accessible to territories that lack resources for comprehensive waste characterization studies.

For policymakers, the results highlight the need for support mechanisms tailored to small-scale agricultural systems, including technical assistance for navigating regulatory complexity and financial instruments that are appropriate for distributed waste generation patterns. Considering the high concentration of agricultural enterprises, targeted interventions in HSTs could lead to disproportionate environmental benefits relative to the investment scale.

Rural HSTs require analytical approaches that acknowledge data limitations without sacrificing rigor, work with existing institutional capacities, and recognize the dual role of traditional practices as both barriers and foundations for circular transitions. This study also shows how volcanic territories and other unique geographical contexts necessitate adaptation of standard waste generation coefficients and valorization strategies.

However, the limitations frame the interpretation of the results and guide future applications. The assumption of dominant crop types in polyculture systems necessarily simplifies complex agricultural realities, where multiple crops often share the same plots. The average coefficients cannot capture farm-level variations in management intensity, technology adoption, or soil productivity. The framework assumes that all registered enterprises are active, though rural depopulation suggests some may be dormant. Additionally, focusing on primary agricultural residues excludes processing wastes from small-scale mills and packing houses, which may contribute significant additional volumes. The static nature of the assessment cannot capture seasonal variations or long-term trends in agricultural production patterns. While the framework provides baseline data for decision-making, it

does not capture social indicators such as community readiness, existing repair and sharing networks, or governance capacity, which influence adoption success.

Future research should address these limitations through multiple avenues. The development of remote sensing techniques could provide cost-effective validation of cultivation area estimates, particularly for distinguishing active from abandoned agricultural land. The integration of participatory mapping with local farmers could capture the complexity of polyculture systems and informal waste management practices. Longitudinal studies tracking actual waste generation from representative farms would refine coefficient ranges for specific territorial contexts. The investigation of minimum viable scales for different valorization technologies under HST conditions would guide technology selection. The analysis of successful collective action models in similar contexts could inform institutional design for waste management cooperatives. Future research could also build upon this quantification methodology by integrating social innovation metrics alongside technical assessments, potentially using mixed-methods approaches that combine quantitative waste estimates with qualitative mapping of community assets and social capital. Balanced sensitivity across parameters suggests that equal improvements in farm surveys, yield monitoring, and waste characterization studies would be needed to reduce overall uncertainty.

The research agenda should also explore dynamic modeling approaches that incorporate seasonal variations and climate change impacts on waste generation patterns. The economic analysis of different organizational models (public, private, cooperative) for waste collection and processing would inform policy design. Social network analysis could identify key actors and relationships that facilitate or hinder CE adoption in small agricultural communities. Comparative studies across different Mediterranean HSTs would test the transferability of findings and identify context-specific success factors.

The framework proposed here shows potential to contribute to the UN Sustainable Development Goals, such as SDG 12 (Responsible Consumption and Production) through agricultural waste valorization, SDG 7 (Affordable and Clean Energy) through bioenergy potential assessment, and SDG 11 (Sustainable Cities and Communities) by enabling small towns to implement circular economy strategies despite resource constraints.

The systematic application of literature-based coefficients to readily available administrative data can generate sufficient insights to initiate CE transitions, identify priority interventions, and justify investments in more detailed assessments. HSTs, despite challenges related to scale, institutional capacity, and demographic decline, possess unique advantages for CE implementation: concentrated agricultural activities, strong community networks, and cultural heritage that could differentiate circular products in premium markets. The path forward requires neither perfect data nor large-scale infrastructure, but rather adaptive approaches that transform constraints into design parameters for locally appropriate CE solutions. For HST administrators, this means leveraging the framework to make evidence-based decisions today while building capacity for more sophisticated analyses tomorrow. The managerial lesson is clear: in data-scarce territories, structured estimation outperforms paralysis by analysis. As Mediterranean territories confront escalating environmental pressures and rural development challenges, the framework developed here offers a practical tool for mobilizing the hidden potential within their agricultural landscapes.

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Abbreviations

The following abbreviations are used in this manuscript:

CE	Circular economy
HST	Historical small town
LAG	Local Action Group
ATECO	Attività Economiche
DOC	Denominazione di Origine Controllata
DOP	Denominazione di Origine Protetta
ISTAT	National Statistics Institute

References

- D’Amico, G.; Arbolino, R.; Shi, L.; Yigitcanlar, T.; Ioppolo, G. Digital Technologies for Urban Metabolism Efficiency: Lessons from Urban Agenda Partnership on Circular Economy. *Sustainability* **2021**, *13*, 6043. [[CrossRef](#)]
- Kirchherr, J.; Reike, D.; Hekkert, M. Conceptualizing the Circular Economy: An Analysis of 114 Definitions. *Resour. Conserv. Recycl.* **2017**, *127*, 221–232. [[CrossRef](#)]
- D’Alessandro, C.; Szopik-Depczyńska, K.; Tarczyńska-Luniewska, M.; Silvestri, C.; Ioppolo, G. Exploring Circular Economy Practices in the Healthcare Sector: A Systematic Review and Bibliometric Analysis. *Sustainability* **2024**, *16*, 401. [[CrossRef](#)]
- Ioppolo, G.; Heijungs, R.; Cucurachi, S.; Salomone, R.; Kleijn, R. Urban Metabolism: Many Open Questions for Future Answers. In *Pathways to Environmental Sustainability: Methodologies and Experiences*; Springer International Publishing: Basel, Switzerland, 2014; pp. 23–32.
- Ioppolo, G.; Saija, G.; Salomone, R. Developing a Territory Balanced Scorecard Approach to Manage Projects for Local Development: Two Case Studies. *Land Use Policy* **2012**, *29*, 629–640. [[CrossRef](#)]
- Muñoz, S.; Hosseini, M.R.; Crawford, R.H. Towards a Holistic Assessment of Circular Economy Strategies: The 9R Circularity Index. *Sustain. Prod. Consum.* **2024**, *47*, 400–412. [[CrossRef](#)]
- Walker, A.M.; Opferkuch, K.; Roos Lindgreen, E.; Raggi, A.; Simboli, A.; Vermeulen, W.J.V.; Caeiro, S.; Salomone, R. What Is the Relation between Circular Economy and Sustainability? Answers from Frontrunner Companies Engaged with Circular Economy Practices. *Circ. Econ. Sustain.* **2022**, *2*, 731–758. [[CrossRef](#)]
- Cader, J.; Koneczna, R.; Marciniak, A. Indicators for a Circular Economy in a Regional Context: An Approach Based on Wielkopolska Region, Poland. *Environ. Manag.* **2024**, *73*, 293–310. [[CrossRef](#)]
- Hamam, M.; Chinnici, G.; Di Vita, G.; Pappalardo, G.; Pecorino, B.; Maesano, G.; D’Amico, M. Circular Economy Models in Agro-Food Systems: A Review. *Sustainability* **2021**, *13*, 3453. [[CrossRef](#)]
- Roig, A.; Cayuela, M.L.; Sánchez-Monedero, M.A. An Overview on Olive Mill Wastes and Their Valorisation Methods. *Waste Manag.* **2006**, *26*, 960–969. [[CrossRef](#)]
- Velázquez-Martí, B.; Fernández-González, E.; López-Cortés, I.; Salazar-Hernández, D.M. Quantification of the Residual Biomass Obtained from Pruning of Trees in Mediterranean Olive Groves. *Biomass Bioenergy* **2011**, *35*, 3208–3217. [[CrossRef](#)]
- Dermeche, S.; Nadour, M.; Larroche, C.; Moulti-Mati, F.; Michaud, P. Olive Mill Wastes: Biochemical Characterizations and Valorization Strategies. *Process Biochem.* **2013**, *48*, 1532–1552. [[CrossRef](#)]
- Lamine, M.; Hamdi, Z.; Zemni, H.; Rahali, F.Z.; Melki, I.; Mliki, A.; Gargouri, M. From Residue to Resource: The Recovery of High-Added Values Compounds through an Integral Green Valorization of Citrus Residual Biomass. *Sustain. Chem. Pharm.* **2024**, *37*, 101379. [[CrossRef](#)]
- Zacharof, M.-P. Grape Winery Waste as Feedstock for Bioconversions: Applying the Biorefinery Concept. *Waste Biomass Valorization* **2017**, *8*, 1011–1025. [[CrossRef](#)]

15. Mihai, F.-C.; Grozavu, A. Role of Waste Collection Efficiency in Providing a Cleaner Rural Environment. *Sustainability* **2019**, *11*, 6855. [CrossRef]
16. Cotella, G. The Planning System in Italy and How It Addresses Tourism-Related Issues. In *Contemporary Challenges of Spatial Planning in Tourism Destinations*; Wydawnictwo Uniwersytetu Łódzkiego: Łódź, Poland, 2022; pp. 13–36.
17. I Borghi più Belli d'Italia What Is "BORGO". Available online: <https://borhipiubelliditalia.it/en/> (accessed on 29 May 2025).
18. D'Amico, G.; Taddeo, R.; Shi, L.; Yigitcanlar, T.; Ioppolo, G. Ecological Indicators of Smart Urban Metabolism: A Review of the Literature on International Standards. *Ecol. Indic.* **2020**, *118*, 106808. [CrossRef]
19. Moraga, G.; Huysveld, S.; Mathieux, F.; Blengini, G.A.; Alaerts, L.; Van Acker, K.; de Meester, S.; Dewulf, J. Circular Economy Indicators: What Do They Measure? *Resour. Conserv. Recycl.* **2019**, *146*, 452–461. [CrossRef]
20. Saidani, M.; Yannou, B.; Leroy, Y.; Cluzel, F.; Kendall, A. A Taxonomy of Circular Economy Indicators. *J. Clean. Prod.* **2019**, *207*, 542–559. [CrossRef]
21. Ellen MacArthur Foundation. Delivering the Circular Economy: A Toolkit for Policymakers. 2015. Available online: <https://www.ellenmacarthurfoundation.org/a-toolkit-for-policymakers> (accessed on 29 May 2025).
22. Beres, C.; Costa, G.N.S.; Cabezudo, I.; da Silva-James, N.K.; Teles, A.S.C.; Cruz, A.P.G.; Mellinger-Silva, C.; Tonon, R.V.; Cabral, L.M.C.; Freitas, S.P. Towards Integral Utilization of Grape Pomace from Winemaking Process: A Review. *Waste Manag.* **2017**, *68*, 581–594. [CrossRef]
23. Burg, P.; Ludín, D.; Rutkowski, K.; Krakowiak-Bal, A.; Trávníček, P.; Zemánek, P.; Turan, J.; Višacki, V. Calo-rific Evaluation and Energy Potential of Grape Pomace. *Int. Agrophys* **2016**, *30*, 261–265. [CrossRef]
24. Ncube, A.; Fiorentino, G.; Colella, M.; Ulgiati, S. Upgrading Wineries to Biorefineries within a Circular Economy Perspective: An Italian Case Study. *Sci. Total Environ.* **2021**, *775*, 145809. [CrossRef]
25. Christoforou, E.; Fokaides, P.A. A Review of Olive Mill Solid Wastes to Energy Utilization Techniques. *Waste Manag.* **2016**, *49*, 346–363. [CrossRef]
26. Khdair, A.; Abu-Rumman, G. Sustainable Environmental Management and Valorization Options for Olive Mill Byproducts in the Middle East and North Africa (MENA) Region. *Processes* **2020**, *8*, 671. [CrossRef]
27. Sayadi-Gmada, S.; Rodríguez-Pleguezuelo, C.R.; Rojas-Serrano, F.; Parra-López, C.; Parra-Gómez, S.; García-García, M.d.C.; García-Collado, R.; Lorbach-Kelle, M.B.; Manrique-Gordillo, T. Inorganic Waste Management in Greenhouse Agriculture in Almeria (SE Spain): Towards a Circular System in Intensive Horticultural Production. *Sustainability* **2019**, *11*, 3782. [CrossRef]
28. Cinardi, G.; D'Urso, P.R.; Arcidiacono, C.; Muradin, M.; Ingraio, C. A Systematic Literature Review of Environmental Assessments of Citrus Processing Systems, with a Focus on the Drying Phase. *Sci. Total Environ.* **2025**, *974*, 179219. [CrossRef] [PubMed]
29. Spinei, M.; Oroian, M. The Potential of Grape Pomace Varieties as a Dietary Source of Pectic Substances. *Foods* **2021**, *10*, 867. [CrossRef]
30. Da Ros, C.; Cavinato, C.; Pavan, P.; Bolzonella, D. Mesophilic and Thermophilic Anaerobic Co-Digestion of Winery Wastewater Sludge and Wine Lees: An Integrated Approach for Sustainable Wine Production. *J. Environ. Manag.* **2017**, *203*, 745–752. [CrossRef]
31. Ruiz, B.; Flotats, X. Citrus Essential Oils and Their Influence on the Anaerobic Digestion Process: An Overview. *Waste Manag.* **2014**, *34*, 2063–2079. [CrossRef]
32. Wikandari, R.; Nguyen, H.; Millati, R.; Niklasson, C.; Taherzadeh, M.J. Improvement of Biogas Production from Orange Peel Waste by Leaching of Limonene. *Biomed. Res. Int.* **2015**, *2015*, 1–6. [CrossRef]
33. Velázquez-Martí, B.; Fernández-González, E. The Influence of Mechanical Pruning in Cost Reduction, Production of Fruit, and Biomass Waste in Citrus Orchards. *Appl. Eng. Agric.* **2010**, *26*, 531–540. [CrossRef]
34. ISTAT APPENDICE—Le Geografie e Le Classificazioni Territoriali Usate Nel Rapporto; Rome, 2020. Available online: <https://www.istat.it/storage/rapporti-tematici/territorio2020/Rapportoterritorio2020.pdf> (accessed on 29 May 2025).
35. Morgan, M.G.; Henrion, M.; Small, M. *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*; Cambridge University Press: Cambridge, UK, 1990.
36. Moore, R.E.; Kearfott, R.B.; Cloud, M.J. *Introduction to Interval Analysis*; SIAM: Philadelphia, PA, USA, 2009.
37. Campolongo, F.; Cariboni, J.; Saltelli, A. An Effective Screening Design for Sensitivity Analysis of Large Models. *Environ. Model. Softw.* **2007**, *22*, 1509–1518. [CrossRef]
38. Saltelli, A.; Ratto, M.; Andres, T.; Campolongo, F.; Cariboni, J.; Gatelli, D.; Saisana, M.; Tarantola, S. *Global Sensitivity Analysis: The Primer*; John Wiley & Sons: Hoboken, NJ, USA, 2008.
39. Spinelli, R.; Magagnotti, N.; Nati, C. Harvesting Vineyard Pruning Residues for Energy Use. *Biosyst. Eng.* **2010**, *105*, 316–322. [CrossRef]
40. Eryildiz, B.; Lukitawesa; Taherzadeh, M.J. Effect of PH, Substrate Loading, Oxygen, and Methanogens Inhibitors on Volatile Fatty Acid (VFA) Production from Citrus Waste by Anaerobic Digestion. *Bioresour. Technol.* **2020**, *302*, 122800. [CrossRef]
41. Dax, T.; Strahl, W.; Kirwan, J.; Maye, D. The Leader Programme 2007–2013: Enabling or Disabling Social Innovation and Neo-Endogenous Development? Insights from Austria and Ireland. *Eur. Urban Reg. Stud.* **2016**, *23*, 56–68.

42. Cáceres, C.X.; Cáceres, R.E.; Hein, D.; Molina, M.G.; Pia, J.M. Biogas Production from Grape Pomace: Thermodynamic Model of the Process and Dynamic Model of the Power Generation System. *Int. J. Hydrogen Energy* **2012**, *37*, 10111–10117. [[CrossRef](#)]
43. Duque-Acevedo, M.; Belmonte-Ureña, L.J.; Plaza-Úbeda, J.A.; Camacho-Ferre, F. The Management of Agricultural Waste Biomass in the Framework of Circular Economy and Bioeconomy: An Opportunity for Greenhouse Agriculture in Southeast Spain. *Agronomy* **2020**, *10*, 489. [[CrossRef](#)]
44. Walker, A.M.; Opferkuch, K.; Roos Lindgreen, E.; Simboli, A.; Vermeulen, W.J.V.; Raggi, A. Assessing the Social Sustainability of Circular Economy Practices: Industry Perspectives from Italy and the Netherlands. *Sustain. Prod. Consum.* **2021**, *27*, 831–844. [[CrossRef](#)]
45. Kazmierczyk, P.; Geerken, T. Resource Efficiency and the Circular Economy in Europe 2019–Even More from Less: An Overview of the Policies, Approaches and Targets of 32 European Countries. EEA Report No 26/2019. Publications Office of the European Union: Luxembourg, EU, 2020.
46. Foray, D.; David, P.A.; Hall, B. Smart Specialisation-The Concept. Knowledge Economists Policy Brief 2009. Available online: http://ec.europa.eu/invest-in-research/monitoring/knowledge_en.htm (accessed on 29 May 2025).
47. Negro, V.; Ruggeri, B.; Fino, D.; Tonini, D. Life Cycle Assessment of Orange Peel Waste Management. *Resour. Conserv. Recycl.* **2017**, *127*, 148–158. [[CrossRef](#)]
48. Papageorgiou, K.; Singh, P.K.; Papageorgiou, E.; Chudasama, H.; Bochtis, D.; Stamoulis, G. Fuzzy Cognitive Map-Based Sustainable Socio-Economic Development Planning for Rural Communities. *Sustainability* **2020**, *12*, 305. [[CrossRef](#)]
49. di Santo, N.; Yazdani, M.; Lopolito, A.; Sica, E.; Sisto, R. Towards Policy Mixes Formulation to Support Green Transitions in Rural Areas: A Methodological Approach. *Sustain. Dev.* **2025**, *13*, 2265. [[CrossRef](#)]

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