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Transitioning towards Circular Agriculture for Sustainable Food Security: An Analytical Study of Regulatory Frameworks and Pioneering Initiatives from the Dutch Experience

Oumeddour Lamia ¹

<https://orcid.org/0009-0001-1632-5948>

PhD, University 8 Mai 1945 Guelma, Algeria,

Email: oumeddour.lamia@univ-guelma.dz

Bousnoubra Abdelali²

<https://orcid.org/0009-0006-3836-5410>

PhD, University of 20 August 1955 Skikda, Algeria,

E-mail: a.bousnoubra@univ-skikda.dz



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Abstract

This study examines the transition towards circular agriculture as a strategic imperative for restructuring food systems on sustainable foundations, through an analysis of policy frameworks and pioneering initiatives drawn from the Dutch experience. Employing a descriptive-analytical methodology alongside a case study approach applied to the "Kipster" and "Protix" initiatives, the findings reveal high resource valorization efficiency; these models succeeded in reducing carbon emissions and releasing vast tracts of agricultural land. The financial analysis, however, indicates divergent performance outcomes: while the "Kipster" model achieved tangible operational savings, the "Protix" model faced capital intensity challenges stemming from the complexity of the technologies employed. The study concludes that the success of this transition hinges on the integration of the "Golden Triangle" model, flexible regulatory frameworks, and sustainable green financing. It recommends that Algeria accelerate the activation of a national biomass valorization economy and the decoupling from global raw material supply chains, thereby ensuring sustainable food sovereignty for future generations.

¹ PhD in Laboratory of Auto Development and Good Governance, University 8 Mai 1945 Guelma, Algeria (2023); a Master's degree from University of Badji Mokhtar, Annaba, Algeria. (2011); a PhD in from university of Larbi Ben M'hidi - Oum el bouaghi, Algeria (2024).

² PhD in Faculty of Law and Political Sciences University of 20 August 1955 Skikda, Algeria (2008); a Master's degree in Law from University of Badji Mokhtar, Annaba, Algeria, (2007); a PhD in Law from Faculty of Law University of Badji Mokhtar, Annaba, Algeria, (2023).

Introduction

The contemporary global food system is confronted with fundamental structural imbalances in its productive architecture, attributable in particular to the dominance of the linear economy predicated on the extraction of resources, their production, and their subsequent disposal. This modality has engendered a manifest deficit in the capacity of existing production systems to meet food security requirements amid demographic explosion, the intensification of geopolitical crises, and the emergence of environmental, economic, and regulatory challenges. These are epitomized most notably in the depletion of natural resources, the escalation of greenhouse gas emissions, excessive dependence on global fluctuations in energy and chemical input prices, the rigidity of legislative frameworks that continue to classify secondary resources as waste rather than raw materials, and the absence of unified international standards governing food safety protocols for novel circular inputs.

This reality necessitates the establishment of a regulatory and legal framework that embraces circular agriculture as a strategic option aimed at valorizing biomass, closing resource loops, and restoring natural capital to guarantee the right to food for future generations. From this vantage point, the Dutch experience emerges as a global benchmark that has succeeded in institutionalizing this transformation through the formulation of an integrated legislative and institutional ecosystem that balances the imperatives of economic efficiency with the obligations of environmental responsibility.

Accordingly, the research problematic of this study crystallizes around the following fundamental question: **How can circular agriculture, as an alternative economic model, address the structural deficiencies of the linear paradigm in securing food, and what mechanisms are required to achieve a balance between productive efficiency and environmental sustainability?**

The significance of this study lies in presenting and analyzing a pioneering global model—the Dutch experience—to elucidate how circular transformation can reduce external dependence and ensure food sustainability through technical innovations and flexible policies. This study seeks to achieve pivotal objectives encompassing the analysis and evaluation of Dutch policies and pioneering initiatives in terms of their economic and environmental viability, culminating in an assessment of the prospects and challenges of localizing this model in Algeria, in alignment with state orientations towards national biomass valorization and the achievement of food sovereignty. Consequently, this necessitates the adoption of an integrative approach that bridges the economic and legal dimensions to address this problematic, contributing to the formulation of a comprehensive policy that balances investment feasibility with the legislative controls governing the circular transition.

To achieve these objectives, the study relied on the descriptive-analytical method, grounded in the analysis of official documents and reports issued by international and national bodies, complemented by the case study method for evaluating Dutch field initiatives, thereby ensuring a profound understanding of operational mechanisms, investment payback periods, and opportunities for replication within the Algerian context.

1. Conceptual Framework of Circular Agriculture and Food Security

Circular agriculture emanates from the concept of the circular economy, which refers to an economic system that replaces the notion of end-of-life through reducing the resources used, or reusing, recycling, and recovering them in production, distribution, and consumption processes (Kirchherr et al., 2017). In this context, circular agriculture

constitutes an economic-productive model that seeks to address the shortcomings of the traditional linear system, which relies on extracting natural resources, transforming them into products, and subsequently disposing of them as waste after use. It achieves this through maximizing the efficiency of natural resource utilization and closing material and energy flow loops. Academically, this concept is anchored in the principle of functional integration between crop and livestock production to reduce dependence on external inputs and non-renewable resources.

1.1. Definition of Circular Agriculture and Its Economic Foundations

Scholars, researchers, and policymakers converge on positioning circular agriculture as a promising strategic pathway for transforming the global food system. Despite this consensus on the importance of this transformation, no unified definition exists within academic and institutional circles, rendering the concept somewhat ambiguous and making it difficult to delineate precise boundaries separating it from other related concepts. Terms such as circular agriculture, circular economy in agriculture, the circular economy in agri-food systems, circularity in food systems, and the circular bioeconomy are frequently used interchangeably, notwithstanding the divergence in their analytical scopes. Whereas the focus of circular agriculture centers on closing nutrient loops within farm boundaries, the concept of circular economy in food systems, for instance, extends to encompass the efficiency of the entire value chain, from primary production through to final consumption and waste management, making the precise distinction between these levels a methodological imperative for understanding transformation mechanisms and their impact on sustainable food security.

Nevertheless, the overarching spirit of circular agriculture generally resides in the transition from the traditional model predicated on the principle of "extract-produce-consume-dispose" to a model in which waste and loss are prevented, secondary products are reused and recycled, resources and organic matter lost along the food supply chain are valorized, environmental conditions are improved, and nutrients and biomass are utilized more efficiently to feed humanity (Jurgilevich et al., 2016; De Boer and Van Ittersum, 2018; Khatami et al., 2024). Circular agriculture is also considered a model for food production and consumption that operates to protect the health of agricultural ecosystems and prevents the loss and waste of biomass and nutrients. It also reuses and recycles unavoidable residual flows in an efficient manner, while minimizing energy consumption to the lowest possible level (Silvius et al., 2023).

From an international institutional perspective, the Food and Agriculture Organization defines the circular economy in agriculture as a sustainable model applicable as an alternative to the current linear economy based on the "extract-manufacture-dispose" principle, through minimizing external inputs for agricultural production, closing nutrient loops, and reducing negative environmental impacts through the elimination of discharges and surface runoff (FAO, n.d.). The Ellen MacArthur Foundation, for its part, considers the circular economy for food as a system that transcends the traditional concept of sustainability to reach regenerative agriculture, aiming to eliminate waste and recycle nutrients, and to rebuild natural capital such as soil health and biodiversity, through mimicking natural ecosystems where organic matter safely returns to the earth (Ellen MacArthur Foundation, 2019; Ellen MacArthur Foundation, n.d.).

At the regulatory level, the European Commission has legally framed this concept with the objective of establishing strategies to ensure that the agricultural sector becomes a lever for restoring natural capital in Europe, by enhancing the sustainability of

renewable biological materials and combating food waste and loss. It adopted binding targets, activated the regulation on water reuse in agriculture, developed a nutrient management plan, and launched legislation to reduce single-use packaging, thereby ensuring a legal framework that promotes the circular economy in food, water, and nutrients (European Commission, 2020).

Based on the foregoing, it can be posited that circular agriculture is a sustainable economic and productive model that aims to close the loops of resource and nutrient flows within the agricultural system, through reducing dependence on external inputs, preventing waste at all stages of the value chain, and converting residues and secondary products into productive resources with added value. Its objective is to maximize the efficiency of natural resource utilization and regenerate natural capital to ensure sustainable food security. Accordingly, circular agriculture rests upon three principal foundations:

- Enhancing the efficiency of inputs required for agricultural production—including water, fertilizers, pesticides, feed, and others—through the search for sustainable local alternatives;
- Closing the nutrient loop through the valorization of organic waste;
- Minimizing environmental impact and achieving environmental sustainability.

1.2. Principles of Transition towards Circular Agriculture

For any agricultural initiative to possess genuine transformative capacity, it must effectively contribute to fulfilling the mission of circular agriculture, namely, achieving a balance between human food production and the integrity of ecosystems. The diverse initiatives of circular agriculture reflect the plurality of visions, varying in how they operationalize and apply the concept of circularity on the ground. Some initiatives merely ride the wave of circular agriculture by reformulating their conventional practices and presenting them as circular activities. Since policymakers primarily seek to support initiatives with genuine transformative capacity, it is of paramount importance to possess the ability to determine the extent to which these initiatives are effective and impactful (Hoogstra, 2025).

In general, the five principles of Muscat et al. (2021) are adopted as a guiding framework that integrates multidisciplinary scientific literature on circularity while balancing it against the diversity of practical applications. The value of any initiative is determined by its capacity to incorporate and address these principles (Hoogstra et al., 2024):

- **Protecting the health of agricultural ecosystems:** Through avoiding the depletion of natural resources beyond their regenerative capacity and the necessity of avoiding environmental pollution. This encompasses protecting and regenerating biodiversity stocks and reducing nutrient leaching and greenhouse gas emissions to the surrounding environment.
- **Avoiding the production of non-essential goods and preventing the waste of essential goods:** Through minimizing unnecessary production and loss along the value chain, which fundamentally requires preventing food waste and ensuring distributional efficiency.
- **Prioritizing the use of biomass for basic human needs:** Biomass must be directed towards feeding humans in the first instance, with animal feeding restricted to biomass unfit for human consumption.
- **Recycling secondary products and residual flows at the highest possible efficiency:** Residual flows, such as crop residues, manure, and flows generated from food

processing, must be recycled within the food system to ensure maximum economic and technical utility.

- **Entropy (energy efficiency):** This principle addresses the importance of minimizing energy consumption to the lowest possible level, in parallel with the expansion of renewable energy sources within the production system.

Table 1. Circular Agriculture Principles. Based on Muscat et al. (2021)

Circular Agriculture Principle	Description
Protecting agricultural ecosystems	Avoiding resource depletion beyond regenerative capacity; preventing environmental pollution; protecting biodiversity; reducing nutrient leaching and GHG emissions
Avoiding non-essential goods / preventing waste of essential goods	Minimizing unnecessary production and loss along the value chain; preventing food waste; ensuring distributional efficiency
Prioritizing biomass for basic human needs	Directing biomass primarily to human nutrition; restricting animal feed to biomass unfit for human consumption
Recycling secondary products and residual flows	Reusing residual flows (crop residues, manure, food processing by-products) within the food system at maximum economic and technical utility
Entropy (energy efficiency)	Minimizing energy consumption; expanding the use of renewable energy sources within the production system

Source: Hoogstra (2025, p. 21)

The table demonstrates that the five principles of circularity transcend the conventional concept of recycling, establishing instead an integrated circular ecosystem. This system sets environmental boundaries for production such that the regenerative capacity of nature is not exceeded, and establishes a preferential hierarchy for biomass consumption that ensures resources are directed towards feeding humans in the first instance, avoiding any waste of material that could feed humans in lower-value uses. Accordingly, subjecting initiatives to measurement against the extent of compliance with these principles constitutes the criterion for distinguishing genuine circular initiatives from those that confine themselves to superficial circularity.

1.3. Contribution of Circular Agriculture to Maximizing Sustainable Food Security

Food security is achieved when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 2008). This concept has traditionally rested on four fundamental dimensions: availability, access, utilization, and stability. However, the scientific literature (HLPE, 2020; Clapp et al., 2022; Termine, 2024) argues that integrating two additional dimensions—agency and sustainability—into food security analysis and policy frameworks will better ensure food security for all, not only today but also in the distant future.

Table 2. The Six Dimensions of Food Security

Dimension	Description
Availability	Sufficient quantities of food of appropriate quality supplied through domestic production or imports
Access	Access by individuals to adequate resources and entitlements for acquiring appropriate foods for a nutritious diet
Utilization	Adequate diet, clean water, sanitation, and healthcare to reach a state of nutritional well-being
Stability	Access to adequate food at all times; not risk of losing access to food as a consequence of sudden shocks or cyclical events
Agency	The ability of individuals and communities to make their own decisions about food systems and to participate in their governance
Sustainability	Food security achieved in the present without compromising the environmental, economic, and social bases for future generations

Source: HLPE (2020, p. 10)

Sustainability is defined as achieving food security and nutrition in a manner that does not compromise the environmental, economic, and social foundations that generate food security for future generations (HLPE, 2020). Circular economy emerges from this perspective as an effective instrument for realizing the sustainability dimension through resource conservation, enhancing system resilience, and reducing costs—not merely through increasing production, but through building a system that withstands crises. This contribution is summarized in the following points:

1.3.1. Enhancing Economic Resilience and Supply Sustainability

The adoption of circular economy strategies achieves superior economic viability for enterprises, as it stimulates economic development through establishing new ventures, creating employment opportunities across diverse sectors such as biomass processing, food technology, reverse logistics, and the reduction of product costs and price volatility. Additionally, it enhances supply security while minimizing environmental externalities. Developing more profitable business models through circular approaches supports resilience and the capacity to maintain financial stability in the face of sudden market fluctuations in the agriculture and food sector, where profits become less susceptible to input and output price fluctuations (Spada et al., 2025). It also effectively reduces the dependence of agricultural supply chains on virgin raw materials, which in turn confers greater capacity for resilience and immunity against global shocks and international input price volatility (Volkov et al., 2022).

1.3.2. Achieving Sustainable Food Availability

The application of the circular economy in the food system implies reducing the volume of waste generated, reusing food, and utilizing secondary products and food waste. Accordingly, the circular economy can construct a food system that ensures food never becomes waste. This model provides practical solutions for transitioning towards a sustainable and inclusive food system (Çalıkoğlu and Sadowski, 2024). Reducing food loss and waste increases the quantity of food actually available for human consumption without the need to expand the exploitation of farmland.

1.3.3. Improving Economic Access to Food

Reducing operational costs through resource recycling leads to price stabilization of final products, thereby enhancing consumers' purchasing power and ensuring food access for vulnerable populations. By relying on locally recycled resources, farm operating expenses are diminished, as closing nutrient loops reduces the need to purchase imported fertilizers and feed, thus lowering production costs (De Boer and Van Ittersum, 2018). Food waste prevention has emerged as a strategic item among the United Nations Sustainable Development Goals, which aspires to halve per capita global food waste and loss by 2030. This orientation contributes to ensuring the redistribution of surplus edible food, helping to divert food waste away from landfills and provide high-quality nutrition to populations experiencing food insecurity. While this direction acknowledges the necessity of reducing edible food waste, it focuses particularly on the multiple options for creating added value from organic secondary products within the bioeconomy framework, thereby enhancing the efficiency and long-term sustainability of the food system (Ellen MacArthur Foundation, 2019).

1.3.4. Preserving Natural Capital

Sustainability constitutes a defining characteristic of food systems, as the concept and metric of the environmental footprint provide a useful representation of the sustainability dimension, given that it accounts not only for what people consume but also how food is produced, processed, transported, and utilized. This encourages practices that preserve or enhance natural capital and repudiates practices that deplete it (HLPE 14, 2019). Sustainability aims to integrate environmental resilience, economic growth, and social inclusion to ensure the well-being of current and future generations through structural changes in production systems. The circular economy emphasizes the necessity of establishing an economic system characterized by resource efficiency and effectiveness through reducing energy consumption, reusing and repairing products, creating restorative industrial systems, and integrating life-cycle cost perspectives into government procurement and development processes. Accordingly, the circular economy emerges as an executive strategy for achieving comprehensive sustainability (Rosário et al., 2024).

2. Analysis of the Policy Ecosystem and Model Initiatives for Circular Agriculture in the Netherlands

The transition towards circular agriculture in the Netherlands represents a unique model that has succeeded in translating the theoretical frameworks of sustainability into highly efficient operational models. Dutch authorities did not confine themselves to formulating ambitious strategies; rather, they established an integrated enabling environment that combines flexible legislation, technological innovation, and multi-stakeholder partnerships.

2.1. Dutch Policy and Institutional Frameworks Supporting Circular Agriculture

The Dutch experience is anchored in an integrated policy framework aimed at reshaping the agricultural and food system to become the most sustainable and circular globally by 2030. The principal pillars of this framework are summarized in the following axes:

2.1.1. The Dutch National Programme for the Circular Economy

In 2016, the Dutch government charted a vision for a sustainable economy serving both current and future generations by establishing a general legislative framework aiming to reduce virgin raw material consumption by 50% by 2030 and to achieve a fully circular economy by 2050. To this end, raw materials will be utilized and reused optimally without posing any risks to health or the environment. Primary raw materials will be extracted, whenever necessary, in a sustainable manner. Products and materials will be designed in ways that allow reuse with minimal value loss and without the emission of any harmful substances into the environment. Within this framework, the biomass and food sector is considered one of five priority sectors for achieving the transition towards the circular economy, alongside plastics, manufacturing, construction, and consumer goods (Government of the Netherlands, 2016).

This signifies that the Dutch vision extends beyond merely setting environmental targets; rather, it represents a fundamental transformation in the economic doctrine of transitioning from a linear to a circular economy within a closed loop wherein resources maintain their economic efficiency for the longest possible period, and waste transforms from a mere financial and environmental burden into an investment asset. Targeting zero harmful emissions elevates the challenge threshold for environmental and technological innovation, and creates a market for secondary raw materials that rivals or surpasses the quality of primary materials, ensuring resource sustainability without depleting nature. To realize these ambitions and create the conditions conducive to the desired transition, the government adopted five instruments for the priority sectors, manifested in strengthening laws and regulations, smart market incentives, financing, knowledge and innovation, and international cooperation.

Strengthening the Regulatory and Legal Framework

The Dutch government focused, through this plan, on reinforcing laws and regulations for the transition towards the circular economy, adopting numerous levers, the most prominent of which are smart regulation, the legal reclassification of waste, the adaptation of standards and certifications, and the imposition of ecodesign (Government of the Netherlands, 2016). For instance, the smart regulation programme aims to remove legal barriers to innovation and open avenues for collaboration and partnerships between the public sector and entrepreneurs to discuss obstacles impeding sustainable investment, thereby reducing the perception of risk among investors and ensuring that legislation keeps pace with the speed of technical innovation.

Among the practical applications of smart regulation are the Green Deals, which constitute a policy instrument aimed at improving the national economy through environmentally friendly practices. They encompass not only agreements between the government, the private sector, and civil society to remove legal barriers that impede emerging circular initiatives, but also a wide range of sustainability-oriented measures, such as supporting sustainable entrepreneurship and the strategic transition towards the bioeconomy. Accordingly, they demonstrate significant potential for supporting small and medium-sized enterprises and other stakeholders in enhancing the transition towards the circular economy, particularly through new initiatives and innovations, thereby transcending traditional instruments limited to grants and financial support alone (Van Langen & Passaro, 2021).

The National Waste Management Plan (LAP3) was established with the objective of enacting more precise laws on the concept of waste, based on provisions that serve the circular transformation. These include establishing a waste management hierarchy that

prioritizes prevention, followed by reuse, then recycling, down to incineration or landfilling as a last resort, with any circular agricultural initiative legally required to demonstrate compliance with this hierarchy. Technical criteria were also established for the legal distinction between waste and secondary products, and the End-of-Waste procedure was activated, which grants recycled materials the legal status of secondary raw materials, provided that a market or demand exists for them and that they meet specified technical criteria ensuring no harm to public health, thus facilitating their circulation and utilization, and converting them from a financial burden into a capital asset. Minimum standards and strict rules for waste transport were imposed to ensure a sustainable environment. Government entities were also mandated to integrate circularity criteria into their procurement processes, providing legal support for circular products that have met the legal conditions to compete with conventional products (Ministry of Infrastructure and Water Management, 2017).

The Dutch plan also adopts a proactive strategy centered on ecodesign as a key tool for preventing waste before it occurs. The government ensured the integration of design innovation criteria into its legislation, not only to extend product lifespans and facilitate their repair, but also to guarantee the return of resources to the production cycle at minimal cost and energy expenditure. In this context, pioneering initiatives emerged, such as the CIRCO programme, which aims to empower small and medium-sized enterprises, business developers, and designers to transform from traditional linear business models to sustainable and innovative circular business models. It converts environmental responsibility into a competitive advantage for Dutch products in global markets. The CIRCO methodology is based on research from Delft University of Technology (TU Delft), helping enterprises identify circular opportunities such as product life extension, repair, and recycling, and develop a circular business model plan, thereby converting sustainable design concepts into profitable circular business models (CIRCO, n.d.).

Smart Market Incentives

Smart market incentives aim to address market failures and steer the market towards the circular economy through targeted price and regulatory incentives. This intervention seeks to enhance demand for recycled and biological materials, stimulate innovations and circular business models, and thereby direct national and international markets towards these categories of raw materials (Government of the Netherlands, 2016). This policy is embodied in the use of the state's purchasing power through targeted green procurement, which ensures stable demand for circular and biological products and encourages field initiatives. This is supported by a system of innovative tax incentives such as the MIA (Environmental Investment Deduction) and VAMIL (Random Depreciation of Environmental Investments) schemes, which offer generous tax exemptions and deductions for investments adopting circular technologies, aiming to reduce the financial risks for investors in regenerative technologies and render them more price-competitive compared to conventional polluting products, which are burdened with pollution and carbon emission taxes. This vision also seeks to gradually phase out environmentally harmful forms of support and digitize measurement standards such as CO₂ equivalent, thereby converting the circular economy from a mere theoretical concept into a profitable economic reality capable of attracting investments in bio-based value chains.

Financing, Knowledge, and Innovation

The financing strategy aims to address the financing gap and the high risks associated with circular projects, through the creation of specialized credit facilities in cooperation with major banks such as BNG Bank to support investments with long payback periods. These financial efforts are complemented by the creation of an incubation environment for entrepreneurs through the *Nederland Circulair!* programme and the Voucher system, which facilitates the transfer of technical and financial knowledge to smallholder farmers. The authorities also succeeded in forging a strategic alliance with the private banking sector, such as Rabobank and ING, to develop financial products and risk management frameworks suited to regenerative business models, thereby enhancing the capacity of circular initiatives to compete with traditional linear models and to establish themselves in the market as a sustainable and profitable alternative (Government of the Netherlands, 2016).

Direct institutional support is made available through specialized bodies such as the Netherlands Enterprise Agency (RVO), the Netherlands Investment Agency (NIA), and Invest-NL. These institutions contribute to supporting enterprise activities domestically and internationally, aiming to enhance the social and economic objectives of circularity through the provision of venture capital. The European Investment Bank (EIB), in cooperation with the NIA, also seeks to develop an investment platform specialized in the circular economy, and to contribute effective government investment in scaling up circular concepts that ensure efficient carbon emission reductions at high economic efficiency, with emphasis on directing support towards innovation rather than permanent structural operations to ensure competitiveness (Government of the Netherlands, 2018). The Dutch government additionally relies on a scientific methodology for managing the circular transition, centered on transforming the Environmental Assessment Agency (PBL) into an integrated measurement and control system to ensure the accuracy of digital monitoring of resource flows, in parallel with activating the National Research Agenda (NWA) to develop innovative solutions in strategic sectors. This vision is manifested in the allocation of government financial support exceeding €6.5 million to enhance the efficiency of research institutions and stimulate field innovation within leading sectors. This is complemented by national and international knowledge networks and platforms such as *Nederland Circulair!* and *Holland Circular Hotspot*, aiming to establish the exchange of technical and policy expertise and to convert theoretical knowledge into tangible, scalable circular business models globally (Government of the Netherlands, 2018).

International Cooperation

The Netherlands assumes a pioneering role that transcends its national borders through strengthening political support for the circular economy in international treaties and programmes. It seeks to convert its sovereign infrastructure, such as Schiphol Airport and the Port of Rotterdam, into leading global hubs (*Circular & Biobased Hubs*) for material and biomass flows in Europe. This vision is embodied in activating the *Holland Circular Hotspot* platform for international experience exchange and the organization of trade missions, in parallel with its commitment to providing technical and innovative support to developing countries in cooperation with the United Nations Environment Programme, to ensure sustainable waste management and accelerate recycling policies. This transforms circularity from a national option into economic diplomacy that secures the leadership of innovative Dutch companies in global markets and reduces transboundary environmental effects (Government of the Netherlands, 2018).

2.1.2. Vision of the Dutch Ministry of Agriculture, Nature, and Food Quality

The Dutch Ministry of Agriculture, Nature, and Food Quality (LNV) launched its strategic vision in 2018 under the title "Agriculture, Nature and Food: Valuable and Connected," which precipitated a fundamental transformation in the production doctrine. Government policy shifted from encouraging the lowest cost per unit produced to the lowest resource use per unit, through enhancing the efficiency of resource utilization within closed loops (Ministry of LNV, 2018). To realize this vision by 2030, the government established three complementary objectives for a robust and sustainable food system:

- **Ensuring the economic stability of producers:** The economic position of farmers, breeders, and fishers in the supply chain must be strong enough to enable them to achieve a good income under circular agriculture conditions, with the capacity to innovate and maintain the continuity of their enterprises for future generations;
 - **Enhancing the value of food:** There is a need to increase appreciation for food among individual consumers, government entities, and the catering sector, and to avoid food waste in order to relieve pressure on the environment and enhance biomass utilization efficiency, while reducing the social and geographical distance between primary producers and citizens;
 - **Achieving global leadership in innovation:** The Netherlands must maintain its leading role in innovating production methods both domestically and in international markets, to present a model to emulate in efficient food production through circular processes, contributing to the prevention and repair of ecosystem damage.
- The circular agriculture system, according to the Dutch vision, rests upon numerous strategies, the most significant of which are as follows:

Closing nutrient loops through achieving organic integration between crop and livestock production sectors, whereby the residues of each sector become inputs for the other. Agricultural residues and food supply chain by-products—including crop residues, food leftovers, manufacturing waste, animal manure, and compost—are reused and reprocessed to convert them into new intermediate products. This linkage reduces logistical costs and resource waste, and creates flexible value chains, thereby enhancing food security through input self-sufficiency.

Biomass valorization and land connection, which ensures economic independence from global raw material price fluctuations and reduces greenhouse gas emissions resulting from the chemical manufacture of synthetic fertilizers. Soil sustainability constitutes the cornerstone of this model; soil is not merely a medium for production but a living reservoir that absorbs the effects of harsh climatic conditions and preserves biodiversity and nutrients through rotational management, wherein human activities extract minerals and water from the soil for production and compensate them with organic matter and nutrients to maintain its productive capacity, through supporting precision agriculture, smarter use of machinery, and the development of new breeds and farming and housing systems for livestock.

The state also seeks to **achieve the optimal balance between animal and plant proteins**, particularly since animal protein production constitutes a major source of greenhouse gas emissions, in addition to its negative effects in polluting groundwater with nitrates and ammonia emissions.

Regarding **urban food provisioning and greening**, securing food for urban populations constitutes a growing challenge. The state therefore aims to develop sustainable systems capable of achieving this goal while building economically, socially, and environmentally

sound earning models. Through innovation leadership, the government aspires to create self-sufficient cities that rely on circular food supply chains.

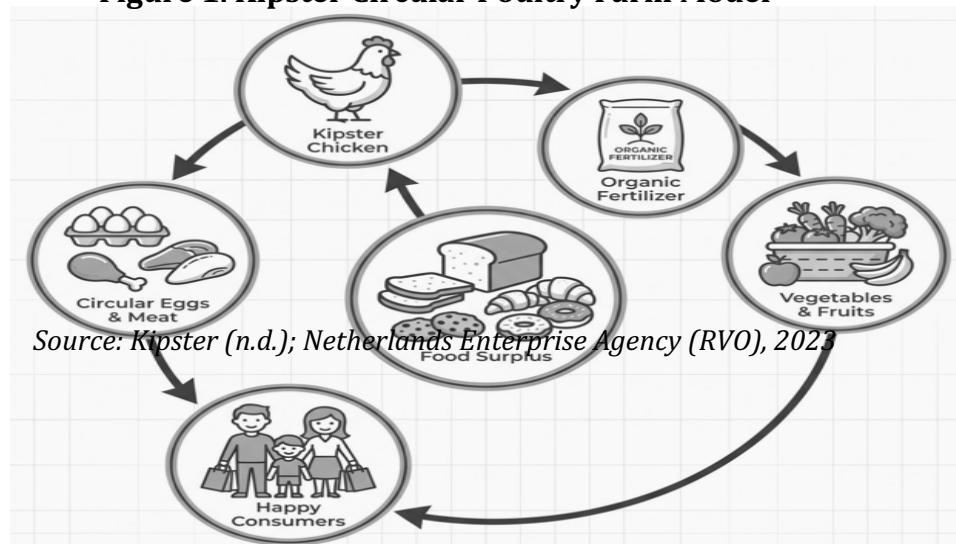
2.2. Pioneering Circular Agriculture Initiatives in the Netherlands

Dutch government policies have materialized in pioneering field projects that have demonstrated their economic and environmental viability, contributing to shaping a more resilient and independent food system. This section presents an analysis of two pioneering initiatives that embody the philosophy of circular agriculture: the company "Kipster," which has redefined the concept of the closed-loop, carbon-neutral farm, and the company "Protix," specialized in alternative protein and biological fertilization through the valorization of organic waste. This analysis aims to understand the operational mechanisms and economic viability of these models, as a prelude to assessing opportunities for their emulation and localization within the Algerian agricultural sector.

2.2.1. The Kipster Circular Poultry Farm Model

The Kipster initiative embodies a fundamental transformation in the philosophy of animal production. Its first farm was inaugurated in 2017, adopting a feed model based on converting surplus human food—such as bakery residues and biscuit waste—into a fortified feed mixture supplemented with additional nutrients to ensure optimal nutritional absorption by poultry. This model was designed to ensure sustainable production that respects animal welfare, farmer income, and planetary health, while avoiding feed-food competition. This is achieved by transitioning from a system dependent on the depletion of agricultural resources for feed production to one that reintegrates waste generated from food industries into the production chain, thereby contributing to the production of a "carbon-neutral egg." Thus, Kipster has succeeded in revolutionizing food production by prioritizing ethics and sustainability to ensure a healthier planet for future generations (Kipster, n.d.).

Figure 1. Kipster Circular Poultry Farm Model



Source: Kipster (n.d.); Netherlands Enterprise Agency (RVO), 2023

The Kipster experience represents the practical application of the principles of transition towards circular agriculture, particularly with respect to the valorization of secondary products, the processing of industrial and logistical waste, reliance on recycled

feed, and the liberation of agricultural land for direct human food crop production instead of animal feeding. This reduces feed-food competition and enhances sustainable food security. The Kipster model is distinguished by its flexibility and scalability through its modular design, which permits the establishment of farms ranging in capacity from 24,000 to 120,000 hens, without surpassing this limit to avoid the transformation into giant corporations that lose control over standards.

The company also seeks to establish a miniaturized Kipster model at the Brightlands Campus Greenport Venlo to conduct experiments, believing that innovation is essential for maintaining leadership. At this facility, residual flows, particulate matter, water, and animal welfare will be tested—experiments that may interest other poultry farmers. Furthermore, the company has made significant progress in developing a fully "plant-based egg." As the world's population continues to grow, the search for alternatives to provide sufficient protein for all in the future has become an imperative necessity (Netherlands Enterprise Agency [RVO], 2023).

By adopting a flexible modular system, the balance between production efficiency and strict control over quality standards and animal welfare is ensured, thereby avoiding the risks associated with giant farms that may lose the transparency of circular supply chains. The company's transition to experimentation at the Brightlands Campus represents a practical application of the "Golden Triangle" model, where environmental challenges are addressed within "living laboratories" that ensure the sustainability of innovation and market leadership. The initiative also leveraged the legislative flexibility provided by the LAP3 law to redefine "food surplus" as a productive input, thereby achieving the "food-not-feed" principle without depleting agricultural land.

Table 3. Comparative Analysis between the Kipster Egg Production Model and Conventional Egg Production (2023)

Analytical Item	Kipster Egg Production	Conventional Egg Production
Resource Use Efficiency	• Reduced agricultural land use for feed crops and pastures by 35–48% • Soy, corn, and dedicated crop usage constitutes only 20–25% of total feed	• Over 75% of total agricultural land is allocated to feed crop production or pastures • Conventional feed consists of approximately 80% high-quality grains and soybeans
Financial Returns	• Feed cost reduction by 30–40%* • Farm electricity cost reduction by 58% through reliance on solar panels	• High operating costs resulting from full dependence on global grain prices and energy price fluctuations
Environmental Returns	• Carbon footprint ranging between 1.67–1.83 kg CO₂-eq per 1 kg of eggs • Carbon footprint of recycled feed lower by 50% compared to conventional feed • Global Warming Potential (GWP) reduction: 56–65%	• Carbon footprint ranging between 2.5–4 kg CO₂-eq per 1 kg of eggs • Poultry feed is responsible for approximately 70% of the carbon footprint of a single egg

Source: Compiled by the author based on Devine (2023) for WWF; Kipster (n.d.); Kipster Impact Report (2023); and Van Zanten et al. (2023) for FAO.

From an examination of the table, the environmental returns achieved by the Kipster initiative are clearly evident. This circular model contributes to reducing the carbon footprint of recycled feed to approximately half, making it the world's first carbon-neutral egg. Investment in renewable energy through solar panels has enabled the company to reduce operational costs and shield itself from the price fluctuations witnessed in the global energy market. Through substantial reliance on the recycling of raw materials considered unfit for human consumption, the company has decoupled from the global soy and corn markets—two of the most important grains entering poultry feed—rendering it immune from geopolitical price fluctuations and freeing vast tracts of agricultural land for direct human crop production, which represents tangible support for sustainable food security. Accordingly, Kipster has demonstrated that circular practices not only contribute to environmental sustainability but have also exhibited high economic viability.

The Kipster production system witnessed notable expansion to multiple sites within and beyond the Netherlands through strategic partnerships, including agreements with Kroger Co. and MPS Egg Farms for expansion into the United States, highlighting the clear international potential of this model as an innovative solution for a sustainable food system (Devine, 2023).

Kipster succeeded in achieving a strategic balance between capital expenditure (CAPEX)—invested in the design of new facilities and the integration of advanced technologies—and the viability of operational and environmental returns. The initial investments, which relatively exceeded those of a conventional poultry farm by 25–30%, encompassed modular structures incorporating indoor and outdoor enclosures to ensure animal welfare, covered with solar panels providing the energy required for the farm, along with the installation of air purification systems to eliminate fine particulate matter and ammonia. Notwithstanding the high initial costs, the company succeeded in reducing operational costs (OPEX) by up to 30–40% on feed costs, approximately 15% on veterinary expenses due to the smart farm design that promotes poultry welfare—thereby reducing loss and disease incidence—and more than 58% on energy consumption costs.

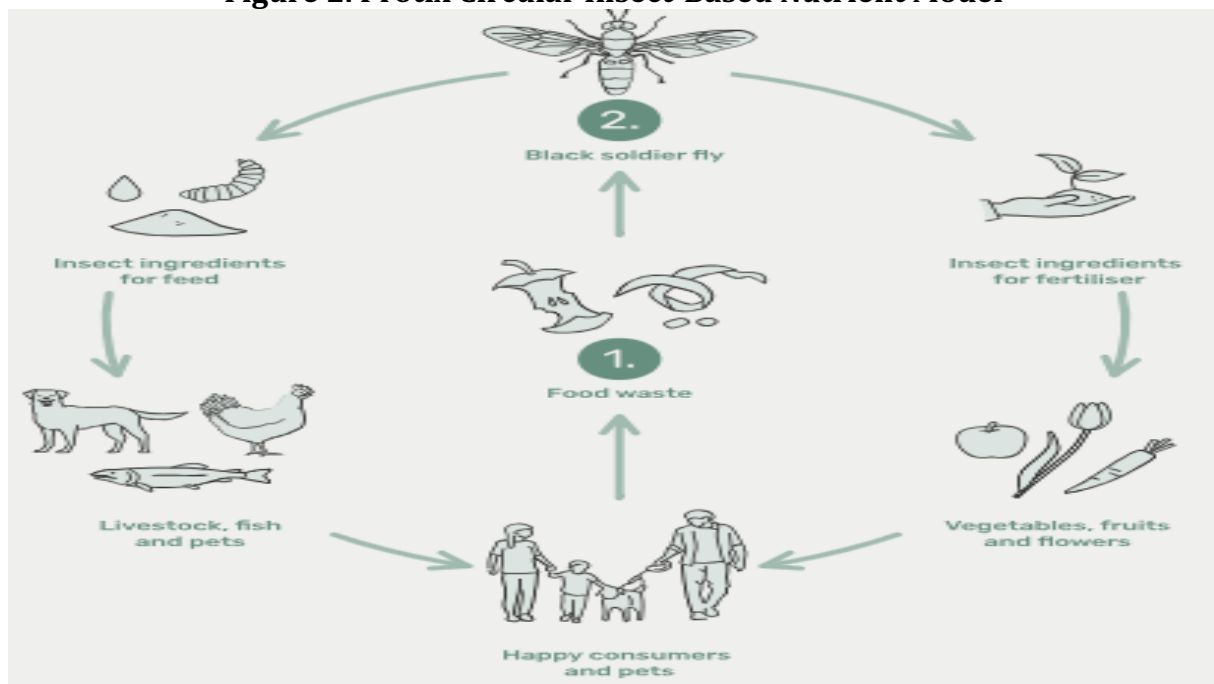
The circular model adopted by Kipster has proven its financial robustness, having forged long-term partnerships with major retail chains, thereby ensuring strong consumer demand and stable revenues. For instance, the company achieved revenues of €8.2 million in 2024, with gross profits estimated at approximately €869,000. To commence international expansion, the company established partnerships with Rabobank, specialized in agricultural financing, and the Brightlands Agrifood Fund, which provided venture capital financing of approximately €500,000. Furthermore, Kipster raised €3,700,275 through crowdfunding campaigns launched on the Invesdor platform in early 2025, based on a prior company valuation of €10 million (Invesdor, n.d.).

These strategic alliances reflect the extent to which it is recognized that the model presented by Kipster is not merely a simple environmental experiment but rather a flexible, robust, and profitable circular business model with enormous potential for international expansion and the capacity for growth under volatile market conditions. Environmental entrepreneurship has become increasingly attractive to investments, particularly with the depletion and price volatility of resources, and the imposition of binding governance and environmental standards. Accordingly, sustainability and circularity are no longer mere ethical and environmental slogans but rather business models with strong economic viability that command the confidence and attention of investors.

2.2.2. The Protix Alternative Protein Model

The Dutch company "Protix" is a global leader in the industrial-scale cultivation and valorization of insects. The initiative has, since its establishment in 2009, relied on the use of Black Soldier Fly (BSF) larvae, which consume all types of low-value organic waste and convert them into high-quality protein and lipid components that enter the production of livestock feed, aquaculture feed, and pet food. Insects are cultivated within a circular production process that fully closes the resource loop, thereby contributing to building a food system with a low environmental footprint. This model embodies the concept of upcycling, wherein nutrients lost in waste are recovered and reintegrated into the food chain as animal feed (Protix, 2024).

Figure 2. Protix Circular Insect-Based Nutrient Model



Source: Protix (2024)

The reliance on deriving protein used in animal feed from soybeans and fishmeal causes numerous environmental problems that undermine food security, given the vast areas of land and water required, the increase in greenhouse gas emissions, deforestation, and overfishing. The company "Protix" has succeeded in addressing these challenges by employing insects on an industrial scale as a sustainable alternative that preserves wild ecosystems and biodiversity (Netherlands Enterprise Agency [RVO], 2023).

One ton of Black Soldier Fly insects is capable of converting 4.5 tons of low-quality plant waste into high-quality nutrients. Insects can be rapidly cultivated in confined spaces, as one ton of insects can be produced within approximately 10 days on an area not exceeding 20 square meters, utilizing an extremely small quantity of water estimated at less than 30 liters per ton of insects. Moreover, the cultivation and processing of these insects generates zero waste, thereby enabling Protix to achieve economies of scale in highly limited spaces.

Protix represents a successful model in agricultural biotechnology (Agri-Tech), having succeeded in converting waste of zero value into high-value productive inputs through the use of insects as biological factories, employing innovative scientific technologies. Through a focus on product quality and automation, the utilization of

biomass has been enhanced and the rates of economic resource waste reduced, while breaking dependence on the prices of conventional feed products. This ensures the stability of local feed supply chains and reduces dependence on global markets, thereby reinforcing food sovereignty. In this manner, the company succeeded in fully closing the resource loop and gaining a competitive advantage that positioned it as an environmental leader.

The successes of Protix rest upon an integrated ecosystem of strategic partnerships that unite scientific research, financing, and industry. Through the "Golden Triangle" model, the company collaborated with leading universities and research institutes to enhance innovation and improve the competitiveness of its technical solutions, while strategic financial support from the European Investment Bank (EIB) and the European Regional Development Fund (OPZuid) accelerated the pace of its growth and expanded the scope of its economic impact. The company did not confine itself to the operational dimension but also led the sector's regulatory efforts by co-founding the International Platform of Insects for Food and Feed (IPIFF) in 2012, aiming to enhance the use of insects as a sustainable source of nutrients in food and feed policies at both the European and international levels (Protix, 2024).

Similar to the Kipster initiative, the role of strategic institutional alliances in the success of sustainable environmental models is clearly evident—through the linkage with universities that conduct research and studies of paramount importance for developing circular solutions and overcoming technical obstacles, while also verifying the reliability of the initiative and granting it scientific legitimacy. On the other hand, the business sector plays an important role in translating innovative ideas, scientific research, and technical knowledge into tangible, competitive products.

Table 4. Comparative Analysis between the Protix Protein Production Model and Conventional Protein Production (2023–2024)

Analytical Item	Protix Protein Production	Conventional Protein Production (Soy/Fish)
Resource Use Efficiency	• Relies 100% on organic waste • Reduced agricultural land use for LipidX® insect fat by less than 99.9% compared to coconut oil used in livestock feed, pet food, and aquaculture • Reduced water consumption by 99.8% for PureeX® insect puree compared to poultry meat used in pet food • 38.7 million m² of agricultural land saved • 88.4 million m³ of water saved	• Relies on virgin inputs (seeds, chemical fertilizers, fossil fuels) • Over 75% of total agricultural land is allocated to feed crop production or pastures • Significant depletion of freshwater resources for crop cultivation
Operating Costs	Operating costs amounted to €36.4 million in 2024, including €14.6 million in specialized human resource costs	• Lower technological investments but lacking resource-saving innovation • Relies on conventional labor in agriculture and processing

Revenue Structure	Comprised primarily of royalties, which constitute the largest share of total revenues amounting to €13.8 million in 2024 versus €12.1 million in 2023	Consists entirely of product sales revenue
Financial & Environmental Returns	• 100% reliance on renewable energy • Carbon footprint of ProteinX® insect meal lower by 78% compared to poultry meal used in pet food and livestock feed • Carbon footprint of ProteinX® insect meal lower by 89% compared to soy protein concentrate used in aquaculture • 27.5 million kg of CO₂ equivalent emissions reduced	• Responsible for deforestation in the case of soy and overfishing in the case of fishmeal

Source: Compiled by the author based on De Heij (2026); Protix (n.d.); and Protix (2024, April 23).

Notwithstanding the remarkable environmental impact of the Protix initiative, the 2024 financial data reveal a clear financial gap (De Heij, 2026). The company recorded an operating deficit of €22.5 million against operating costs of €36.4 million. This deficit is primarily attributable to the cost of the sophisticated infrastructure requiring complex technology for its operation and maintenance, encompassing energy costs, automation, research and development expenditures, in addition to reliance on highly qualified human capital at a cost of €14.6 million. The growth in gross revenues from €12.1 million in 2023 to €13.8 million in 2024 is attributed to income derived from royalties, indicating that Protix has transitioned to a knowledge-based business model. The company now relies on the sale of technical solutions and patents to diversify its income sources and cover its operating deficit.

The Protix financial report confirms that the circular protein industry is an intelligent bio-industry, not merely conventional insect farming. It is characterized by high capital intensity and requires long payback periods before reaching the stage of profitable mass production. This demonstrates that the transition towards certain circular systems, particularly in their initial stages, constitutes high-risk investments that may result in failure and expose enterprises to bankruptcy, leaving them in a state of financial fragility and strategic dependence on investors and venture capital funds. The company remains a model of start-ups that rapidly consume liquidity (cash burn) while awaiting the break-even point. It must therefore balance production capacity growth with actual demand to avoid the fate of struggling companies in the European alternative protein sector, such as Ynsect. From this, we deduce that environmental initiatives require sustainable government financial support, such as sovereign loans and green financing, to enable them to overcome high risks, particularly in the initial stages.

2.2.3. Evaluation of Dutch Initiative Models against the Five Principles of Circularity

The success of the transition towards circular agriculture cannot be measured merely by the adoption of sustainability slogans, but rather by the capacity of field initiatives to effectuate a fundamental transformation in the structure of production and consumption. This section aims to subject the Kipster and Protix experiences to an evaluation of their transformative capacity based on the five principles of circularity formulated by Muscat et al. (2021), through examining the extent to which these models comply with ecosystem protection, waste prevention, biomass valorization, and energy

efficiency. The objective is to identify the technical and financial gaps encountered and to distill the fundamental lessons that ensure the successful replication and localization of these experiences within the Algerian context, transcending superficial circularity towards genuine field impact.

Table 5. Evaluation of the Kipster and Protix Initiatives according to the Principles of Muscat et al. (2021)

Circular Agriculture Principles	Kipster Initiative	Protix Initiative
Ecosystem Protection	High: High carbon neutrality; carbon footprint of recycled feed reduced by half	Very high: Very high carbon neutrality; carbon footprint of processed proteins and lipids reduced by 78–89%
Avoiding Non-Essential Goods	Effective: Utilization of organic waste at 85% in feed	Excellent: 100% of protein and lipids produced from organic waste
Priority for Human Food	Exemplary: No use of crops directed to human nutrition (complete elimination of feed-food competition)	Moderate: Some of its products are directed to pet food
Resource Recycling Efficiency	Excellent: Conversion of organic waste into feed; recycling of poultry waste as organic fertilizer	Excellent: Conversion of organic waste into high-quality protein and lipids; conversion of insect residue into organic fertilizers
Entropy (Energy Efficiency)	Excellent: Relies 94% on renewable energy (distributed between 33% self-produced solar energy and 61% purchased green energy); net energy producer (re-surplus of produced solar energy to the general grid)	Moderate: Despite 100% reliance on renewable energy (wind and solar); intensive energy consumption (high automation and strict climate control)

Source: Compiled by the author based on the principles of Muscat et al. (2021).

The table demonstrates that Kipster represents a circular model of environmental excellence, having succeeded in closing the resource loop with minimal external energy intervention. Protix, by contrast, represents a technology-focused circular model centered on material valorization, yet it continues to face challenges of financial and energy sustainability due to the intensity of the technology employed.

3. Prospects and Challenges of Localizing the Circular Agriculture Model in Algeria in Light of the Dutch Experience

The pioneering Dutch models have achieved remarkable successes, yet they have also revealed structural challenges relating in particular to the capital-intensive nature of circular projects and the lengthy payback periods, necessitating appropriate financial support. In this regard, we seek to assess the feasibility of transferring this pioneering experience and adapting it to the Algerian context through the establishment of intelligent localization mechanisms anchored in local potentials and comparative advantages, while highlighting certain legislative, financial, and technical challenges that continue to impede the actual transition from a virgin resource economy to a valorization economy in the Algerian agricultural sector.

3.1. Available National Opportunities and Potentials

Algeria possesses enormous potentials that render the adoption of circular agriculture both an available option and an economic imperative simultaneously. These potentials are highlighted in several key points:

- **Development of the National Strategy for Integrated Waste Management (SNGID 2035):** This strategy, with a horizon of 2035, primarily aims to develop the circular economy, reduce waste generation, and accompany the transformation pathway through the establishment of national executive plans and effective monitoring and evaluation tools (National Waste Agency [AND], 2021). It aspires to achieve precise, quantitative objectives, the most significant of which include:

- Reducing the production of household and similar waste by 10%, while working to valorize 47% thereof;
- Establishing a mechanism for the gradual generalization of selective waste sorting;
- Incorporating the "polluter pays" principle to regulate waste management operations and enhance service quality;
- Closing 1,300 uncontrolled landfill sites by 2024;
- Establishing incentive mechanisms to develop public-private partnerships;
- Creating the equivalent of 100,000 jobs, comprising 30,000 direct and 70,000 indirect positions in the short and medium term;
- Reducing greenhouse gas emissions by the equivalent of 45 million tons annually (Ministère de l'Environnement, s.d.).

- **Establishment of a general legal and institutional framework for environmental protection and sustainable development and waste management:**

This aims to address environmental challenges and comply with international environmental obligations. Law No. 01-19 of 12 December 2001 concerning waste management, control, and elimination, as amended and supplemented by Law No. 25-02 of 20 February 2025, is among the most significant laws defining the concept of waste and the principal guidelines governing the management of various types of waste from inception to final disposal, including prevention, reduction, sorting, collection, transport, treatment, and valorization through reuse or energy recovery.

The recent amendments to this law explicitly aim to enshrine the principles of the circular economy and confirm Algeria's orientation towards converting waste from an environmental burden into an economic resource, through adopting a national integrated waste management strategy anchored in digitization and ecodesign to reduce environmental impacts, and establishing a hierarchy of waste treatment methods prioritizing reuse, repair, and valorization. The incorporation of the extended producer responsibility principle, selective sorting, and the transition from waste status to material and product status represents a qualitative leap in enshrining resource valorization rather than its waste, while reinforcing the deterrent dimension through stringent penal provisions to ensure environmental compliance. Additionally, Law No. 03-10 of 25 December 2003 concerning environmental protection within the framework of sustainable development establishes the general rules for environmental management and the protection of natural environments and imposes penalties for violations of environmental protection provisions, alongside numerous other related laws and implementing texts in the fields of environment, sustainable development, and waste management.

- **Abundance of raw biological material:** The National Waste Agency report (AND, 2020) indicates that biodegradable organic waste constitutes approximately 53.61% of total household and similar waste, amounting to approximately 13.5 million tons annually. The economic value of household waste alone is estimated at approximately 94 billion Algerian dinars annually. This opens enormous investment potentials in the organic composting and biomethanization sectors, contributing to the biological and energy valorization of organic waste. Furthermore, the agricultural sector generates vast quantities of agricultural residues, including crop residues, olive pomace, palm tree residues, date remnants that remain unexploited, as well as market waste and slaughterhouse waste, providing ideal raw material for the production of organic fertilizers, animal feed, and alternative proteins.
- **Enormous energy potentials in the field of renewable energy:** Particularly in the high plateaus and southern regions, these represent an enabling factor for gaining major competitive advantages, particularly with respect to reducing operational costs and the carbon footprint of agricultural products.
- **Dynamics of start-up enterprises:** The will of the Algerian state is clearly manifested towards supporting entrepreneurship and innovation across all domains, including the agricultural sector, which constitutes a fertile ground for start-ups seeking to capitalize on opportunities to localize precision agriculture technologies and agricultural waste recycling.

3.2. Operational Challenges and Obstacles

Notwithstanding the numerous promising opportunities in the regulatory and institutional framework within the Algerian context, localization encounters obstacles and challenges requiring fundamental solutions:

- **Low rate of waste valorization in general and organic waste in particular:** The National Waste Agency (AND, 2020) indicates that the waste valorization rate currently does not exceed 10% of total waste produced, consisting of dry materials suitable for recycling that are not classified as hazardous—namely paper, cardboard, plastic, glass, iron, and wood—which are the residues most readily valorized by actors in the field. Regarding the valorization rate of organic waste, which exceeds half of the total volume of household and similar waste, it is virtually nil and does not exceed 1%. Its valorization is manifested through composting activities, which result from a limited number of pilot projects presented by certain operators and environmental associations, such as a promising experience of a single economic operator in the city of Blida, which emulates the Protix model by converting organic waste using Black Soldier Fly larvae, albeit on a small scale, relying on insect larvae in their raw form as poultry feed without conversion into integrated protein as in the Dutch company. This is complemented by pilot composting facilities in three wilayas—Mostaganem, Mascara, and Sidi Bel Abbès—through the project for Supporting Integrated Waste Management (AGID); and the production of innovative livestock feed known as "Sheep Dates" in Biskra wilaya, developed by the Scientific and Technical Research Centre for Arid Regions (CRSTRA) through the valorization of date secondary products (Ould Ali, 2026).
- **Inadequate infrastructure:** Near-total absence of waste sorting, recycling, and processing facilities at the national level, with excessive reliance on technical landfill sites as the sole and primary option (Merad Boudia, 2025). Furthermore, household waste management methods in Algeria remain far from the required standard, limited to direct management by the municipality with its modest and conventional human and material resources (Kebab, 2021).

- **Regulatory deficiencies:** Despite the promulgation of the new Law No. 25-02 in February 2025, amending and supplementing Law No. 01-19 on waste management, control, and elimination—which represents a serious step towards enshrining the principles of the circular economy—its realization on the ground encounters multiple obstacles. According to Radio Algérienne (2025), the Director General of the National Waste Agency stated that the new law aims to prepare a comprehensive national waste management strategy, adopt a national information system providing real-time data on the nature and sources of waste, and grant broader powers to the Ministry of Environment and Quality of Life, particularly in precisely defining producer responsibilities and ensuring the necessary financing. However, this law, which is in reality a theoretical achievement, lacks the actual activation of all the measures and provisions that will enable the upliftment of the waste valorization sector in Algeria, pending the issuance of the implementing decrees governing its provisions.
- **Financing gap:** Circular agriculture projects—such as anaerobic digestion plants for biomethane production, industrial insect farms, or circular poultry farms—require massive initial capital investments in sophisticated technological infrastructure. This renders entry costs into this sector high, requiring substantial liquidity for project launch. Given the nature of Algerian banks, which are predominantly public and adopt a cautious lending policy requiring physical guarantees, the financing of such innovative projects entails high credit risks that make banks reluctant to engage, particularly as such projects have relatively long payback periods.

3.3. A Practical Vision for Realizing Circular Agriculture in Algeria in Light of the Dutch Experience

The effective implementation of circular agriculture in Algeria requires the formulation of an integrated strategy based on assessment, planning, development, and capacity building (Abdellaoui et al., 2025). Based on the analysis of the Dutch regulatory and institutional reality and pioneering initiatives in circular agriculture, represented by the two Dutch companies Kipster and Protix, it is necessary to proceed towards establishing an integrated ecosystem within a comprehensive vision for the transition towards a circular model suited to local comparative advantages, encompassing the following axes:

- **Biomass valorization:** The transition to the circular agriculture model necessitates the valorization of organic waste and its conversion into productive inputs with added value. Organic residues in household and similar waste and various agricultural residues can be exploited to launch circular projects tailored to the specificities of each region, based on an assessment of available resources. These include: establishing modular smart poultry farms on the Kipster model, designed with modular architecture from the outset, operated entirely on solar energy, and utilizing feed from organic secondary products such as local bakery and mill residues and date remnants, while recycling poultry waste to produce organic fertilizers for soil enrichment. This model achieves a complete closure of the resource and nutrient loop, providing a final product of eggs or white meat at minimal cost and with a low carbon footprint. Projects for alternative protein production directed to livestock, poultry, or fish feed can also be launched, as in the Protix initiative, exploiting organic waste as a growth medium for Black Soldier Fly reproduction, thereby reducing dependence on importing feed in hard currency and lowering meat and egg production costs, converting organic waste from an environmental burden in landfills into a strategic resource. In this regard, the initiative of the economic operator in Blida for alternative protein production and the CRSTRA

innovation in Biskra for "Sheep Dates" feed represent the cornerstone for transitioning from limited pilot projects—which have not yet exceeded a 1% valorization rate—towards a fully integrated national circular economy. The generalization of these models, supported by the emerging composting projects of the AGID initiative, will enable Algeria to transform into genuine food and feed sovereignty, ending the era of waste and inaugurating a new era of sustainable agricultural renewal.

- **Building knowledge and human capacities:** Through activating the Algerian Golden Triangle by strengthening cooperation and activating partnerships between universities and agricultural research centres and technical institutes; relevant ministries such as the Ministry of Agriculture and the Ministry of Environment; and start-up companies and investors, to transfer modern technologies, conduct technical studies, and convert patents into field projects. Specialized training programmes for farmers and agricultural technicians should also be provided to introduce them to the principles and practices of circular agriculture and the use of modern technologies, ensuring the adoption of these techniques by farmers and the continuity of projects with effectiveness (Abdellaoui et al., 2025).

- **Activating government support:** To encourage circular projects, the role of the state as the primary driver of the circular economy must be activated through a series of measures, such as providing targeted price and regulatory incentives through green public procurement, for example, by obliging public entities to integrate circularity criteria into their public tenders to enhance demand for circular agricultural products and render them more competitive compared to conventional products. A system of tax exemptions for environmental investments should also be applied, which directly reduces the financial risks for investors during the initial years of establishment and lowers the barriers to entry for the circular market.

- **Activating environmental legislation:** Law No. 25-02 constitutes a genuine achievement for promoting circular practices in Algeria, having addressed the deficiencies and gaps in the previous legislative framework. It introduces provisions that keep pace with the most prominent international legal contexts in the field of environmental sustainability, akin to the Dutch National Waste Management Plan (LAP3). These include legal provisions concerning end-of-waste status to stimulate recycling investment, particularly for start-ups; the establishment of extended producer responsibility to obligate companies to contribute to the financing of waste collection and valorization; in parallel with establishing a national digital system for resource tracking, where the digitization of waste enables resource tracking through a national platform linking organic waste producers to valorization units, ensuring a continuous flow of raw materials. Nevertheless, this advanced legislative structure remains hostage to procedural inertia, pending the issuance of the implementing decrees necessary to activate all the measures and provisions.

- **Addressing the financing gap:** Circular projects, as we have seen, require massive capital investments that traditional banks are generally reluctant to finance. The state must therefore establish innovative financing mechanisms commensurate with the nature of high-technology circular projects. Drawing upon the pioneering Dutch experience, it is possible to begin by establishing an integrated financing ecosystem dedicated to entrepreneurs and start-ups wishing to invest in the circular economy in general and circular agriculture in particular, from the seed stage through to financing growth and upscaling phases. This can be achieved through venture capital mechanisms, for example, by allocating investment budgets from sovereign funds to develop circular excellence hubs within universities and technical institutes, to convert patents—such as

the "Sheep Dates" product—into commercial business models scalable globally, and by establishing sovereign green funds emulating the role of Invest-NL to ensure economic viability while avoiding permanent structural support that may diminish the competitiveness of these projects. The Voucher system experience should be adopted to facilitate the transfer of technical knowledge from research centres, such as the CRSTRA in Biskra, to smallholder farmers and start-ups. In parallel, dedicated financial products for circular projects should be developed, such as green credit lines with long repayment periods suited to the nature of smart farms, with a transition towards digital monitoring of resource flows to ensure that support is directed to the most environmentally and economically efficient projects, precisely as in the advanced Dutch measurement systems.

Conclusion

The study concludes that the transition towards circular agriculture is not merely an environmental option but a strategic imperative for restructuring food systems on sustainable and sovereign foundations. The Dutch experience has demonstrated that closing resource loops through converting waste into feed and fertilizer achieves a balance between economic profitability—through attracting venture capital—and food security—through liberating agricultural land and providing protein at competitive prices with a very low environmental footprint.

The economic analysis of the Kipster and Protix initiatives revealed divergent results in terms of reducing production costs through the adoption of circular agriculture technologies. While the Kipster model demonstrated that circularity ensures financial sustainability through reducing operational costs (OPEX) by 30–40% in feed costs, approximately 15% in veterinary expenses, and more than 58% in energy consumption costs; the Protix model exhibited different challenges, with operating costs reaching €36.4 million in 2023 due to the complex and expensive technologies in their maintenance and operation, in addition to the magnitude of capital investments (CAPEX) requiring lengthy periods for value recovery. Notwithstanding this divergence, both initiatives demonstrated high resource efficiency, succeeding in releasing vast tracts of agricultural land up to 95% and reducing carbon emissions by up to 89%, rendering them an ideal solution for achieving food security amid water scarcity and climate change.

Both initiatives also demonstrated their capacity to reduce economic resource waste and decouple from global raw material supply chains such as soy and corn, thereby enhancing the stability of food systems, contributing to food price stability and protection from external shocks, and reinforcing consumers' purchasing power. The success of circular models is also attributable to the institutional integration anchored in the Golden Triangle (university, government, private sector) and flexible legislation, which constitute the primary engine transforming academic innovations into successful and sustainable investment projects. Algeria must accelerate its transition from a virgin resource economy to a valorization economy by activating the Golden Triangle model to innovate local solutions relying on national biomass valorization, thereby ensuring decoupling from global markets and achieving sustainable food sovereignty for future generations.

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