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SYSTEMIC ENABLERS OF CIRCULAR ECONOMY TRANSITION IN THE AGRIBUSINESS SECTOR: A SYSTEMATIC REVIEW OF BUSINESS MODELS, REGULATORY FRAMEWORKS, AND WORKFORCE READINESS

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ABSTRACT

Agribusiness production still relies on the linear "take-make-dispose" model, which causes greenhouse gas emissions, food waste, and natural resource degradation. The circular economy offers an alternative through material cycle closure, waste minimization, and the regeneration of natural systems. However, previous studies have analyzed business models, regulatory frameworks, and workforce competencies separately,

leaving no systematic synthesis of their interactions. This review aims to identify circular business models, analyze regulatory drivers and barriers, and explore the systemic interactions of the three dimensions in the agribusiness supply chain. The research uses the systematic literature review method, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 guidelines, with searches across the Scopus, SpringerLink, and ScienceDirect databases using Boolean operators. Quality assessment was conducted using the Mixed Methods Appraisal Tool. Out of 904 initial articles, 32 empirical studies (2015-2025) met the inclusion criteria. The results show that waste valorization and the use of byproducts dominate circular business models, but their economic viability depends heavily on context, scale, and policy incentives. A multi-level policy framework leads to greater adoption of the circular economy than single-instrument regulations. The gap in workforce competencies, particularly digital skills and Industry 4.0 knowledge, is the most consistent cross-sectoral barrier. No study has empirically examined the simultaneous interaction of the three dimensions. Further research needs to use the Multi-Level Perspective framework to model the three factors as an interdependent system.

KEYWORDS: Circular Economy, Agribusiness Sector, Business Models, Regulatory Frameworks, Workforce Readiness.

1. INTRODUCTION

About one-third of global anthropogenic greenhouse gas emissions originate from the food system. In 2022, it emitted 16.2 billion tons of CO_2 equivalent (CO_2eq), arising from farming, land-use change, and other stages of the supply chain, both upstream and downstream of production (FAO, 2024). On the other hand, in 2022, about 1.05 billion tons of food were wasted in stores, restaurants, and homes. This was 19% of all the food that people could buy (UNEP, 2024). Food waste accounts for 8% to 10% of global greenhouse gas emissions. This is much more than the aviation industry (UNEP, 2024). More than half of the world's arable land is used for farming, and more than 70% of the world's freshwater is used for farming (Velasco-Muñoz et al., 2021). In agribusiness supply chains, linear "take-make-dispose" production models are still the norm. This makes natural resources run out faster, worsens biodiversity loss, and accelerates soil degradation (Esposito et al., 2020). The findings suggest that the current production and consumption patterns in agribusiness are inherently unsustainable.

It is becoming increasingly important to address this situation. The FAO (2009) says that global food production needs to increase by 70% by 2050 to feed a population of 9.1 billion people. Without significant changes, emissions from the agriculture sector are projected to increase substantially by 2050 relative to 2022 levels (FAO, 2024). Food waste and loss cost the world economy more than USD 1 trillion a year, and 783 million people still go hungry every day (UNEP, 2024). The effects on the environment go beyond just releasing carbon. Agriculture is responsible for more than 90% of the environmental impacts on land and water, including water shortages and biodiversity loss (Velasco-Muñoz et al., 2021). These pressures put the food supply and the long-term viability of agribusinesses worldwide at risk.

The circular economy offers a viable alternative. This concept seeks to dissociate economic growth from resource exploitation by advocating for material-cycle closure, waste minimization, and the regeneration of natural systems (Donner et al., 2020). Circular economy solutions in agriculture encompass waste valorization into biogas and compost, nutrient recycling, byproduct usage, and closed-loop supply chain design (Mehmood et al., 2021). The Ellen MacArthur Foundation (2019) Projects that implement circular economy principles in the food system might yield annual economic benefits of USD 2.7 trillion by 2050. The implementation of the circular economy in agribusiness remains fragmented. Regulatory inconsistencies, elevated transition costs, inadequate worker preparedness, and insufficient institutional support persist and continue to obstruct the transition from a linear to a circular agriculture model (Martínez et al., 2024).

Several previous studies have attempted to answer this challenge. Donner et al. (2020) classified six typologies of circular business models in agribusiness based on 39 case studies in France, covering biogas plants, recycling companies, and environmental biorefineries. Donner et al. (2021) further analyzes the success factors and critical risks of circular business models that use agricultural waste, emphasizing the roles of partnerships, subsidies, and regulatory frameworks. Mehmood et al. (2021) conducted a systematic review of 58 articles on the drivers and barriers of the circular economy in the agricultural food supply chain. Their review results show that environmental protection (67%), policy and economics (47%), and financial benefits (43%) are the main drivers. Chiaraluce et al. (2023) investigated barriers to the adoption of the circular economy through in-depth interviews with food business people in Italy. Their findings reveal that operators struggle to define a circular economy and face constraints in accessing waste data. Martínez et al. (2024) map circular practices, drivers, and barriers to traditional olive plantations in Spain. They highlight regulatory limitations and a lack of institutional support for reverse logistics. In the labor aspect, Straub et al. (2023) developed a taxonomy of employee skills needed for the implementation of circular business models. Buyukyazici and Quatraro (2025) propose an empirical framework to identify and monitor the need for circular-economy skills at the regional level.

While these contributions are important, several critical research gaps remain. Previous studies have tended to examine business models, regulatory frameworks, and workforce competencies separately. There has been no research that has systematically synthesized how these three dimensions interact as systemic drivers or inhibitors in the transition to a circular agribusiness economy. Most research focuses on the European context and specific sub-sectors, leaving the perspectives of developing countries underexplored (Mehmood et al., 2021). The economic viability of circular business models compared to conventional linear practices has also not been adequately documented through empirical evidence (Keyser & Mathijs, 2023). In addition, the intersection between regulatory design and workforce development, as a combined driver of circular-economy adoption in agribusiness, has not been discussed in the literature. These gaps limit policymakers, business leaders, and educators' capacity to design integrated strategies for the transition to the circular economy.

This study aims to fill this gap through a systematic literature review that addresses three interconnected questions: (1) identifying the circular economy business models that have been adopted in the agribusiness supply chain and their economic viability; (2) analyze the *enablers* and regulatory barriers that influence the adoption of circular practices; and (3) explore the systemic interactions between business model innovation, regulatory frameworks, and workforce competency development as enablers or barriers to the transition to a circular agribusiness economy. This research contributes to the literature by presenting an integrated cross-dimensional analysis that goes beyond the separate study of each component of the circular economy. For practitioners, these findings offer guidance on identifying the combination of business model design, regulatory support, and workforce investment that yields the strongest transition impact. For policymakers, this review shows how regulatory coherence and targeted skills-development programs can accelerate the adoption of the circular economy. This research is relevant to the global push towards Sustainable Development Goal 12.3, which aims to halve food waste by 2030. It demands evidence-based strategies that align business innovation, regulation, and human resource development in agribusiness systems (UN, 2015).

2. RESEARCH METHOD

2.1 Research Approach

This study uses a systematic literature review approach to synthesize empirical evidence on the circular economy. A systematic literature review was chosen because, over the last ten years, research on the circular economy has yielded fragmented findings and methodological variation, necessitating systematic synthesis to produce a coherent, evidence-based understanding (Chong et al., 2022). The systematic literature review method effectively integrates empirical findings across industries and time periods, thereby strengthening understanding in agribusiness (Kraus et al., 2020). To ensure reporting results using relevant articles, articles are selected from various sources in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, which provide a transparent framework for identifying, selecting, and synthesizing studies in systematic reviews (Page et al., 2021).

In this study, the articles were collected through leading international databases, namely Scopus, SpringerLink, and ScienceDirect. These three databases were chosen for their credibility and rigorous review processes for scientific publications. In addition, these three databases have access to leading international journals with strict selection criteria, thereby maintaining the quality of each article published and minimizing predatory publications and duplication. It offers a broad literature base across multidisciplinary fields, particularly in business management. Combining articles from these three databases helps authors compile comprehensive and high-quality articles.

A comprehensive analysis is enabled by integrating data from Scopus, SpringerLink, and ScienceDirect. To ensure analytical rigor, the researchers employ a systematic synthesis process based on carefully selected references. A structured screening procedure, guided by explicit inclusion and exclusion criteria, is applied to enhance relevance and minimize selection bias. Duplicate records and non-relevant articles are removed to maintain dataset integrity. The selected articles from these reputable databases ensure that the analysis remains focused on the circular economy in the agribusiness sector, particularly regarding business models, economic viability, regulatory frameworks, and green skills development.

2.2 Search Strategy and Initial Screening

To maintain a consistent focus on the article's findings, literature searches on these three databases were conducted using the same keywords. Keyword combinations are arranged using Boolean operators as follows: ((“circular economy” AND (“agribusiness” OR “agro-industry”) AND (“business model” OR “regulatory” OR “governance framework” OR “green skill” OR “workforce readiness” OR “human capital”)). The search was conducted on March 6, 2026, and yielded 904 preliminary findings, comprising 34 articles from Scopus, 123 from SpringerLink, and 747 from ScienceDirect. Additionally, the process of identifying and selecting articles follows the PRISMA 2020 flow, which includes identification, screening, and feasibility assessment, using inclusion and exclusion criteria to ensure the relevance and quality of the included studies. Specific inclusion and exclusion criteria are detailed in Table 1.

Table 1: Exclusion Inclusion Criteria.

Criteria	Inclusions	Exclusion
Year	>2015	<2015
Document Type	Article	Review Article, Book Chapter, Note, Editorial
Language	English	Non-English

Of the 904 articles in the initial stage, 15 duplicates were identified and removed using rayyan.ai, leaving 889 for filtering. Furthermore, articles were excluded based on temporal criteria (<2015; n = 5), type of article review document (n = 246), book (n = 187), conference paper (n = 9), editorial note (n = 60), and other than English (n = 2). At this stage, articles in languages other than English and documents that do not contain substantial content, such as Notes and Editorials, are also excluded. A total of 509 articles were eliminated during the initial screening, leaving 380 for full-text screening. Of these, 233 articles were inaccessible due to access restrictions, leaving 147 for the feasibility assessment stage.

2.3 Eligibility Assessment and Quality Appraisal

The next stage focuses on evaluating the article's suitability for the research question and its methodological quality. Study quality was assessed using the Mixed Methods Assessment Tool (MMAT) for non-randomized quantitative studies, incorporating two initial screening criteria and five key quality indicators. Each study was also reviewed to ensure alignment with the research objectives. Only studies demonstrating sufficient methodological rigor and reliability were included in the analysis. Articles that did not meet the MMAT criteria were excluded from subsequent stages, even if they were topically relevant.

Table 2: Assessed For Eligibility.

Category Data	Specific extraction items	Relevant	Analysis Method
Study characteristics	Author, Title, sector	Agribusiness	Statistics descriptive
Design Studies	Research Methods,	Qualitative, Quantitative, Mixed Methods	Statistics descriptive
Implementation Context	Results	Is the data collected in accordance with the RQ?	Content analysis

At this stage, several articles were excluded from the selection process because they did not meet the quality criteria based on the MMAT (n = 47) or because inconsistencies existed between the full-text content and the research questions (n = 68). Overall, 115 articles were excluded, and 32 empirical studies met the eligibility criteria for inclusion in this systematic literature review. The iterative screening process ensured that only studies that were systematically reviewed and demonstrated adequate methodological quality and conceptual relevance were included in the synthesis.

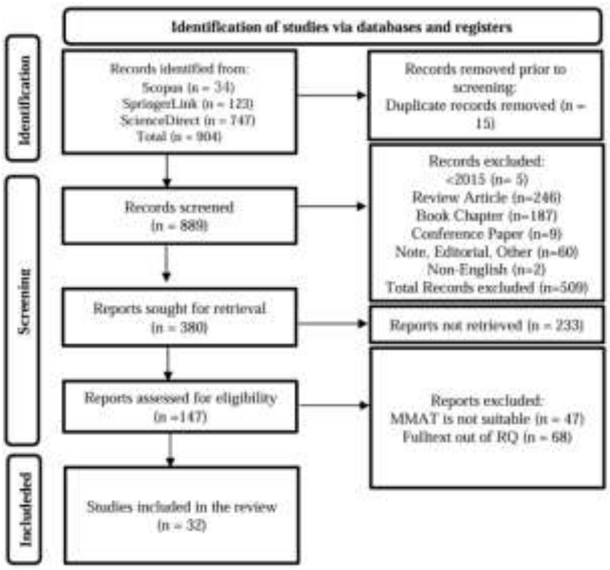

Figure 1: Research Framework.

Figure 1 presents the PRISMA flow diagram outlining the stages of article identification, screening, eligibility assessment, and inclusion in this study. The diagram shows the number of articles at each step and the reasons for exclusion, making the literature selection process traceable. The main components examined include empirical findings on the circular economy in the agribusiness sector, with a focus on economic viability, regulatory frameworks, and green skills development.

3. RESULTS AND DISCUSSION

3.1 Overview of Selected Studies

The systematic search and screening process identified 32 peer-reviewed articles published between 2019 and 2025. These studies span six continents and cover various agribusiness subsectors, including crop residue valorization, anaerobic digestion, agrifood supply chains, bioenergy, organic certification, and digital traceability. The geographic distribution shows a strong European presence (n = 14), followed by Asia-Pacific (n = 8), Latin America (n = 6), and mixed or global scope (n = 4). This range allows for cross-contextual comparison of circular economy adoption patterns, while the five-year window maintains policy and technological relevance.

Methodologically, the corpus is diverse. Quantitative approaches include mathematical modeling (Sujanto et al., 2024), regression analysis (Castillo-Díaz et al., 2023), difference-in-differences panel data (Guo et al., 2025), and cross-impact analysis (Wepner et al., 2025). Qualitative and mixed-method studies employ case studies, life-cycle assessment, longitudinal observation, systematic mapping, and ethnographic analysis. This methodological diversity enhances the robustness of the synthesis while also making it more difficult to directly compare effect sizes across studies.

3.2 *RQ1: Circular Economy Business Models and Economic Viability in Agribusiness Supply Chains*

3.2.1 Waste Valorization as the Dominant Circular Economy Business Model

Waste valorization and byproduct use are among the most common circular economy business models in agribusiness supply chains. They transform low-value residues into high-value products, generating new revenue streams and lowering disposal costs. Donner et al. (2020) identified six agro-industrial circular economy business model typologies: biogas plants, upcycling entrepreneurship, environmental biorefineries, agricultural cooperatives, agroparks, and support structures. While these models differ in their value creation and organizational structures, they all rely on partnerships among various actors and on the ability to adapt to external conditions. In Italy, biogas plants under 1 MW receive EUR 280 per MWh in subsidies for the first 15 years, whereas in Germany, feed-in tariffs are guaranteed for 20 years. Their main revenue sources include the sale of electricity, heat, and digestate, as well as waste treatment services.

These circular models considerably outperform linear practices in terms of financial and environmental sustainability. Reddy et al. (2025) provide concrete data on India's economic viability, estimating that annual agricultural residues are worth over USD 32 billion and could yield up to 14.28 billion liters of bioethanol. Water extraction technology can further reduce ethanol production costs from USD 0.87 to USD 0.70 per liter. Regarding emissions, converting one ton of straw into electricity and biogas reduces CO_2-eq emissions by 1,471 kg and 1,023 kg, respectively, significantly more than open burning. Additionally, Sujanto et al. (2024) demonstrated, through mathematical modeling, that a circular dual supply chain can generate a total profit of USD 15,805.1, much higher than that of traditional methods. It demonstrates that closed-loop supply chains for deteriorating products reduce both costs and environmental impacts compared to linear chains.

Resource efficiency and social impact are further documented through a range of global case studies. Das and Mishra (2025) report that closed-loop textile systems in East Asia reduce freshwater use by 67% and COD emissions by 48%, while in the dairy sector, interventions such as closed-loop cooling and reverse osmosis can reduce the total water footprint by 35%. AI-based wastewater treatment plants can also reduce chemical and energy consumption by 30% to 50% through real-time adjustments. Socially, Suresha et al. (2025) documented the Eco Bliss closed-loop model in Karnataka, India, which uses areca leaves to make biodegradable plates; this model employs over 500 people and has successfully raised workers' per capita income from low wages to middle-class levels. Similarly, Losada et al. (2019) reported a 6.20% reduction in carbon footprint and measurable savings in energy and fertilizer costs for wine cellar circular systems in Central Spain after three years of operation.

However, the transition to circularity faces significant hurdles regarding commercial readiness and financial self-sufficiency. Aza-Mengoa et al. (2025) note that while pineapple leaf silage as animal feed has reached technology readiness level 9 in Costa Rica, other models, such as paper pulp, remain at technology readiness level 5-7. In contrast, Awad (2023) documented the commercial failure of struvite recovery from potato waste in the Netherlands due to the abundance of cheap primary phosphate and limited secondary markets. Furthermore, Pilla et al. (2024) revealed a critical condition in Brazil's pesticide packaging closed-loop supply chain, where recycling activities generate an 87% deficit, covering only 13% of operational costs. This suggests that circular economy models in agribusiness reverse logistics often cannot be financially independent without industry subsidies, tax regulations, or the resolution of high initial investment costs and early profitability uncertainties, as noted by Losada et al. (2019). Table 3 presents the evidence of economic viability mapped across business model types.

Table 3: Mapping of Circular Economy Business Models and Economic Viability in Agribusiness Supply Chains.

Business Model / Circular Economy Approach	Economic Viability	Comparison vs. Linear	Source
Bioenergy and Biogas Systems (Agro-industrial waste, Brazilian AD, Swedish Co-digestion, Spanish Wine Cellar)	High reliance on subsidies. Italy: EUR 280/MWh; Sweden: 12% electricity bill savings; Spain: 6.20% carbon reduction. Revenue comes from electricity, heat, and digestate.	More feasible with policy incentives; non-competitive as a standalone market without external support.	Donner et al. (2020); Mühl and Oliveira (2022); Magnusson et al. (2022); Losada et al. (2019)
Biorefinery and High-Value Upcycling (India Waste-to-Biorefinery, Mexico Sugarcane, Poland Biorefinery, Upcycling General)	Scalability is key. India residue value > USD 32B (ethanol cost USD 0.70/L). Mexico shows 53% improvement opportunity. Poland requires an investment of>EUR 300 M.	Far more feasible at large scales; addresses the negative energy balance of current linear models.	Reddy et al. (2025); Díaz et al. (2025); Ayrapetyan et al. (2025); Donner et al. (2020)
Closed-Loop Manufacturing and Supply Chain (Eco Bliss Areca, Dual SC Feed, Pesticide Packaging, Textile Membrane)	Mixed financial success. Eco Bliss (India) and Dual SC show profit increases (4.3%). However, Pesticide RL in Brazil shows an 87% deficit.	Socially superior (job creation) and environmentally efficient (67% water reduction).	Sujanto et al. (2024); Suresha et al. (2025); Pilla et al. (2024); Das and Mishra (2025)
Circular Water and Resource Recovery (AI-powered wastewater treatment plants, Potato-to-Struvite, Pineapple Silage)	Technology readiness level varies. AI-based wastewater treatment plants reduces costs by 30-50%. Pineapple silage is technology readiness level 9. Struvite recovery failed due to the use of cheap primary phosphate.	High potential for resource saving, but fails if secondary markets aren't established.	Suresha et al. (2025); Das and Mishra (2025); Awad (2023); Aza-Mengoa et al. (2025)
Digital and Market-Based Innovations (Blockchain Smart Contracts, Organic Certification, Regenerative Ag, EV Batteries)	Premium pricing and efficiency. 75% of consumers pay premiums of 31-50%. Blockchain cuts costs by 50% and boosts revenue by 34%. Second-life batteries save 12.62% Total Cost of Ownership.	More efficient via digitalization; bypasses conventional certification costs and maximizes product life.	Soe et al. (2025); Castillo-Díaz et al. (2023); Valve et al. (2025); Habiburrahman et al. (2025)

3.2.2 Industrial Symbiosis and Cross-Sector Partnerships

Industrial symbiosis within agribusiness supply chains exemplifies a circular economy model in which materials, energy, water, or byproducts are exchanged between businesses, effectively turning one company's waste into another's input. This approach shifts supply chain relationships from simple transactions to closed-loop value networks, as seen with agroparks. According to Donner et al. (2020), these agroparks serve as spatial clusters of agricultural and related economic activities that close water, mineral, and gas cycles while reducing fossil energy use. However, they require strong multi-actor collaboration. The effectiveness of such teamwork is demonstrated by Magnusson et al. (2022) In their comparison of anaerobic digestion models, their study found that the Swedish multi-actor local system, which manages substrate logistics, distribution networks, and biofertilizer supply, was more competitive than the single-actor model in Parana, Brazil, achieving municipal electricity savings of up to 12% and direct payments to farmers based on biogas volume.

The scale and financial sustainability of these symbiotic networks often depend on substantial capital investment and policy backing. Ayrapetyan et al. (2025) documented industrial symbiosis in Central Europe, in which stakeholders invested over EUR 300 million in bioethanol plants, supplemented by EUR 21 million from the European Regional Development Fund to develop internal markets for the exchange of electricity and process water via dedicated pipeline networks. Despite such large investments, the lack of a policy-driven "level playing field" for bio-based products beyond ethanol continues to limit broader scalability. Similarly, in the Australian algae-based bioplastics industry, Lee et al. (2024) proposed a cooperative and mutual enterprise model that blends industrial symbiosis with wastewater-to-algae-to-bioplastics valorization, noting that carbon capture and manufacturing generate significantly greater economic value through value-added products than through carbon capture and storage alone.

While these models offer clear paths for resource efficiency, they also face significant structural and regulatory hurdles. In Brazil, Mühl and Oliveira (2022) mapped agricultural AD plants, identifying two organizational routes: large-scale plants that utilize massive biomass and smaller, decentralized units, confirming their technical and economic feasibility, while noting that unorganized markets and insufficient regulations currently limit widespread adoption. Furthermore, Gesing (2023) provides a critical view of slurry management in Germany, where the NutriBank model brings together feed producers, logistics companies, and biogas plants to transport waste. However, Gesing warns that framing the export of slurry as a circular economy approach might be problematic if it simply serves to manage disposal costs, which can reach EUR 12-15 per cubic meter, rather than transforming the underlying unsustainable agro-economic structures.

3.2.3 Closed-Loop Supply Chains and Digital Integration

Industrial symbiosis in agribusiness supply chains exemplifies a circular economy model that involves exchanging materials, energy, water, or byproducts among different businesses, effectively turning waste from one business into an input for another. This approach shifts supply chain relationships from single transactions to closed-loop value networks, as seen in agroparks. According to Donner et al. (2020), these agroparks serve as spatial clusters of agricultural and related economic activities that close water, mineral, and gaseous cycles while reducing fossil energy use, although they require extensive multi-actor collaboration. The success of such collaboration is demonstrated by Magnusson et al. (2022) in their comparison of anaerobic digestion models, where the Swedish multi-actor local system, which integrates substrate logistics, distribution networks, and biofertilizer supply, is more competitive than the single-actor model in Paraná, Brazil, saving up to 12% of municipal electricity and providing direct payments to farmers based on biogas volume.

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3.2.4 Systemic Barriers to Circular Economy Business Model Adoption

Barriers to adopting circular economy business models extend beyond financial issues and encompass challenges at the micro, meso, and macro levels. At the micro level, individual businesses face major obstacles related to technical and financial capacity; for example, Donner et al. (2020) highlight that upcycling agro-industrial byproducts is often not cost-effective due to low market prices, seasonal availability, high moisture content, and inconsistent resource quality. These technical problems are exacerbated by Sgroi's (2022) findings on the fragmented structure of small-scale farming in Italy, where limited capital and low self-financing capacity prevent smallholders from having sufficient time and resources to achieve a return on investment. Likewise, Howard et al. (2022) point out that small and medium-sized enterprises (SMEs) face difficulties with funding, specialized skills, and supportive networks, making the shift from simple waste reduction to full-scale circular practices especially challenging because it requires ongoing commitment and resources.

Logistical and infrastructural constraints pose a significant meso-level barrier, particularly in the physical handling of agricultural residues. Aza-Mengoa et al. (2025) describe a major logistical challenge in Costa Rica's pineapple industry, where moving 9 million tons of high-moisture biomass would require 175,000 containers annually, making the process inefficient and extremely costly. Reddy et al. (2025) similarly highlight these issues in India, where high upfront investments in advanced thermochemical conversion facilities and the costly logistics of residue collection and transportation pose serious economic obstacles for farmers. Additionally, these logistical problems are often worsened by a lack of social capital; as Aza-Mengoa et al. (2025) note, startups frequently face deep-seated distrust from producers and a general lack of awareness of the long-term benefits of circular collaboration.

At the macro level, regulatory and market-driven barriers significantly constrain the scalability of circular models. Awad (2023) highlights critical regulatory hurdles, such as EU bans on certain secondary phosphate fertilizers derived from recycled waste, and a lack of market awareness or incentives for sustainable phosphate products. This regulatory disconnect is further analyzed by Pilla et al. (2024) in Brazil, where structural tax discrepancies, specifically, higher tax rates on recycled materials than on virgin raw materials, make circularity unattractive to value chain participants. These findings challenge the common belief that firm-level economic incentives alone can drive the circular economy transition, underscoring the need for comprehensive policy reform to create a level playing field against established linear systems.

3.3 RQ2: Regulatory Environment Shaping Circular Economy Adoption in Agribusiness

3.3.1 Sectoral Agricultural Policy: Common Agricultural Policy and National Programmes

Agricultural policy, particularly the EU common agricultural policy, emerges as the dominant regulatory factor shaping the adoption of the circular economy. Castillo-Díaz et al. (2023) empirically demonstrated that Total CAP Investment (standardised beta: 0.380) and Market Measures CAP (beta: 0.381) are significant positive predictors of the composite sustainability index across EU agrifood sectors. Castillo-Díaz et al. (2024) confirmed that FEAGA and FEDER subsidies directly improved social sustainability in the Seville region. However, the effects of the common agricultural policy are not uniform. Sgroi (2022) observed that repeated common agricultural policy reforms created market distortions, while Losada et al. (2019) found that direct subsidies induced risk aversion among viticulture farmers in central Spain, thereby suppressing the motivation to invest in circular-economy innovation. This dual effect macro-level investment promotion, paired with individual-level dependency, represents a structural paradox in European agrifood circular economy policy (Donner et al., 2020).

3.3.2 Bioenergy and Biogas Policy: Quantifiable Causal Effects

Bioenergy and biogas policy produces the most quantitatively traceable causal effects in the literature. Mühl and Oliveira (2022) documented that Brazil's ABC Program (2010) triggered a tenfold increase in anaerobic digestion installation—from an average of 5 plants per year (2003–2011) to 51 per year (2012–2020). In Sweden, Magnusson et al. (2022) recorded a fivefold increase in the volume of digested manure between 2009 and 2019, attributing this directly to a special government subsidy scheme combined with renewable fuel tax exemptions. In France, Ayrapetyan et al. (2025) documented that mandatory biofuel blending regulation (2007) catalysed EUR 272 million in local bioeconomy investment.

In contrast, Lee et al. (2024) identified the lack of sustained government incentives as the key reason algae-based biofuels failed to scale in Australia. Sujanto et al. (2024) added modelling evidence that carbon cap-and-trade schemes consistently outperform carbon taxes in reducing total supply chain cost and energy consumption. Donner et al. (2020) cautioned that progressively declining feed-in tariffs create investment uncertainty for biogas operators, particularly after 20-year subsidy guarantees expire, underscoring the importance of long-term regulatory stability.

3.3.3 Regulatory Gaps and Institutional Barriers

Regulatory gaps are the most consistent barrier identified across geographies and sectors. Awad (2023) documented that EU waste classification legislation, which categorises products made from waste as waste themselves, was the primary obstacle to the commercialisation of secondary phosphorus in the Netherlands for over a decade. No regulations mandated phosphorus recycling; the government's laissez-faire approach placed full responsibility for innovation on industry, without economic incentives to act. Kaewchutima et al. (2025) found that Thai agricultural policy lacks measurable targets for greenhouse gas reduction, renewable energy, and waste reduction, and is reactive rather than preventive, changing with each successive government administration.

In Indonesia, Habiburrahman et al (2024) found that voluntary EPR under Government Regulation No. 81/2012 failed to drive systematic circular-economy adoption, with no specific regulations for electric-vehicle battery recycling. Howard et al. (2022) identified the absence of agreed circular economy accreditation standards as the most significant barrier for European SMEs. Gesing (2023) added a political dimension: intensive agricultural lobbying in Germany prevented stricter environmental regulations for decades, until the European Commission threatened fines of EUR 850,000 per day in 2017. In Costa Rica, Aza-Mengoa et al. (2025) documented that leadership discontinuity following government changes halted the momentum of the National Bioeconomy Strategy, forcing international cooperation agencies to take over coordination. Fiscal paradoxes also emerge in Brazil, where Pilla et al. (2024) demonstrated that although industrial structures achieve a 95-96% return rate for pesticide packaging, the lack of tax incentives for recycled materials relative to virgin raw materials renders supply chain operations economically inefficient.

3.3.4 Extended Producer Responsibility Regulations and Certification

Extended producer responsibility and certification schemes are regulatory tools with varied impacts on promoting the circular economy in agribusiness, highlighting notable differences between developed and developing countries. Pilla et al. (2024) present a compelling example: Brazil's Law No. 14.785/2023 requires pesticide producers to manage used packaging, achieving return rates over 95%. However, this reveals a key paradox: success is not solely due to regulation but also depends on industrial structures in place before the law. At the same time, the lack of tax incentives still distorts cost efficiency. Lilavanichakul et al. (2025) further analyzes this disparity, showing that developed nations enforce mandatory extended producer responsibility with strong compliance, whereas developing countries such as Thailand rely primarily on weak voluntary efforts. In Indonesia, Habiburrahman et al. (2025) confirm that voluntary extended producer responsibility under Government Regulation No. 81/2012 has failed to promote systematic adoption of the circular economy, in contrast to the EU's mandatory extended producer responsibility system for batteries, which requires manufacturers to finance the entire recycling process.

International certifications and market-driven mandates have proven to be equally effective drivers of circular economy adoption, especially through export channels. Aza-Mengoa et al. (2025) documented that Rainforest Alliance and Fair Trade certifications prohibit open burning and promote the environmentally friendly reuse of pineapple residues in Costa Rica, while the European Green Deal acts as a direct motivator for producers to change their practices to keep market access. Adding a technological aspect, Soe et al. (2025) show that Thailand's organic certification regulations, such as the Personal Data Protection Act 2019 and the Thailand Greenhouse Gas Management Organization – Greenhouse Gas Methodology 2023, have been successfully integrated into blockchain protocols, turning static policies into an active part of supply chain traceability systems. Despite these advancements, structural and legal definitions remain significant obstacles for the industry. Awad (2023) identified a fundamental barrier in EU legislation: waste classification remains inflexible. As long as the system treats a product made from waste as "waste" rather than a secondary resource, it creates a major hurdle to the commercial development of agro-waste circular products. This institutional "way of thinking," which emphasizes disposal over recovery, mirrors findings in Brazil, where the lack of fiscal incentives for recycled materials makes the entire circular supply chain less competitive than linear alternatives.

3.3.5 Effective Multi-Level Policy Frameworks

Findings across the analyzed articles indicate that a multi-level policy framework that coherently integrates national, sectoral, and local instruments leads to more effective adoption of the circular economy than standalone regulations. Zhao et al. (2025) found that such a policy framework is the most critical enabler for the adoption of Industry 4.0 and circular economy technologies in agrifood supply chains. This is evident in China, where rural revitalization policies and new infrastructure plans send strong signals to supply chain actors. To address regional diversity, Castillo-Díaz et al. (2024) recommend "green architectures" based on the 10 pillars of the Common Agricultural Policy (CAP), a differential policy model empirically proven to be relevant for the diverse European agribusiness landscape.

The success of these frameworks often relies on policy consistency and complementary tools rather than isolated efforts. Magnusson et al. (2022) emphasize that Sweden successfully promoted the adoption of anaerobic digestion through a mix of landfill bans on organic waste, incentives for biogas vehicles, and specific manure subsidies that work together. Conversely, Paraná, Brazil, experienced regulatory fragmentation between the federal and state levels, hampering the development of the biogas market. Similarly, Reddy et al. (2025) observed that China's post-2013 model, which combined strict enforcement with alternative subsidies, effectively reduced agricultural residue burning, while Brazil's RenovaBio offers a structured market-based bioeconomy framework for agro-waste valorization.

Furthermore, moving toward systemic change requires goal-oriented and incentive-driven strategies. Fielke et al. (2025) argue that "mission-oriented policies," co-developed by governments and research institutions, are more effective at driving systemic shifts than conventional regulations. Practical evidence from Colombia, provided by Vandana and Cerchione (2025), shows that combining concrete fiscal incentives, such as Law 1715 (50% tax deduction and VAT exemptions for renewable energy equipment), with an ambitious national bioeconomy agenda creates a conducive environment for the adoption of the circular economy among SMEs. Finally, Kaewchutima et al. (2025) emphasize that a preventive policy framework featuring measurable targets, clear deadlines, and robust enforcement mechanisms, such as the Sustainability Assessment of Food and Agriculture Systems model, is a fundamental prerequisite for an effective, sustainable agricultural transition. Table 4 presents the complete regulatory mapping.

Table 4: Regulatory Factors Influencing Circular Economy Adoption in Agribusiness.

Category	Regulatory Mechanisms and Instruments	Findings and Directions	Source
Direct Subsidies and Financial Support	Common agricultural policy investment, European Agricultural Guarantee Fund/ European Regional Development Fund, Agricultura de Baixo Carbono Program (Brazil), European Agricultural Fund for Rural Development, Sweden Manure Subsidies	High Impact but Mixed Outcomes. Direct funding and subsidies significantly boost sustainability indices and bioenergy adoption (e.g., 5-fold increase in Swedish manure digestion). However, they can create "inertia" and risk aversion, making farmers dependent on subsidies rather than independent innovation.	Castillo-Díaz et al. (2023); Castillo-Díaz et al. (2024); Losada et al. (2019); Mühl and Oliveira (2022); Magnusson et al. (2022)
Mandatory vs. Voluntary Extended Producer Responsibility and Standards	Law 14.785 (Brazil), EU Battery Extended Producer Responsibility, Indonesia Government Regulation 81/2012, Single-Use Plastic Ban (EU 2019/904)	Mandatory Requirements Drive Results. Mandatory extended producer responsibility achieves return rates of up to 96% for packaging. In contrast, voluntary extended producer responsibility in developing countries (Indonesia, Thailand) results in weak enforcement and non-systematic adoption.	Pilla et al. (2024); Habiburrahman et al. 2025); Donner et al. (2020); Lilavanichakul et al. (2025)
Legal Definitions and Market Access	Waste Classification Laws, Struvite Legalization, Biofuel Blending (France), Law 14.134 (Brazil)	Regulatory "Bottlenecks." Classifying recycled products as "waste" prevents them from entering the fertilizer or feed markets. Legalizing these products (e.g., Struvite in 2014) or granting "equivalence" to fossil versions (e.g., biomethane in Brazil) is essential for commercial trade and cross-border deals.	Awad (2023); Ayrapetyan et al. (2025); Mühl and Oliveira (2022)
Strategic Targets and Environmental Pacts	Farm to Fork, EU Green Deal, National Bioeconomy Strategies (Australia, Costa Rica), Thailand GHG Targets	Need for Continuity. Quantitative targets (e.g., a 50% reduction in pesticide use) push producers to innovate for export markets. However, a lack of national strategies or "policy shelving" after government changes (as in Costa Rica) halts long-term investment momentum.	Castillo-Díaz et al. (2024); Lee et al. (2024); Aza-Mengoa et al. (2025); Kaewchutima et al. (2025)
Market-Based and Digital Incentives	Carbon Cap-and-Trade, Fuel Tax Exemptions, Blockchain Certification, Organic Premiums	Efficiency through Innovation. Carbon trading is considered more efficient than taxes for clean-tech investment. Tax exemptions help renewables compete with fossil fuels. Digitalizing policy via blockchain transforms regulation into an "active agent" for SMEs to access carbon markets.	Sujanto et al. (2024); Magnusson et al. (2022); Soe et al. (2025); Castillo-Díaz et al. (2023)
Institutional and Political Barriers	Lobbying (Germany), Regional Fragmentation (Italy/Thailand), SME Accreditation Gaps	Structural Resistance. Strong agricultural lobbies and fragmented regional laws impede the implementation of strict environmental regulations. The absence of universal circular economy accreditation (such as Cradle to Cradle) remains a major hurdle for SMEs to demonstrate circularity.	Gesing (2023); Ruggeri et al. (2025); Howard et al. (2022); Lilavanichakul et al. (2025)

3.4 RQ3: Systemic Integration and Workforce Readiness in the Circular Agribusiness Transition

3.4.1 Workforce Competency Gap as the Most Consistent Barrier

Labor competency gaps are the most consistent barrier in the literature on the transition to circular agribusiness. Zhao et al. (2025) found that willingness to learn new knowledge and skills in Industry 4.0 and the circular economy ranked highest among 27 identified enablers in the Chinese agrifood supply chain. However, this study also highlights a serious demographic paradox: many young workers are migrating away from rural areas, leaving behind farmers aged 50–70 who struggle to adopt new ideas. This suggests that the skills gap is not just about technical training but also involves broader issues in human resource renewal in agriculture.

From a technical and managerial perspective, Donner et al. (2020) documented that, in most of the researched agro-waste cooperatives, members lacked the professional background to manage valorization units, making expert assistance essential for implementation. Similarly, Habiburrahman et al. (2025) identified that workforce competency certification in waste management technology is a top weakness for EV battery waste management companies in Indonesia. These findings are supported by quantitative evidence from Wepner et al. (2025), whose cross-impact analysis in Lower Austria showed that digital competence and agricultural education received the highest active impact scores among 35 factors, indicating that these variables are the most influential leverage points in agrifood system transformation.

The lack of specialized expertise extends to safety protocols and conceptual understanding across various global contexts. Reddy et al. (2025) emphasized that many local farmers and entrepreneurs in India lack technical skills in waste processing and commercialization strategies. This conceptual knowledge gap is further echoed by Aza-Mengoa et al. (2025) in Costa Rica, where the bioeconomy concept remains poorly understood by stakeholders, creating significant limitations for researchers trying to transfer knowledge to small-scale producers. Notably, while these articles address the skills gap individually, there is very limited evidence in the literature on how this factor interacts with regulation and business models.

3.4.2 Regulatory Fragmentation and Policy Voids

Weaknesses in the regulatory framework create systemic barriers at the meso and macro levels, generating uncertainty that impedes long-term investment in circular business models. According to Kaewchutima et al. (2025), Thailand's agricultural policies tend to be reactive rather than proactive. Because most are not legally binding and depend heavily on local implementation, their effectiveness varies greatly across regions. The absence of specific, measurable targets with clear deadlines complicates the evaluation of the success of agricultural sustainability initiatives. Howard et al. (2022) also highlight that this institutional challenge is reflected in European SMEs, where the lack of a cross-stakeholder consensus on circular economy principles and standardized accreditation remains the biggest obstacle to adoption.

The trajectory of technological adoption is also deeply influenced by national economic institutions and the maturity of the socio-technical system. Magnusson et al. (2022) explain through a comparative study of anaerobic digestion in Sweden and Brazil that navigating regulatory environments is particularly difficult for emerging systems because appropriate policies and standards often do not exist in the early stages. Their study uses the Varieties of Capitalism (VoC) framework to show how differences between a coordinated market economy like Sweden and a liberal market economy like Brazil lead to vastly different paths for circular economy technology adoption.

Conversely, well-targeted and proactive regulations can serve as transformative enablers rather than mere constraints. Guo et al. (2025) empirically demonstrated using a difference-in-differences model on Chinese agribusiness panel data that public data openness regulations significantly drive sustainable development, particularly in regions with high-innovation environments. This highlights the potential of proactive policy to catalyze progress. However, it is important to note that most current research treats regulation as an isolated factor rather than analyzing its simultaneous interaction with business models and human resource competencies.

3.4.3 Structural Barriers and System Lock-in

Structural lock-ins are the most significant barriers to switching to circular agribusiness. Gesing (2023) ethnographically showed that, in western Germany, expanding manure transport networks reinforced existing intensive livestock farming structures rather than changing them, demonstrating that socio-technical innovation can strengthen the status quo rather than disrupt it. Ayrapetyan et al. (2025) highlighted a corporate-level lock-in: incumbents focus on short-term profits and establish strong technological lock-ins in natural resource use, remaining hesitant to diversify into high-value bio-products even when policies support such diversification. Awad (2023) identified a critical conceptual barrier: research that remains firm-centric fails to capture the complexity of collective action in circular transitions, treating external context and stakeholders as mere enablers or barriers for individual firms rather than as co-constitutive elements of the transition system. Castillo-Díaz et al. (2023) found, from composite indicator data across 27 EU member states, that no single country achieved maximum scores on all sustainability indicators, indicating a real trade-off between economic expansion and environmental quality, meaning that an overly rapid green transition risks excluding socio-economically important local production systems in rural regions.

3.4.4 The Three-Factor Integration Gap

This review identifies a significant gap in the existing literature: none of the 32 articles in the sample empirically and simultaneously examine the interaction among all three factors—business model viability, regulatory environment, and workforce competency—as an integrated system. Instead, the literature presents partial analyses of two-factor interactions. Kaewchutima et al. (2025) and Guo et al. (2025) explore the linkages between regulation and business models. Donner et al. (2020) and Zhao et al. (2025) examine connections between workforce and business models. Habiburrahman et al. (2025) mention government-workforce facilitation but do not provide empirical causal testing. This gap serves as the main theoretical contribution of this review and underscores the need for future research to use a multi-level perspective (Geels, 2002; Markard et al., 2012) or transition management frameworks to model all three factors as a connected, interdependent system (Rotmans et al., 2001).

Table 5: Systemic Integration Factors and Workforce Readiness in Circular Agribusiness Transition.

Systemic Category	Interacting Factors and Dimensions	Findings on Role and Impact	Source
Human Capital and Competency Gaps	Managerial Skills, Digital Literacy, Technical Expertise, and Conceptual Bioeconomy knowledge.	Critical Barrier & Leverage Point. Digital and managerial competencies are the highest-leverage points for the transition; however, an aging workforce and rural "brain drain" create a demographic paradox. Lack of technical safety and commercialization skills prevents the operationalization of infrastructure.	Wepner et al. (2025); Donner et al. (2020); Habiburrahman et al. (2025); Zhao et al. (2025); Aza-Mengoa et al. (2025); Reddy et al. (2025)
Regulatory Gaps and Policy Uncertainty	Reactive vs. Preventive Laws, Lack of Measurable Targets, Standards/Accreditation, and Public Data Openness.	Systemic Barrier to Investment. Inconsistent and "reactive" policies (enacted after problems occur) create high uncertainty. The absence of a "common language" (CE accreditation) and specific waste management laws leaves actors without a legal foundation, though "Public Data Openness" serves as a rare proactive enabler.	Kaewchutima et al. (2025); Magnusson et al. (2022); Howard et al. (2022); Sgroi (2022); Guo et al. (2025); Habiburrahman et al. (2025)
Structural and Institutional "Locks"	Intensive Farming Reproduction, Incumbent Resistance, Path Dependency, and Enterprise Fragmentation.	The "Status Quo" Guard. Existing systems are often "locked in" by large incumbents who prioritize short-term profits over high-value diversification. Small farm size limits capital for "innovation time," while improved logistics sometimes paradoxically reinforce intensive linear structures rather than circular ones.	Gesing (2023); Ayrapetyan et al. (2025); Sgroi (2022); Magnusson et al. (2022); Castillo-Díaz et al. (2023)
Partial Interactions and Theoretical Gaps	Regulation + Business Model, Competence + Business Model, Individual Knowledge + Organization.	Fragmented Evidence. Existing research only captures "two-factor" interactions (e.g., how regulation affects a business model). There is a significant Systemic Gap in which no empirical evidence simultaneously tests the interaction among Business Model, Regulation, and competence as a unified system.	Kaewchutima et al. (2025); Guo et al. (2025); Pilla et al. (2024); Donner et al. (2020); Zhao et al. (2025); Habiburrahman et al. (2025)

3.5 Cross-Cutting Findings and Integrated Analysis

3.5.1 Context Dependency is the Most Robust Cross-Study Finding

Across all three research questions, the most consistent and overarching finding is the importance of context dependence. The viability of circular economy business models, regulatory effectiveness, and workforce readiness are not solely determined by the circular economy approach or policy tools but are shaped by the institutional environment, scale, and development stage of each setting. Northern Europe's coordinated market economies (such as Sweden, Germany, France, and the Netherlands) show markedly different adoption patterns compared to Latin America's liberal market economies (Brazil, Mexico, Costa Rica) or the developing-country regions of South and Southeast Asia (India, Thailand, Indonesia), even when the technological solutions involved are identical.

This finding aligns with the Varieties of Capitalism framework used by Magnusson et al. (2022) and the multi-level perspective literature on socio-technical system transitions. It suggests that policy recommendations and business model designs should be tailored to specific contexts rather than applied universally. A biogas subsidy scheme that causes a tenfold increase in installations in Brazil might result in dependency and hinder innovation in a European context, where direct subsidies already heavily influence farmers' decisions (Losada et al., 2019; Sgroi, 2022)

3.5.2 The Interdependence of the Three Dimensions

The findings from RQ1, RQ2, and RQ3 are interconnected. They form an interdependent system. A viable circular economy business model needs regulatory certainty to secure long-term investment; without it, even economically promising models (such as biogas and biorefineries) stall. Conversely, regulation alone is not enough without a workforce capable of implementing the necessary technical and organizational changes. Wepner et al. (2025) found that digital competence is the highest-impact leverage point in agrifood transformation systems, combined with Zhao et al. (2025) identification of knowledge and willingness to learn as top circular economy enablers, indicates that workforce readiness is not merely downstream of business model and regulatory development but co-constitutive of it.

The most successful cases in the literature—namely Sweden's anaerobic digestion ecosystem, France's bioeconomy cluster, the Eco Bliss model in India (Suresha et al., 2025) , and the blockchain certification system in Thailand (Soe et al., 2025)—all share three common features: an economically viable and clearly structured business model, a stable and supportive regulatory environment, and actors with sufficient technical and managerial skills to implement and maintain the system. The failure cases of struvite recovery in the Netherlands (Awad, 2023), algae bioplastics in Australia (Lee et al., 2024), and pesticide packaging CLSC in Brazil each lacks at least one of these three conditions (Pilla et al., 2024).

3.5.3 The Green Transition Equity Concern

Castillo-Díaz et al. (2023) identified a trade-off between economic expansion and environmental quality indicators across EU member states: no country simultaneously maximises performance on both dimensions, and a rapid green transition risks excluding local production systems with high socioeconomic significance in rural regions. This finding should caution policymakers against treating circular economy transitions as uniformly beneficial. The benefits of circular economy adoption, improved profitability, environmental performance, and supply chain resilience are real but unevenly distributed. Small agribusiness firms (Sgroi, 2022), rural smallholders in developing countries (Reddy et al., 2025; Aza-Mengoa et al., 2025), and workers in resource-dependent communities (Gesing, 2023) bear disproportionate transition costs without necessarily capturing equivalent benefits. A socially just circular agribusiness transition, therefore, requires policy instruments that are not only environmentally effective but also redistributively sensitive, ensuring that the costs of structural change do not fall disproportionately on the actors with the least capacity to absorb them.

4. CONCLUSION

This systematic literature review synthesizes empirical evidence from 32 peer-reviewed articles (2019–2025) on the adoption of the circular economy in agribusiness supply chains. The findings identify three key dimensions that shape circular economy implementation: business model viability, regulatory frameworks, and workforce capability, all within the broader system integration. Waste valorization and byproduct reuse emerge as the most prevalent models, followed by industrial symbiosis and closed-loop supply chains. Economic outcomes remain highly context-dependent, ranging from profitable large-scale implementations to unviable cases constrained by weak secondary markets and costly reverse logistics. Coherent policy frameworks across governance levels are more effective than fragmented approaches, yet persistent gaps—such as unclear waste classification and weak enforcement—continue to hinder adoption. Workforce capability, particularly digital competence, represents a critical constraint, exacerbated by rural demographic decline. The transition toward a circular economy is inherently a collective action problem requiring multi-stakeholder coordination, with cooperatives playing a key intermediary role. Notably, no study in the sample empirically examines the interaction of these dimensions within a unified analytical framework. Future research should adopt transition management or multi-level perspectives to model these dynamics holistically, with greater emphasis on longitudinal and mixed-methods studies in developing regions.

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