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Economics of Circular Agriculture: Principles, Barriers, and EU Perspectives

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ABSTRACT

This article explores the theoretical foundations and systemic implications of circular agriculture as a transformative model for sustainable agri-food systems. Building on the principles of the circular economy, circular agriculture emphasizes closed-loop nutrient cycles, waste valorization, and ecological regeneration. The paper contributes to the evolving literature by synthesizing conceptual definitions, identifying key barriers to adoption, and examining enabling policy frameworks with a particular focus on the European Union. It proposes a conceptual model that integrates production-level practices, circular value chains, and institutional mechanisms such as the EU Green Deal, Farm to Fork Strategy, and Common Agricultural Policy. A comparative analysis of related approaches - including agroecology, regenerative agriculture, and the bioeconomy highlights the distinct economic framing of circular agriculture. The research was concluded by suggesting additional works in economic modelling, behavioral incentives, and the creation of circularity indicators, which are a form of sustainability metrics. The goal of the results is to foster interdisciplinary dialogue and durable reconceptualization of agriculture policy frameworks.

INTRODUCTION

Agriculture is facing unprecedented pressure to adapt to climate change, biodiversity loss, and the depletion of natural resources. The existing linear production systems- based on extract, exploit, and dispose - are increasingly incompatible with long-term economic viability and environmental sustainability (Kirchherr, Reike and Hekkert, 2017). Within this context, circular agriculture has emerged as a theoretical and practical framework which aims to transform the agri-food system by integrating circular economy principles into agricultural production, focusing on waste as a resource, nutrient recycling, and ecological regeneration (Rodino et al., 2023; Streimikis, 2025).

The circular agriculture paradigm not only aims at closing material and energy loops but also at integrating agricultural practices into broader sustainability transitions (Karpavicius, Balezentis, 2025). It transforms traditional supply chain frameworks, pervades new dimensions of business interrelationships and highlights systemic interdependencies between the economy, the environment, and society (Dagevos and Lauwere, 2021). This shift profoundly reshapes economic analysis considering value creation, efficiency, and resilience in food and farming systems.

Recently, the policy of the European Union (EU) has been adopting circular agriculture more closely with the use of the Europe Green Deal, Farm to Fork Strategy, and Common Agricultural Policy (CAP)(European Commission, 2019; 2020). These frameworks try to implement circularity across sectors through the adoption of low-carbon technologies, regenerative and holistic food systems, and integrated food systems. However, the move towards circular agriculture is still impeded by significant economic, institutional, and behavioral obstacles, with increased policy and academic attention being insufficient for such a need (Jesús and Mendonça, 2017). There is often insufficient integration between the principles of a circular economy and agricultural economics.

This paper seeks to contribute to the theoretical foundation of circular agriculture by integrating conceptual insights, identifying key systemic barriers, and examining enabling policy frameworks, with a focus on the EU context. It also introduces a conceptual model that synthesizes the economic dynamics of circular agricultural systems and outlines future research directions to support their development.

The paper is structured as follows: Section 2 reviews conceptual foundations, identifies major barriers, and discusses relevant policy enablers. Section 3 presents a conceptual model of circular agriculture. Section 4 offers a broader discussion of the theoretical and policy implications. Section 5 concludes with final reflections and recommendations for future research.

1. LITERATURE REVIEW

The concept of circularity in economic and environmental thought has evolved as a response to the shortcomings of linear production and consumption systems. The circular economy (CE) paradigm promotes closed-loop systems where materials, energy, and resources are continuously reused, thereby minimizing waste and reducing pressure on natural ecosystems (Kirchherr, Reike and Hekkert, 2017). The CE framework has been increasingly adopted in various sectors - energy, manufacturing, and construction - but its application to agriculture remains a relatively recent and underexplored area of study.

Circular agriculture (CA) is conceptually grounded in CE principles but tailored to the specific dynamics of food and farming systems. It focuses on regenerative use of biological resources, particularly through nutrient recycling, organic waste valorization, and multifunctional land use (Batlles-delaFuente et al., 2022). Definitions of CA vary in emphasis but generally converge around a shared goal of reducing external inputs and environmental impacts while improving resilience and productivity. Unlike industrial applications of CE that often emphasize technological innovation and material engineering, CA is deeply ecological in nature, prioritizing soil health, biodiversity, and closed-loop biological flows (Jayasinghe et al., 2023).

In the academic literature, circular agriculture overlaps conceptually with several other sustainability-oriented frameworks, including agroecology, regenerative agriculture, organic farming, and the bioeconomy (Velasco-Muñoz et al., 2021) . While all these approaches advocate for reduced environmental impact and improved ecosystem services, circular agriculture distinguishes itself through its direct alignment with CE's material flow logic and economic framing. (Geissdoerfer et al., 2016) argue that CE offers a new sustainability paradigm by integrating economic and ecological dimensions, a perspective that is especially relevant in the case of CA.

A number of sustainability-focused frameworks - such as agroecology, regenerative agriculture, organic farming, and the bioeconomy - share overlapping goals with circular agriculture, including reduced environmental impact, improved resource use, and enhanced ecosystem resilience (Batlles-delaFuente et al., 2022). However, these approaches differ significantly in terms of their theoretical grounding, policy alignment, market integration, and economic orientation. While agroecology and regenerative agriculture prioritize ecological functions and local knowledge systems, they often lack explicit economic frameworks (Jayasinghe et al., 2023). Organic farming, by contrast, is codified through certification and compliance mechanisms but does not necessarily promote circularity in resource flows. The bioeconomy emphasizes biomass-based production and innovation, yet may prioritize growth over ecological limits (Tan and Lamers, 2021). Circular agriculture is unique in its integration of material flow logic, economic efficiency, and systems thinking within a regenerative agricultural framework. Table 1 presents a comparative overview of these approaches, highlighting key conceptual distinctions that inform ongoing theoretical and policy debates.

Table 1. Conceptual Comparison of Circular Agriculture and Related Approaches

Criterion	Circular Agriculture	Agroecology	Regenerative Agriculture	Organic Farming	Bioeconomy
Core Focus	Resource cycling, waste valorization, and system efficiency	Ecological principles in farming; social justice	Soil health and ecosystem regeneration	Avoidance of synthetic inputs; certification standards	Biomass-based production across sectors
Theoretical Basis	Circular economy, systems thinking	Agroecological science, political ecology	Systems ecology, land stewardship	Environmentalism, consumer ethics	Innovation, industrial policy, green economy
Economic Framing	Efficiency, value recovery, closed-loop markets	Often critiques capitalist models	Emphasis on long-term ecological-economic health	Market-based (certification), but limited economic theory	Strong economic framing (growth, innovation, competitiveness)
Technological Emphasis	Medium to high; includes biogas, composting, IoT	Low; emphasizes traditional and local knowledge	Medium; blends traditional and modern methods	Low to medium; technology constrained by organic principles	High; biotechnology and industrial processing
Policy Alignment (EU)	Green Deal, CAP, Farm to Fork Strategy	Supported via agroecological transition (indirect)	Emerging but not formally codified	Long-standing regulation and support via organic labeling	Horizon Europe, Bioeconomy Strategy, Circular Bio-Based Europe
Market Integration	Encourages new circular value chains	Often localized and community-based	Encourages local resilience and regenerative markets	Formalized market via certification (e.g., EU Organic logo)	Industry-oriented; large-scale biomass markets
Critiques	Needs stronger economic integration and metrics	Lacks scalability and economic modeling	Sometimes vague or unstandardized in metrics	Limited systemic thinking; certification doesn't ensure circularity	May prioritize growth over ecological boundaries

Source: compiled by the author based on Jayasinghe et al. (2023), Velasco-Muñoz et al. (2021), Batlles-delaFuente et al. (2022), Tan and Lamers (2021), Pannell, Llewellyn and Corbeels (2013) and Hassan and Faggian (2023)

Despite increasing interest, the literature on circular agriculture remains fragmented. Much of the existing research is either conceptual or policy-oriented, with limited integration into mainstream economic theory. Studies often describe CA as a normative goal or design principle, without clearly articulating its place within established economic models (Pannell, Llewellyn and Corbeels, 2013). For example, there is limited exploration of how CA practices affect marginal productivity, land use efficiency, labor allocation, or pricing mechanisms in agricultural markets. As De Jesus and Mendonça (2018) highlight in their critique of eco-innovation pathways, theoretical alignment and economic rigor are often missing in CE applications.

Furthermore, existing CE literature tends to focus more on technical feasibility and industrial symbiosis than on primary production systems like agriculture. As such, key concepts like systems thinking, feedback loops, and multifunctionality are often referenced in sustainability science and ecological economics, but not well-developed in agri-economic models (Hassan and Faggian, 2023). This theoretical gap presents an opportunity for expanding the economic discourse around agriculture, particularly by incorporating circularity into analyses of cost structures, value creation, and policy effectiveness.

At the same time, emerging EU policy frameworks are beginning to stimulate academic engagement with the economic aspects of CA. The European Green Deal (European Commission, 2019), the Farm to Fork Strategy (European Commission, 2020), and updated CAP mechanisms explicitly promote circular practices and encourage new metrics for agricultural sustainability. These developments signal a growing recognition that circularity is not just an environmental goal but also an economic transition requiring robust theoretical underpinning.

In summary, while the literature has established a foundation for understanding the principles of circular agriculture, significant gaps remain in conceptual clarity, economic modeling, and empirical validation. This paper contributes to addressing these gaps by synthesizing existing knowledge, identifying barriers and policy enablers, and presenting a conceptual model that integrates circular agriculture within a broader economic and institutional framework.

2. BARRIERS AND ENABLERS OF CIRCULAR AGRICULTURE

While circular agriculture holds significant promise as a sustainability-oriented production model, its implementation remains constrained by a range of structural, economic, institutional, and behavioral barriers. These challenges are not unique to agriculture but are particularly acute in this sector due to its embeddedness in ecological cycles, land tenure systems, and historically path-dependent policy frameworks.

From an economic perspective, one of the main barriers is the upfront cost of transition. Investments in composting infrastructure, precision technologies, biogas systems, or regenerative soil management techniques often require significant capital expenditures. Small and medium-sized farms, which dominate many EU agricultural landscapes, frequently lack access to financing mechanisms or are excluded from innovation funding streams (Sellami and Lavini, 2023). Moreover, market structures typically undervalue ecosystem services and circular outcomes—such as nutrient cycling or biodiversity preservation—further discouraging adoption from a cost-benefit standpoint (D'Amato et al., 2017).

Institutional and regulatory barriers also hinder the diffusion of circular practices. Although the Common Agricultural Policy has recently introduced eco-schemes, subsidies and support mechanisms are still heavily oriented toward conventional production, yield maximization, and monoculture systems (Duquennoi and Martínéz, 2022). Regulatory fragmentation across water, energy, waste, and agricultural domains creates administrative complexity for farms seeking to implement circular systems that span these sectors. In some member states, waste reuse laws or sanitary regulations obstruct the safe and legal application of composted biomass or treated wastewater in agriculture(Chiaraluce, Bentivoglio and Finco, 2021).

In addition, behavioral and informational barriers slow down the systemic transformation required for circular agriculture. Farmers often lack adequate training, peer examples, or localized evidence on the economic viability of circular practices. Risk aversion, tradition-based decision-making, and distrust of public programs can all contribute to resistance, especially in rural areas where knowledge diffusion mechanisms are weak (Rodino et al., 2023). The absence of a shared understanding of what constitutes "circularity" in agriculture further complicates both education and policy design.

Despite these constraints, a growing number of enablers are emerging, particularly within the European Union. The European Green Deal provides an overarching sustainability vision that promotes resource efficiency, emissions reduction, and regenerative land use (Fayet et al., 2022). Its operational arm in the food system, the Farm to Fork Strategy, explicitly supports the reduction of external inputs and the creation of shorter, circular value chains in agri-food systems (European Commission, 2019; 2020). The revised CAP (2023–2027) introduces new tools such as eco-schemes and conditionality frameworks that reward circular and climate-smart practices.

Beyond direct subsidies, EU programs such as Horizon Europe, LIFE, and EIP-AGRI are financing demonstration farms, cooperative innovation platforms, and digital tools that facilitate circular resource use. These initiatives foster multi-actor networks and support participatory governance models, which are essential for overcoming fragmentation and building local capacity. In parallel, new financial instruments - including green bonds, carbon farming credits, and agroecological transition funds - are being piloted to attract private investment into sustainable farming transitions (Lange et al., 2021).

Additionally, technological innovation is increasingly aligned with circular goals. Digital solutions such as remote sensing, blockchain traceability, and precision irrigation are improving the efficiency and transparency of resource flows. At the same time, circular economy business models - such as nutrient exchange platforms, shared machinery services, and closed-loop animal - crop systems - are demonstrating potential for scale-up across diverse farming contexts (Dagevos and Lauwere, 2021).

The diverse and often overlapping nature of these barriers and enablers calls for a systemic perspective. Table 2 summarizes the main obstacles and enabling factors relevant to the adoption of circular agriculture in the EU context, categorized by economic, institutional, behavioral, technological, and market-related dimensions.

Table 2. Key Barriers and Enablers of Circular Agriculture in the EU Context

Category	Barriers	Enablers
Economic	High upfront investment costs for circular technologies and infrastructure	EU subsidies (eco-schemes, CAP), green finance tools, and innovation grants
	Lack of market value for ecosystem services	Growing demand for sustainable and traceable food; carbon and nutrient trading mechanisms

Institutional	Conventional subsidy bias; regulatory fragmentation across sectors	Alignment through Green Deal, Farm to Fork, and CAP; harmonization of agri-environmental regulations
	Legal obstacles for biomass reuse (e.g., compost, treated wastewater)	Evolving EU waste and reuse directives; pilot projects validating safe use
Behavioral/Knowledge	Low awareness or trust in circular practices; risk aversion among farmers	Knowledge-sharing networks (e.g., EIP-AGRI); demonstration farms and peer-learning platforms
	Absence of unified definitions or frameworks for circular agriculture	Increased academic focus; EU policy guidance clarifying principles and outcomes
Technological	Limited access to appropriate tools or local-scale circular innovations	Growth of precision farming, digital traceability, and nutrient recycling technologies
Market Structure	Dominance of linear, input-intensive value chains	Emerging circular business models (e.g., nutrient platforms, equipment sharing, closed-loop systems)

Source: Compiled by the author based on Sellami and Lavini (2023), D'Amato et al. (2017), Duquennoi and Martínéz (2022), Chiaraluce, Bentivoglio and Finco (2021), Rodino et al. (2023), Fayet et al. (2022), Lange et al. (2021) and European Commission (2019; 2020)

Overall, the transition to circular agriculture is not merely a technical or environmental challenge, but a systemic transformation of how agriculture is organized, valued, and supported. Overcoming its barriers will require coordinated policy efforts, institutional adaptation, and inclusive capacity-building at the local level. If adequately enabled, circular agriculture could become a core pillar of a more resilient, regenerative, and economically viable European food system.

3. CIRCULAR AGRICULTURE CONCEPTUAL MODEL

The transition to circular agriculture requires more than isolated practices or technical improvements - it entails a systemic redesign of how agricultural resources are managed, valued, and connected within broader economic and environmental systems. To capture this complexity, we propose a conceptual model that integrates the principles, enablers, and expected outcomes of circular agriculture within a multi-layered framework. The model aims to synthesize theoretical and policy-oriented insights to inform future analysis and policy design. The simplified conceptual model is demonstrated in Figure 1 and its detailed description is given below.

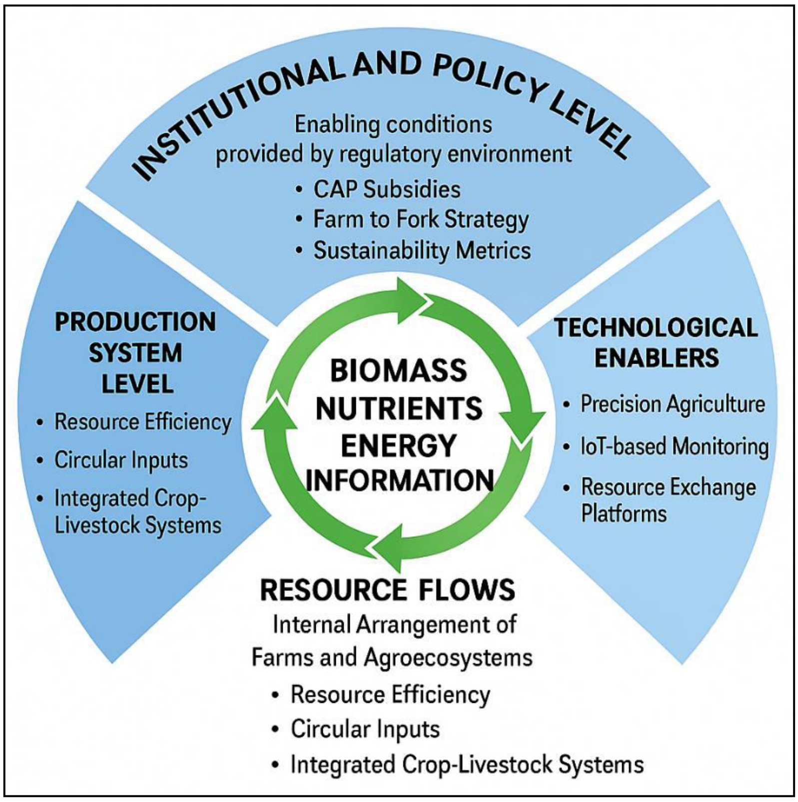

Figure 1. Conceptual Circular Agriculture Model
Source: made by the author

At the core of the model lies the circular flow of biomass, nutrients, energy, and information within and across agricultural systems. Farms are conceptualised not as isolated units but as nodes in regenerative value chains, where waste from one subsystem becomes an input for another. For example, animal manure or crop residues can be converted into compost or biogas, closing nutrient loops and reducing reliance on synthetic inputs. These flows are supported by technological enablers such as precision agriculture tools, IoT-based monitoring systems, and platforms for resource exchange.

The model is structured around four interconnected layers:

1. Production System Level – Focuses on the internal organization of farms and agroecosystems, including resource efficiency, circular inputs, and integrated crop-livestock systems.

2. Resource Flow Management– Involves supply chain actors and circular business models, such as food-waste valorization firms, local composting cooperatives, or shared logistics.

3. Institutional and Policy Level – Encompasses enabling conditions provided by the regulatory environment, including CAP subsidies, the Farm to Fork Strategy, and sustainability metrics that reward ecosystem services.

4. Technological Enablers – It involves precision agriculture, IoT–based monitoring, resource exchange platforms.

These layers interact dynamically. For example, policy instruments such as eco-schemes can incentivise circular practices at the production level, while digital traceability standards can enhance market recognition for circular products at the value chain level. Similarly, financial incentives from green bonds or EU rural development funds can accelerate investment in infrastructure that supports nutrient cycling or renewable energy integration.

The model also highlights several feedback loops and leverage points. These include knowledge diffusion (e.g., via farmer cooperatives or EU innovation hubs), data flows (from sensors to policy dashboards), and behavioral shifts (as consumers demand sustainable food). Circular agriculture, in this framing, is not a single technology or practice but a co-evolving system enabled by interactions across sectors and scales.

4. DISCUSSION

The analysis conducted in this paper shows that circular agriculture is more than a technical innovation, it is a civilizational change which disrupts the accepted agricultural economics and policy frameworks. The CA principles are based fundamentally on the blending of ecology with economics rationality, and serves as a regeneration of the linear “take-make-dispose” model.

The model elaborated on in this research highlights the circular flow of resources (biomass, nutrients, energy, data) is optimally realized when a certain level production, innovations within the value added chain, and policy level structures complement each other. This aligns with Kirchherr et al (2017) and Geissdoerfer et al (2017) as they focus on the need for integration of systems approach for the transitioning towards circular economy. Nevertheless, our model applies this reasoning to consider the agri-food system, which is particular due to the biological cycles and spatial diversity.

As the EU has created several enabling frameworks like the Green Deal and the Farm to Fork Strategy, some frameworks remain incomplete due to persistence of institutional and behavioral barriers. There is a paradox noted in our findings where there is greater political and financial support for CA, farmers are still held back by outdated subsidy systems, fragmented governance, sparse circular technology access, and regulation. This is in line with De Jesus and Mendonça’s (2018) criticism which states that the transitions to Circular Economy are largely confined to the divergence of the policies adopted and practices implemented.

The most distinguishing factor of CA is its economic framing which sets it apart from agroecology, regenerative agriculture and bioeconomy. They try to implement social or ecological objectives without market incentives, while CA aims to achieve sustainability through value recovery and closed-loop efficiency. This difference has tangible consequences for how indicators and subsidy strategies and research agendas are crafted. On the other hand, there is an unresolved issue: the agricultural focus lacks standardized circularity metrics, which hampers the scaling and benchmarking of CA initiatives. Without robust evaluation tools, efforts to mainstream CA risk becoming norm-driven instead of action-driven.

Incorporating knowledge dissemination, digital traceability, and consumer demand as feedback loops to the model’s core leverage points is a case in point. These feedback loops exemplify a dynamic and co-evolving system in which behavioral changes and institutional learning are equally as important as the technologies utilized. However, this situation also adds another layer of complexity: patterns of adoption may vary from region to region and farm to farm, indicating further testing is needed to assess the model's generalizability.

One limitation faced during this conceptual synthesis is the lack of empirical works quantifying the economic tradeoff of circular practices. Policy documents appear to be abundant, but very few seem to focus on the rigorous economic impact assessment on the farm level. This lack of documenting directly impacts the ability to rigorously validate the models provided or offer targeted prescriptive policies. More importantly, it showcases the need for research that integrates agricultural economics with environmental policy, as well as systems engineering.

To conclude, this research adds distinct value by providing a rigorously tested and theory-based-with policy implications model of circular agriculture which identifies enablers and barriers and situates circular agriculture in broader sustainabilty transitions frameworks. This is a call for shifting towards an economically rational and systemically-conscious restructuring of agri-food systems within the European Union.

CONCLUSION

This study has looked into circular agriculture as a transformative model for achieving ecological regeneration alongside economic resilience within the agri-food system. Integrating elements of the circular economy into the context of agricultural production, circular agriculture develops as a unique model defined by resource recycling, closed loops, and system-levelcoordination.

This paper outlines a conceptual model merging the synthesized practices at the production level, circular value chains, and the enabling policy instruments, underscoring the holistic character of circular agriculture. The analysis demonstrates that successful implementation relies on the complex interplay of economic drivers, technology, institutional frameworks, and action shifts. European Union frameworks such as the Green Deal and Farm to Fork Strategy offer critical enabling frameworks, however, EU financing and regulatory frameworks along with farmer engagement still remain barriers.

A key takeaway from this research is that circular agriculture should be perceived both as an environmental necessity and, equally, as an economic prospect. This reframing requires the development of standardised metrics, robust economic modelling, and more coherent policy instruments. Without these elements, circular practices risk remaining aspirational rather than operational.

This work also highlights significant gaps in empirical evidence, especially in relation to economics and put into practice the trade-offs of circular agriculture at the farm level. Closing these gaps will be important for expanding successful interventions and developing appropriate, evidence-based policies.

Future research should focus on:

1. Circular Agriculture Economic Modelling: research gaps exist in the theoretical and empirical frameworks estimating the economic consequences of circular practices as they pertain to cost-benefit analysis, labor participation, and overall efficiency of resources utilised.
2. Instrument Design and Policy Evaluation: there are knowledge gaps around the integration of CAP eco-scheme, carbon farming, and digital traceability in fostering circularity at farm and regional scales that need to be addressed.
3. Circular Behaviour and Institutional analysis: Understanding the perception of circularity among farmers, including adoption and engagement with policy frameworks, is crucial for effective program design to aid targeted, tailored support.
4. Development of Indicators and Metrics: there is a need to extend and standardise the indicators that define circularity in agriculture such as output vs inputs within EU frameworks.

5. Comparative And Cross-Sectoral Research: cross-national studies and integration with circular economy transitions in food processing, retail, and waste management sectors could provide deeper insights into systemic coordination challenges.

In summary, circular agriculture presents a compelling pathway for reimagining European agri-food systems. By grounding sustainability goals in economic logic and systemic design, it offers the potential for meaningful change-provided that research, policy, and practice move in coordinated and evidence-based directions.

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