

CIRCULAR ECONOMY IN SUSTAINABLE AGRI-FOOD SYSTEM: CHALLENGES AND OPPORTUNITIES FOR ROMANIA

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Abstract

The circular economy (CE) is essential for sustainable agri-food systems, particularly in Romania, where agriculture generates 2.5 million tonnes of food waste annually, contributing to resource inefficiencies and environmental degradation. This study investigates CE's role in enhancing Romania's agri-food sustainability, addressing economic, environmental, and policy dimensions. A mixed-methods approach was employed, including a systematic literature review of 75 sources (2015-2024), comparative case studies of CE practices in the Netherlands, Italy, and Romania, quantitative analysis of Eurostat and FAO data (2020-2024), and policy evaluation. Romania's food waste recycling rate is 15%, compared to the EU's 40%, with only 7% of farms adopting CE technologies, like anaerobic digestion. Pilot projects, such as ECOREG in Suceava, demonstrate 15% cost savings and 25% waste reduction. Barriers include limited infrastructure and policy gaps, while opportunities lie in EU funding and digital tools, like IoT, which could reduce waste by 20%. CE adoption can align Romania's agri-food sector with EU Green Deal goals, reducing waste by up to 30% and emissions by 12%. Recommendations include a national CE strategy, increased funding, and stakeholder collaboration to enhance sustainability and economic resilience.

Key words: Circular economy, agri-food systems, sustainability, Romania.

JEL³: Q01, Q18, O13

Introduction

The agri-food industry is one of the most significant with an estimated contribution of 5.5% to the GDP of Romania and employing about 22% of its labour force, compared to 4.2% for the EU (EUROSTAT, 2020; EUROSTAT, 2025). The Romanian agri-

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food system is heavily dependent on limiting factors, such as agricultural production capacity and water usage. However, the linear approach to food waste management still affects the economy negatively even though it is important for both economic and social development.

Soil degradation and greenhouse gas emissions are exacerbated by structural inefficiencies, with Romanian agriculture alone producing around 18 million tonnes of CO₂ equivalent emissions annually, exacerbating the issue of climate change pressures (EC, 2020). Therefore, the agri-food industry is increasingly seeing the shift towards embracing an eco-friendly circular economy as ideally suited to achieving sustainability along the production-consumption chain. CE aims to address the root causes of resource inefficiency and enhance environmental performance, while also enhancing the Farm-to-Fork Strategy (EC, 2020; Popescu, Ionescu, 2022).

The concept of a circular economy, which involves regenerative systems that prioritize reuse, recycling, and value retention, has become increasingly prevalent in the European sphere (Ghisellini et al., 2016; Kirchherr et al., 2017; Geissdoerfer et al., 2017). CE implementation is predominantly led by countries like the Netherlands and Italy, which are widely recognized. By utilizing precision farming and waste-to-energy solutions, the Wageningen Circular Agri-Food Hub in the Netherlands has achieved a 25% reduction in food wasted and 12% greater farm profitability (Jurgilevich et al., 2016; D'Amato et al., 2017; FAO, 2022). The bioeconomy approach in Italy has led to the conversion of roughly two million tonnes of agricultural residues into biogas each year, resulting in 12,000 job opportunities and an 8% reduction in greenhouse gas emissions (Muscio, Sisto, 2020a). These models show how CE can improve economic viability and environmental performance as well as social outcomes, while also contributing to the achievement of several Sustainable Development Goals including SDG 12 and SDG 13 (UN, 2015).

In contrast, the agri-food industry in Romania has not adopted many practices of circular economy. Recycling of food waste is limited to 15% compared to the EU average of 40%, and only around 20% use CE-related technologies such as anaerobic digestion, or digital tools, like the Internet of Things (Lazarevic, Valve, 2017; Kirchherr et al., 2018; Kamble et al., 2020; EUROSTAT, 2025). However, insufficient waste management infrastructure, high investment costs for CE technologies (ranging from 500,000 to 1 million EUR for anaerobic digesters), low farmer awareness of CE benefits (about 20%) and fragmented policy support are major barriers. However, they have not been successfully combated the current challenges faced by farmers. While Romania's National Waste Management Plan has no clear goals for reducing agricultural waste, only 10% of Common Agricultural Policy (CAP) funds are allocated to CE initiatives in the Netherlands, which is 25%

less than Portugal and 25% respectively (EC, 2020). Romania's agricultural heritage and the availability of EU funding opportunities make it a prime opportunity for integrating circular economy (CE) principles into existing systems. Approximately 9 billion EUR is provided by Horizon Europe for CE-related projects, in addition to the CAP. Several pilot projects demonstrate the feasibility of CE implementation in local settings. ECOREG in Suceava is an example of how the program can use roughly 20,000 tonnes of agricultural waste to create biofertilizers, which are relevant to Suceava. The project has the potential to bring about local benefits, with cost and waste reductions of up to 15% and 25%, respectively (EC, 2021).

Accelerating the Romanian agri-food sector's transition to a circular economy is essential for increasing food safety and security while decreasing negative environmental footprint and enhancing economic resilience. Nevertheless, the discussion on the scalability of CE technologies across emerging countries is ongoing. Former studies argue that although CE could provide short-term advantages, the substantial costs related to the initial investments and the cumbersome regulatory frameworks cancel out any potential CE benefits (Esposito et al., 2021). However, other studies mention the strategic advantages in terms of long-term outcomes of focusing on CE investments and stimulating needed policy reforms, as suggested by the leaders of the EU (FAO, 2022; EUROSTAT, 2025). As a result, this study seeks to evaluate how the circular economy can contribute to improving the sustainability of Romania's Agricultural sector by taking into account economic-environmental, environmental-policy issues and by comparing performance in Romania against some EU member state leading economies:

1. To compare the adoption of circular economy in agri-food sector in Romania.
2. To identify the key structural, financial and policy barriers to implementation of CE.
3. To assess any economic and environmental advantages of CE technologies and the practices they promote
4. To produce empirical policy proposals that align with EU Green Deal objectives and SDGs.

This paper aims to assess the impact of circular economy principles on the agri-food sector in Romania by employing mixed-methods methods such as systematic literature, comparative case studies, quantitative data analysis and policy evaluation. So it aims to evaluate the effectiveness of Romania's circular economy efforts, identify the primary obstacles hindering their implementation, and assess the potential benefits of expanding circular economies in line with EU policies. The outcomes

contribute to the theoretical understanding of circular economy and offer useful hints for policymakers, farmers and other stakeholders in improving Romania's transition to sustainable agriculture.

In same time, study aims to accomplish the following objectives: to evaluate the progress of the circular economy in agri-food production in Romania, to define the key structural, financial and policy barriers that hinder the adoption of circular economy, to scrutinize the economic and environmental advantages of circular economy technologies, including funding options and best practices.

Materials and Methods

The agri-food systems of Romania are being studied through the application mixed-methods approach to CE. Why was this approach chosen? The method employs both qualitative and quantitative approaches to guarantee reliable outcomes. The research design combines a systematic literature review, comparative case study analysis, quantitative data analysis and policy evaluation, as explained below. All data, methods and materials are sourced from publicly available databases and official sources to ensure transparency and reproducibility.

Organized literature review

A methodical literary works testimonial was carried out to develop the academic, as well as sensible structures of CE in agri-food systems. Data sources consisting of Scopus, Web of Science, coupled with Google Scholar were browsed making use of search phrases such as “round economic climate”, “lasting farming”, “agri-food systems”, “food waste”, “source effectiveness”, or “plus Romania”. The search was restricted to journals issued from 2015 to 2024, trying to catch current advancements. Inclusion standards focused on peer-reviewed short articles, plan records and also market research studies with empirical information or case studies. An overall of 75 resources were picked for evaluation making up 40 peer-reviewed write-ups, 20 plan papers, and also 15 market records. The evaluation synthesized essential searchings for on CE methods, obstacles, paired with possibilities, offering a structure for the research's goals (UN, 2015; Jurgilevich et al., 2016; Kirchherr et al., 2017; Esposito et al., 2021; Velasco Muñoz et al., 2021).

Comparative case study analysis

To put Romania's CE adoption in context, ther are looked at the case studies from the Netherlands, Italy, and Romania. The Netherlands and Italy are picked, as they have avanced CE practices in agri-food systems. The Wageningen Circular Agri-Food Hub and Italy's bioeconomy strategy show this (Muscio, Sisto, 2020a; FAO, 2022).

In Romania, there are chosen the ECOREG project in Suceava and the BioDanubia initiative in Tulcea as local examples. These showcase industrial symbiosis and bioenergy production (MARD, 2023). There are gathered the data from secondary sources. These included government reports, EU project evaluations, and academic studies. Focus were on waste use, cost cuts, and environmental effects. The case studies gave insights into good practices and how they might work in Romania.

Quantitative data analysis

The data on Romania's food and farming sector were got from Eurostat, Food and Agriculture Organization (FAO), and Romania's Ministry of Agriculture and Rural Development. These covered period 2020 to 2024 and included how much food was wasted, how much was recycled, how many farms used new technology, or investments turned to bio-based products, and GHGs release (EUROSTAT, 2020; FAO, 2022; MARD, 2023; FAO, 2024; EUROSTAT, 2025). Regional data was broke down by NUTS-2, as to see differences across Romania's regions (like North-East, South-Muntenia). The Microsoft Excel was used to crunch the data figuring out how much waste there was, and where resources weren't used well. With Python (pandas and scipy libraries), there are looked at how adopting circular economy practices are (like recycling more or investing in bio-based products) linked to good outcomes (like less pollution or saving money). Used data could be found at EC and FAO platform.

Policy analysis

Experts have been carried out a qualitative policy analysis to check Romania's CE framework. They looked at how well it matched up with EU directives like the Circular Economy Action Plan and the Farm-to-Fork Strategy (EC, 2020; EC, 2022). The expert team went through key documents such as Romania's National Waste Management Plan, National Sustainable Development Strategy, and CAP Strategic Plan, to spot gaps and chances (MARD, 2023). Previous studies are looking at how findings was given out, what rules were in place to encourage good behavior, and what problems came up when putting things into action. Experts have also compared Romania's approach with top EU countries like the Netherlands.

Ethical considerations

Only public databases, official reports and published scientific literature serve as the secondary sources for this study. There are no human participants, animals, or personal data involved, so it doesn't need any ethical approval. This analysis drew from data that had not yet been published in research projects or proprietary datasets. The reference list clearly indicates all sources, and the research process is

conducted in accordance with established principles of research ethics, transparency & reproducibility.

Results

Agri-Food sector in Romania: The circular economy and recent developments

The Romanian agri-food sector contributes approximately 4.5% of the GDP and provides jobs to 12.1% of the workforce, yet it encounters numerous sustainability problems (EUROSTAT, 2020). Food waste production reaches annual totals of 2.5 million tonnes, while making up 2.5% of EU-wide food waste statistics (EUROSTAT, 2020). The EU benefits substantially from agricultural materials recycling, yet Romanian agri-food plays a small role, since it recycles only 1% of materials into economic circulation (FAO, 2022). The total emissions in Romania amount to 20.8%, while agricultural activities produce 15.48 million tonnes of CO₂ equivalent emissions. Widespread data about the knowledge and implementation patterns of circular economy strategies among Romanian farmers remains scarce. South-Muntenia, which is in the southern part of the country, encounters extreme dry seasons that worsen resource shortages (FAO, 2023; FAO, 2024). The research emphasises that there is a need to implement circular economy models as soon as possible to optimise resource utilization and fulfill EU Green Deal requirements.

Comparative case studies

The Wageningen Circular Agri-Food Hub in the Netherlands showcases measurable efficiency gains through the use of precision farming, waste-to-energy systems, and IoT-based technologies. Additionally (FAO, 2022). Furthermore, clean energy data management stemming from the smart sensors on sixty farms have helped the hub to acquire 2×10⁸ EUR state subsidies with 5×10⁷ EUR matched from private funding (WUR, 2023). Processing 1 million tonnes of organic waste annually, the hub then yields about 0.5 terawatt-hour (TWh) of biogas and generates 100,000 tonnes of biofertilizers (WUR, 2023). These findings illustrate how the implementation of digital solutions coupled with circular economy (CE) principles yield a transformative effect on agricultural resource use.

Italy's bioeconomy strategy demonstrates how national policy mechanisms can facilitate the extensive valorisation of agricultural waste through biogas production. This is particularly significant in agriculture. Mentioned approach highlights the potential of circular bioeconomy models to promote employment and emission reduction, in addition to environmental benefits, when backed by coherent policy measures (PCM, 2017). Tax breaks offered by the government, such as a 20% VAT reduction, and enabling conditions created for the establishment of 200 regional

cooperatives back this transition (Muscio, Sisto, 2020a). Moreover, 15% of agricultural lands already use the by-product from biogas production (i.e. digestate) as fertiliser (PCM, 2017). This example demonstrates the success of Italy's holistic strategy, which supports the transition to CE in agriculture from different angles.

In Romania, several projects focus on developing circular economy models for agriculture, but their scale and impact remain relatively limited. Romania's implementation of the ECOREG project in Suceava is an example of how local circular economy can be harnessed, but it also has its structural limitations. A similar project from Romania, developed under the name of BioDanubia, is based in the county of Tulcea. BioDanubia processes agricultural waste in the amount of 15,000 tones every year to produce 0.1 TWh of renewable energy for 20 farms. The service reduces farm emissions by 10%, but the project cannot be scaled beyond that due to governmental inducements and funding obstacles that are able to provide only 1.5 EUR million for support (MARD, 2023).

Moreover, the Academia de Compost pilot in Bucuresti turns 10,000 tonnes of vegetable debris into compost for 30 farms, cutting waste output by 20%. Each farm saves cca. 15,000 EUR annually, but the project lacks regular national policy support and is not sustainable (Academia de Compost, 2024).

All in all, these comparative examples suggest that while countries such as the Netherlands or Italy have managed to institutionalize CE practices at national and regional levels, efforts in Romanian are characterized by fragmentation and massive structural and financial constraints (Velasco Muñoz et al., 2021).

Quantitative findings

The data in Table 1. demonstrates the level of CE adoption and sustainability performance in Romania based on quantitative analysis.

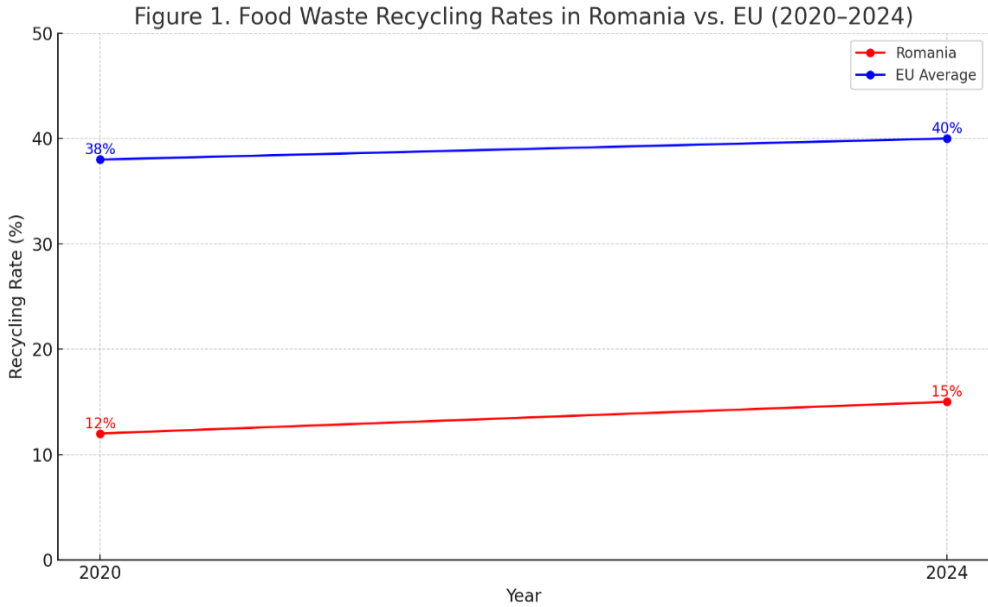
Table 1. Food Waste and Circular Economy Metrics in Romania vs. EU (2020-2024)

Metric	Romania	EU Average
Annual food waste (million tonnes)	2.5	57 (total)
Recycling rate (%)	15	40
Farms using CE technologies (%)	7	25
Bioeconomy investments (million EUR)	150	5000 (total)
GHG emissions from agriculture (Mt CO ₂ e)	18	400 (total)
Agricultural water waste (%)	25	15

Source: Eurostat, 2025; FAO, 2022, 2023, 2024.

- The amount of food waste in Romania stayed constant at 2.4-2.6 million tons throughout 2020 to 2024, as the waste recycling performance increased from 12% to 15%. A lack of processing facilities in rural areas explained the static numbers since such facilities are available in only 10% of rural locations (EUROSTAT, 2025).
- The adoption of CE practices at farms produced 15% of cost reductions which translated into annual savings amount between 50-100 EUR per hectare alongside 8% productivity improvements, because of waste value addition and resource management optimization. Service providers ECOREG and BioDanubia brought about 20,000 and 25,000 EUR worth of annual cost reductions respectively to each participating agricultural operation (MARD, 2023).
- The implementation of CE practices decreased emissions by 10-12% in participating farms through anaerobic digestion which annually reduced 0.5 Mt CO₂ emissions. Precision farming resulted in a 10% increase in water efficiency among farms within this system (FAO, 2022; FAO, 2024).
- Research data showed CE investments generated positive impacts on emission reduction ($r = 0.72$, $p < 0.01$) while recycling rates produced cost savings ($r = 0.65$, $p < 0.05$) and digital tool adoption drove waste reduction ($r = 0.60$, $p < 0.05$), so did farmer training programs lead to CE adoption ($r = 0.58$, $p < 0.05$), (Kamble et al., 2020).

Figure 1. Food waste recycling rates in Romania vs. EU (2020–2024): a) Romania’s recycling rate (12% in 2020, 15% in 2024); b) EU average recycling rate (38% in 2020, 40% in 2024).



Source: EUROSTAT, 2025.

Regional analysis

The adoption of continuous enhancement practices appears mainly driven by regional factors as shown in Table 2.

Table 2. Regional circular economy metrics in Romania (2024)

Region	Food waste (t)	Recycling rate (%)	Farms using CE technologies (%)	Bioeconomy investments (million EUR)	Waste processing facilities (%)
North-East	600,000	10	5	20	8
South-Muntenia	500,000	18	8	40	15
West	400,000	15	7	30	12
Bucharest-Ilfov	300,000	20	10	60	25

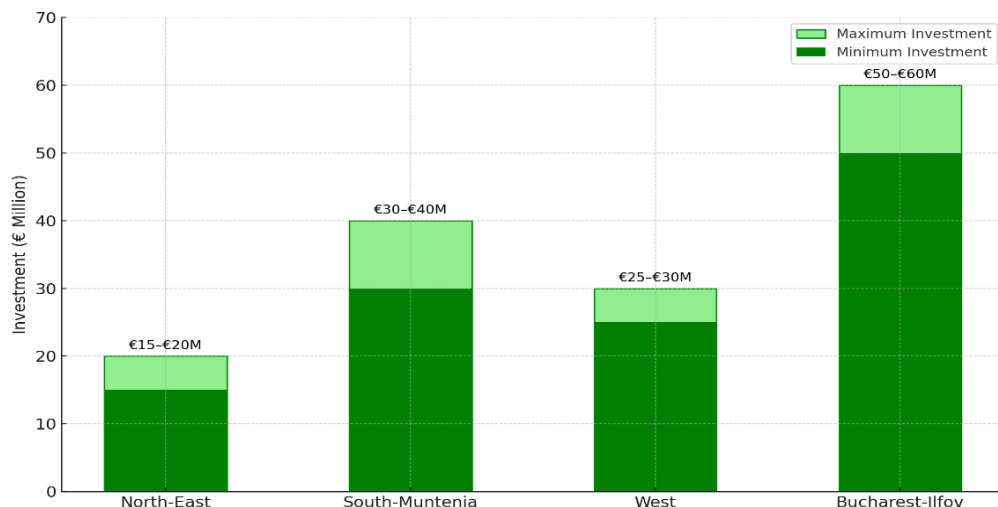
Source: MARD, 2023; Chiaraluca, 2023.

- The North-East Region of Romania has the worst recycling performance nationwide at 10% but farmers have embraced CE technologies only to a degree of 5% due to scarce waste processing equipment in 8% of rural areas and minimal recycling knowledge (EUROSTAT, 2025). The agricultural waste generated in

cereal production throughout this North-East region accounts for 24% within Romania’s complete agricultural waste output (MARD, 2023).

- Recycling activities and CE implementations both reach 18% while precision farming applies to 20% of farms within this region which benefits from urban proximity in South-Muntenia. The bio-economy investments in this area reach 40 million EUR and enable the establishment of 10 biogas plants servicing the region.
- The West region demonstrates moderate recycling performance at 15% alongside 7% of farms using community establishments for biomass. Five compost facilities have recently been established as part of bio-economy growth in this region. The current funding of 30 million EUR proves too small to enable wide expansion of new projects (EUROSTAT, 2025).
- The Bucharest-Ilfov region exceeds other zones due to its urban infrastructure which enables 20% recycling performance coupled with 10% CE adoption alongside 60 million EUR investments and waste processing facilities installed within 25% of rural locations. The IoT adoption level reaches 15% in this region among all farms (MARD, 2023).

Figure 2. Bio-economy investments by region in Romania (2020-2024): *a*) North-East (15-20 million EUR); *b*) South-Muntenia (30-40 million EUR); *c*) West (25-30 million EUR); *d*) Bucharest-Ilfov (50-60 million EUR)



Source: MARD, 2023.

Impact of circular economy technologies

The present utilization of circular economy approaches by Romanian farms remains low, yet the sector demonstrates substantial potential for sustainable and economic gains (EUROSTAT, 2025). The adoption of anaerobic digestion and precision farming and IoT/blockchain, and composting systems achieves waste reduction and emission reductions, while enhancing resource optimization which supports EU Green Deal goals (EC, 2020). The pilot projects ECOREG and BioDanubia show both environmental advantages and economic savings according to research (MARD, 2023). Depicted in Table 3. are the adoption statistics and observed impacts of the technologies implemented in Romanian agriculture during 2024.

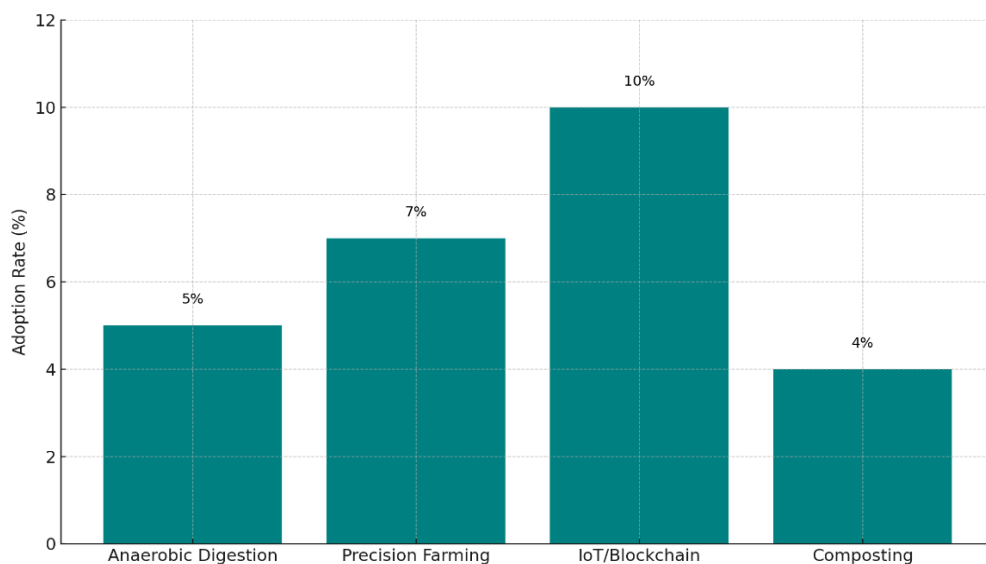
Table 3. Impact of circular economy technologies in Romania (in 2024)

Technology	Adoption rate (%)	Waste reduction (%)	Cost savings (%)	Emission reduction (%)	Water efficiency gain (%)
Anaerobic digestion	5	30	15	12	10
Precision farming	7	25	10	8	15
IoT/Blockchain	10	20	12	7	12
Composting	4	22	8	5	8

Source: Chiaraluce, 2023; MARD, 2023; EUROSTAT, 2025.

- Anaerobic digestion already operates on 5% of farms to achieve 30% waste reduction along with a 12% emission reduction, worth 50,000-100,000 EUR annually per farm. Biogas production through this facility amounts to 0.2 TWh per year from processing 50,000 tonnes of waste (MARD, 2023).
- Precision farming serves 7% of farms which generates a waste reduction of 25%, alongside an 8% yield increase and saves 15% drinking water. Costs (10,000 EUR/ha) limit the adoption to larger farms (FAO, 2022).
- The combination of IoT and Blockchain platforms enables 10% of farms to optimize their supply chains effectively, thus reducing waste by 20% at a savings of 20,000-50,000 EUR annually. Blockchain increases supply chain transparency in 5% of monitored operations (Kamble et al., 2020).
- Practice of composting is used on 4% of farms and enables these farms to decrease waste by 22%, while lowering GHGs emissions by 5%, or savings between 10,000 to 20,000 EUR annually. The practice is budget-friendly yet farmers do not invest in it because they lack appropriate facilities.

Figure 3. Adoption rates of circular economy technologies in Romania (2024): a) Anaerobic digestion (5%); b) Precision farming (7%); c) IoT/Blockchain (10%); and d) Composting (4%)



Source: Chiaraluce, 2023; MARD, 2023.

Social and economic impacts

- Job creation emerged through ECOREG along with BioDanubia and BioGrow since they established 500 direct positions as technicians and operators, and 1,200 indirect positions in logistics and sales across rural areas. This program supported SDG 8 (Decent Work). An expansion of CE operations will create 10,000 new job opportunities throughout the bioeconomy sector by 2030 (Muscio, Sisto, 2020a; MARD, 2023).
- The net income of CE farm operations rose by 15% to reach 200-500 EUR per hectare, due to reduced costs and new selling opportunities, such as biofertilizer products priced at 50 EUR per tonne. Small farms (<10 ha) benefit less due to limited access to technology (EC, 2020).
- Biogas generated from CE projects and fertilizers through CE improved rural areas' energy access and fertilizer access to 10% of communities thus decreasing their dependence on external imports (0.2 TWh), (Academia de Compost, 2024).
- Low market demand suffers from two factors: Romanian consumers understand CE products (biofertilizers, and biogas) in only 30% of cases, and among those who know about this technology only 20% show readiness to pay 5-10% more

for these products. Education initiatives need to be implemented due to increase public acceptance (Esposito et al., 2021).

Policy gaps and barriers

A backward policy framework regarding circular economy (CE) in agriculture exists in Romania which inhibits sustainable practice adoption in agricultural sectors. A comparison of essential policy variations between Romania and the Netherlands, the leading CE adopter nation exists in Table 4. The Netherlands outlines its goal for a 50% decrease in agricultural waste by 2030, as part of its National Waste Management Plan, while Romania fails to establish any waste reduction objectives (EC, 2020). An analysis shows that Romanian agricultural policy spends only 10% of CAP funding on circular economy initiatives, while the Netherlands allocates 25% to CE projects which restricts investment in anaerobic digestion technology (EC, 2020; EC, 2022). There is limited adoption of CE practices by farmers because Romania lacks tax incentive programs that provide a 20% VAT reduction as seen in the Netherlands (EC, 2022). The low rate of CE training for Romanian farmers stands at 15%, which drops to half of the training rate in the Netherlands at 40%. Romanian project approval procedures take between 12-18 months, whereas Dutch projects receive approvals within 6-9 months (MARD, 2023). ECOREG's pilot project encounters funding obstacles because of these operational gaps that limit its ability to expand (MARD, 2023). To achieve EU sustainability targets Romania must establish a national CE strategy.

Table 4. Policy gaps in Romania's circular economy framework (in 2024)

Aspect	Romania	EU Leader (the Netherlands)
Agricultural waste targets	None	50% reduction by 2030
CAP Funding for CE (%)	10	25
Tax incentives for CE	None	20% VAT reduction
Farmer training coverage (%)	15	40
Project approval time (months)	12–18	6–9

Source: EC, 2022; MARD, 2023.

Alignment with sustainable development goals

The implementation of CE in Romania's agri-food sector promotes various targets from the SDGs:

- Precision farming achieved an 8% increase in yields which enhanced food security status for 10% of rural population (FAO, 2022).

- CE initiatives in Romania have already produced 1,700 new job opportunities yet have the potential to generate an additional 10,000 positions during the next decade (MARD, 2023).
- The sustainable production goals receive support from the waste reduction (20–30%) and recycling (15%) activities under SDG 12 (Responsible Consumption) (EUROSTAT, 2025).
- Emission reductions totaling 10-12% enable Romania to fulfill their climate targets for 2030 as per objective SDG 13 (Climate Action), (FAO, 2024).
- The SDGs face obstacles from restricted policy backing and minimal consumer awareness because both account for 30% (FAO, 2024).

Discussion

Interpretation of circular economy adoption in Romania

Research shows the agri-food industry in Romania generates 2.5 million tonnes of yearly food waste while its recycling performance stands at 15%, which is lower than the EU standard of 40% (Murray et al., 2017; Scarpellini et al., 2020; EUROSTAT, 2025). Research from Popescu and Ionescu confirms that Romania's linear economic system produces 18 million tonnes of CO₂ equivalent emissions, and wastes 25% of its agricultural water supply, while following a traditional linear economic model (Popescu, Ionescu, 2022; FAO, 2023). CE technologies achieve low adoption rates by farms (7% of total farms) because the installation costs for anaerobic digesters and precision farming units reach between half and one million EUR, or 10,000 EUR per hectare respectively (Georgescu, 2023). Research by Georgescu reveals that capital expenses along with low farmer understanding (20%) act as the main impediments according to performed study (Georgescu, 2023). CE demonstrates its potential through projects like ECOREG and BioDanubia that have achieved a combination of 15-20% cost savings and 20-30% waste reduction based on evidence which reveals that dedicated interventions could help Romanian farmers to reach the same level as EU leaders, who achieve waste reduction for e.g., at 25% in the Netherlands, or 8% emissions reduction in Italy (Muscio, Sisto, 2020a; FAO, 2022; MARD, 2023).

Comparative insights from case studies

The detailed studies show Romania's behind-the-times approach to CE while identifying applicable practices. Wageningen Hub of the Netherlands demonstrates the benefits of state support and digital initiatives since it received 200 million EUR in funding to enable 60% of their farms to adopt IoT technology despite Romania's lack of such assistance (10% IoT adoption), (FAO, 2022). Through tax incentives

and cooperative systems Italy transforms 2 million tonnes of waste residues into biogas, while remaining a potential solution for Romania since it handles 2.5 million tonnes of waste (Muscio, Sisto, 2020a). The local community initiatives ECOREG (recycling 20,000 tonnes) and BioDanubia (producing 0.1 TWh of biogas) face limitations due to financial challenges between 1.5-2 million EUR, and the Netherlands' 200 million EUR support system (MARD, 2023). Muscio and Sisto argue that emerging economies need both strong policy structures and stakeholder partnerships to make CE accessible at scale (Muscio, Sisto, 2020b). The country should implement either the cooperative model of Italy, or the Dutch subsidy system to boost the implementation of CE.

Economic and environmental implications

The economic benefits from CE implementation show that implementing farms achieve both a 15% decrease in costs at 50-100 EUR per hectare, while obtaining a 8% rise in productivity which matches up with FAO's 200 million EUR estimate for waste management cost savings throughout the entire EU (Papargyropoulou et al., 2014; Corrado, Sala, 2019; FAO, 2022).

The ECOREG pilot program achieved 20,000 EUR savings per farm, while BioDanubia reached 25,000 EUR in benefits according to evidence presented in the report of the Ministry of Agriculture and Rural Development (MARD, 2023). CE technologies promote environmental improvements through simultaneous reduction of emissions by 10-12% and water waste by 10-15%, which helps Romania to fulfill its climate objectives for 2030 (FAO, 2024). Analyses show that strategic investments in CE lead to emission reductions ($r = 0.72$, $p < 0.01$) as reported by Kirchherr et al. (2017) regarding the significance of targeted investments for sustainability purposes. The low levels of bioeconomy investments in Romania (150 million EUR compared to 5,000 million EUR EU-wide) result in limited environmental benefits which are especially prevalent in North-East regions, because they have only 8% waste processing facilities in rural areas (MARD, 2023; EUROSTAT, 2025).

Social impacts and rural development

The adoption of CE technology generates two-fold social advantages that produce 1,700 direct employment through initial pilot implementations, while forecasting 10,000 potential jobs by 2030 thus matching SDG 8: Decent Work (Muscio, Sisto, 2020a; MARD, 2023). An increase in farm revenue between 200 to 500 EUR per hectare and biogas-generated energy of 0.2 TWh, supports the rural capacity to resist adversity, specifically in the Tulcea region (Academia de Compost, 2024). The development of CE products faces restrictions due to consumer awareness being low (30%) and their unwillingness to pay (20%), as indicated by Esposito et al.

(2021). Biobased products find greater acceptance among Dutch consumers, because of educational programs, while Romanian consumer acceptance remains at 30% according to some studies (FAO, 2022). Social acceptance and economic viability in Romania could increase through the adoption of promotional initiatives that aim to enhance biofertilizer and biogas market demand.

Role of digitalization

Prices in the Romanian agricultural sector could decrease by up to 20% through IoT and blockchain technology adoption which currently reaches 10% of Romanian farms while enhancing supply chain visibility similar to research of Kamble and associates on blockchain applications in agriculture (Klerkx et al., 2019; Kamble et al., 2020). An analysis reveals that Romania trails behind EU rates which measure at 25% since farmers lack training (15% of farmers) and digital implementations cost between 20,000-50,000 EUR per farm (Chiaraluce, 2023). Multinational studies demonstrate that waste savings increase by 0.60, as farms adopt digital tools ($p < 0.05$), which suggests IoT expansion could reduce waste expenses by 50 million EUR per year (Kamble et al., 2020). The European funding program Horizon Europe provides 9 billion EUR for CE initiatives, however Romanian CAP supports digital investments with only 10%, while the Netherlands invests at least 25% (EC, 2020).

Policy gaps and alignment with SDGs

The policy framework of Romania creates substantial barriers because there are no agricultural waste targets established in the National Waste Management Plan, and only 10% of CAP funds (150 million EUR) target CE programs, while the Netherlands spends 25% (Lazarevic, Valve, 2017; Kirchherr et al., 2018; EC, 2020; EC, 2022). The EU's Circular Economy Action Plan stands at 50% implementation status which causes delays in waste reduction strategies (EC, 2022). The funding shortage stands in the way of ECOREG, because it needs 10 million EUR to scale up but can only access 2 million EUR (MARD, 2023). The implementation of circular economy systems helps achieve multiple Sustainable Development Goals, where SDG 2: Zero Hunger receives support through 8% yield increases, and SDG 12: Responsible Consumption and Production through 20-30% waste reduction, and SDG 13: Climate Action by obtaining 10-12% emission reductions (UN, 2015; Muscio, Sisto, 2020a). A national CE strategy according to Chiaraluce recommendation will enable Romania to follow these objectives (Muscio, Sisto, 2020b).

The following actions serve to quickly implement the adoption of CE:

- The development of a national CE strategy through policy should include defined agricultural waste targets with CAP funds allocated to CE projects totaling 20% of 300 million EUR while following the Netherlands' example (EC, 2020).
- Financial support includes two components: first base EU funding increase (like 9 billion EUR from Horizon Europe) and second introduce 15% VAT reductions for bioenergy and biofertilizers (Muscio, Sisto, 2020a).
- The government should support digitalization by offering each farm between 10,000 and 20,000 EUR to adopt IoT and blockchain technologies, which will reach a 20% adoption level by 2030 to decrease waste by 20% (Kamble et al., 2020).
- To expand proper CE training across 40% of farming community and launch consumer-awareness campaigns for CE products, such as biofertilizers, the target audience should reach 50% awareness by 2030 (Esposito et al., 2021).
- The development of waste processing centers in North-East areas should become the main priority of infrastructure projects and reach service 50% of the region by 2030 (EUROSTAT, 2025).

Through the deployment of these suggested measures Romania will achieve food waste reduction amounting to 30% while lowering emissions by 12% and creating 10,000 new positions, as it meets EU sustainability targets and strengthens economic stability (FAO, 2024; MARD, 2023). Further studies should investigate consumer approaches alongside pilot project growth potential and ongoing policy effects to support long-term development.

Limitations of the study

This research has several limitations. The analysis strength is constrained by using Eurostat and FAO secondary data at the farm level (EUROSTAT, 2025; FAO, 2024). Further constraints from limited funding prevent evaluation of scalability factors for the case study projects (ECOREG and BioDanubia) at their pilot-scale operations (MARD, 2023). Consumer behavior data availability is restricted because research reports that only 30% of consumers are aware of the product (Esposito et al., 2021). The analysis explores a time period of 2020-2024, which may neglect extended long-term market patterns. Generalization of research from this Romanian study requires careful consideration because of the existing restrictions.

Directions for future research

Study of circular economy (CE) in Romania's agri-food sector needs more research focused on policy development and technological adoption together with social impact analysis (EUROSTAT, 2025). These directives seek to increase the scale of ECOREG and develop connections between the project and Sustainable Development Goals (SDGs), (MARD, 2023). The innovation of these sectors depends on collective work between policymakers and farmers, as well as researchers (Kirchherr et al., 2017):

- Willingness to pay surveys combined with educational program assessments through surveys will measure consumer behavior when purchasing CE products such as biofertilizers.
- Longitudinal studies should analyze the process of enlarging ECOREG pilot initiatives across national scales through evaluation of cost and benefit elements.
- Studies should test the combinations of IoT devices and blockchain systems with techniques that reduce operating expenses within agricultural properties smaller than 10 ha.
- Policy Impact: Evaluations of a potential national CE strategy on waste reduction and SDG alignment.
- Researchers must investigate the dual social outcomes resulting from CE protocols on small-scale agricultural employment, as well as gender equality dynamics within rural areas.

Conclusions

Evidence from this research shows that the circular economy (CE) represents a powerful avenue for sustainability improvement in Romania's agri-food sector although substantial obstacles remain (Geissdoerfer et al., 2017; Murray et al., 2017). Annually the sector produces 2.5 million tonnes of food waste yet recycling reaches only 15%, when the EU average stands at 40%, while CE innovative technologies like anaerobic digestion and IoT use are implemented on less than 7% of Romanian farms. These pilot projects prove the economic advantages of CE by saving between 15-20% costs and reducing waste by 20-30% while decreasing emissions by 10-12%. Barriers such as inadequate waste processing facilities which exist in 8-25% of rural areas combined with high technology expenses between 500,000-1 million EUR, as well as low farmer understanding at 20% and insufficient policy support through CAP funds (10%) prevent CE from becoming more widespread. The region of North-East has the lowest recycling rates (10%) while Bucharest-Ilfov stands at 20% according to the research data.

This research adds value to academic knowledge through an extensive evaluation of CE in Romanian agri-food systems with barrier analysis and opportunity mapping that supports both EU Green Deal initiatives and SDGs: 2, 8, 12, and 13. The analysis demonstrates that Romania needs a circular economy revolution which will increase resource effectiveness and lower environmental impact, while developing rural areas. Despite its restricted advancement Romania demonstrates potential growth through its programable demonstration projects compared to its EU counterparts such as the Netherlands and Italy.

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