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# LOCAL ENVIRONMENTAL GOVERNANCE AND THE CIRCULAR ECONOMY IN ALGERIA: ASSESSING THE LEGAL–INSTITUTIONAL FRAMEWORK THROUGH AGRI-FOOD BY-PRODUCT VALORIZATION

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**Abstract**
This study evaluates the effectiveness of Algeria's legal and institutional framework for local environmental governance in advancing the circular economy, using agri-food by-product valorization as a practical entry point. Although Algeria has expanded its regulatory instruments to structure waste management and promote resource recovery, field evidence from multiple agri-food sectors demonstrates that the translation of these regulatory ambitions into effective local practice remains limited. The analysis reveals that organic and liquid by-product flows are still poorly recovered, with only a few segments—such as packaging and sugar-processing co-products—showing meaningful progress toward circularity. A comparative perspective involving Maghreb, African, and European experiences indicates that Algeria's challenges are primarily structural rather than regulatory, stemming from insufficient infrastructure, weak economic incentives, and fragmented institutional coordination at the local level. The study concludes that strengthening local governance mechanisms, improving inter-institutional cooperation, and aligning legal frameworks with local implementation capacities are essential for transforming Algeria's circular economy potential in the agri-food sector into tangible environmental outcomes.
The transition to a circular economy is a strategic imperative for the agri-food industry. In Algeria, despite an expanding regulatory framework aimed at structuring waste management and the recovery of by-products, the effectiveness of practices remains limited. This study combines an in-depth analysis of the legislation adopted with a field survey covering several agri-food sectors in order to assess the real place of circularity in companies.

**Keywords:** Circular economy; Agri-food industry; local governance; Environmental Legal Framework; valorization; Algeria.

## 1. Introduction

The intensification of industrial activities, combined with a global demographic increase projected to reach 9.7 billion people by 2050, has led to a substantial rise in waste generation, particularly within the agri-food sector (FAO, 2019). This sector, essential for food security and economic development, produces a wide variety of organic and inorganic residues, whose inadequate management represents a major environmental challenge. Rich in fermentable matter, such waste can contribute to soil, water and air pollution, while also promoting greenhouse gas emissions—especially methane identified as one of the main drivers of climate change (IPCC, 2021). In a global context marked by resource scarcity and ecosystem fragility, the transition towards a circular economy has become a strategic necessity to transform waste into resources and support the sustainability objectives set out in the United Nations 2030 Agenda. The valorization of biowaste thus directly contributes to Sustainable Development Goals 2, 7, 11, 12 and 13 (UN, 2015; UNDP, 2023).

In Algeria, the agri-food sector occupies a central position within the national economy, accounting for nearly 50% of the industrial GDP excluding hydrocarbons and comprising more than 31,000 enterprises employing approximately 170,000 people (APS, 2023). However, this dynamic is accompanied by the generation of significant quantities of solid and liquid waste, estimated at between 12% and 15% of total industrial waste, amounting to more than two million tonnes of by-products annually (Ministry of the Environment, 2023). Key industries—including dairy, milling, sugar, biscuit production, meat processing, and fruit and vegetable transformation—generate residual flows with high valorization potential for animal feed, energy production (biogas), organic amendments, or the extraction of bioactive compounds (Hadj Ali et al., 2023). Concurrently, Algeria has progressively developed a structured regulatory framework designed to govern environmental protection, waste and effluent management, and to promote sustainable practices. Recent legislation, such as Executive Decree No. 20-293 on the circular economy and Law No. 25-02 (2025) introducing extended producer responsibility, demonstrates a national commitment to aligning with international circularity principles.

In addition to these national instruments, the governance of waste management in Algeria relies heavily on local institutions. According to Law No. 01-19 on the management, control and elimination of waste, municipalities are responsible for day-to-day waste management operations, while wilayas oversee territorial planning and coordination through waste management plans. The Wali, as the delegated central authority, plays a supervisory role and has the power to enforce compliance with environmental regulations. Furthermore, Executive Decree No. 04-199 on hazardous waste and Executive Decree No. 09-336 on special industrial waste assign inspection, monitoring and technical control missions to the Directorates of Environment at the wilaya level.

However, several studies (Hassaine & Abrika, 2024; Benouali, 2019; Moussaoui, 2020) highlight that the distribution of responsibilities among these actors remains insufficiently defined in practice, creating ambiguities that limit the effective implementation of regulatory obligations at the territorial level. These institutional gaps weaken the capacity of local authorities to support waste valorization initiatives and contribute to the observed discrepancy between regulatory ambition and field performance.

Despite this extensive legislative framework and the existence of technological and economic opportunities, the effective valorization of agri-food by-products in Algeria remains limited. A persistent gap exists between regulatory ambitions and industrial practices, raising questions regarding the obstacles, operational capacities and level of integration of legal requirements within internal environmental management systems. This leads to a central question: to what extent does the Algerian regulatory framework on environmental protection and circular economy effectively support the valorization of agri-food by-products, and how can these requirements be efficiently embedded within an environmental management system compliant with ISO 14001? To address this issue, this study aims, firstly, to analyse the full body of laws, decrees and national programmes governing environmental management, and secondly, to provide a detailed assessment of by-product valorization practices within the agri-food sector. The objective is to evaluate the coherence between legal requirements and industrial practices in order to identify potential levers for improvement and propose pathways to strengthen the transition towards a sustainable circular economy.

## 2. Materials and Methods

### 2.1 Analysis of the Algerian regulatory framework on environmental protection and waste valorization in relation to the agri-food industry.

The first part of this study focused on compiling and examining the Algerian regulatory framework relating to environmental protection and the circular economy. The objective was to establish an overview of legislative and regulatory developments linked to these two domains. To achieve this, a documentary analysis was carried out by consulting legal texts, governmental reports

and national standards, particularly those governing atmospheric emissions, liquid effluents, waste management, the circular economy and classified installations. In addition to identifying the main regulatory obligations applicable to the agri-food sector, this phase also included an examination of the institutional architecture involved in the implementation of these regulations. *This institutional review aimed to determine the roles formally assigned to local authorities—namely municipalities, wilayas, the Wali and the Directorate of Environment.*

The main sources used for this regulatory review were:

-LegalDoctrine: a digital Algerian platform that centralises and organises the full corpus of legal texts (laws, decrees, codes and case law). It provides structured, updated and rapid access to legislation, enabling professionals, researchers and institutions to effectively monitor changes in Algerian law.

**-Official Journal of the Algerian Republic**

**-Website of the Ministry of Environment and Renewable Energies**, specifically the *Waste & Recycling* and *Regulation* sections.

**2.2 Assessment of by-product management and valorization practices in the agri-food industry.**

The second part of the study focused on the valorization of by-products generated by agri-food companies. For this purpose, a structured questionnaire was developed to gather detailed information from enterprises operating across the national territory.

**2.2.1 Data collection method.**

Data collection was carried out through several channels to ensure maximum coverage of companies:

**-Electronic questionnaire**: The survey was distributed via e-mail and WhatsApp to company managers, allowing outreach to a large number of agri-food enterprises nationwide.

**-Field survey**: On-site visits were conducted in selected companies to supplement information obtained electronically and to directly observe by-product management practices.

**-Professional exhibitions**: Participation in major events such as SIPSA 2024 (International Exhibition of Agriculture, Livestock and Agro-Industry), Agro Pack 2024 (Packaging and Processing Exhibition) and Djazagro 2024 (Agri-food Production Trade Fair) enabled interactions with key actors in the sector and the collection of additional insights on by-product valorization methods.

**2.2.2 Questionnaire design**

The questionnaire focused on the type of by-products generated by enterprises in sectors such as meat processing, dairy, cereals, fruit and vegetable processing, and the valorization techniques employed, including reuse, composting and the production of bioproducts.

The questions comprised closed formats (yes/no, multiple choice) and semi-open formats, enabling the collection of both quantitative and qualitative data.

Several challenges were encountered during the survey:

**-Unavailability of managers**: Some company directors were not available to complete the questionnaire, limiting the representativeness of data for certain entities.

**-Hesitant responses**: Some respondents were reluctant to provide detailed information about internal waste management practices due to confidentiality concerns.

**-Restricted access to industrial sites**: Security constraints and limited site access impeded direct observation of by-product management practices in some facilities.

**2.3 Data analysis.**

The collected data were processed using Microsoft Excel to identify trends in by-product management and the adoption of environmental practices. The results were presented in the form of tables and graphs to facilitate interpretation and sectoral comparison across different segments of the agri-food industry.

## 3. Results.

### 3.1 Analysis of the Algerian regulatory framework on environmental protection and waste valorization in relation to agri-food industries

The comprehensive analysis of the Algerian regulatory corpus, as summarised in Table 1, reveals a coherent and structured legal architecture progressively aligned with modern principles of environmental protection and the circular economy. This framework is characterised by a functional complementarity between the texts governing atmospheric emissions, liquid effluents, waste management and industrial risk prevention, reflecting a national commitment to regulating the entire production cycle—from pollution prevention to the valorization of residual flows.

Regulations concerning atmospheric emissions (Decrees 07-144, 07-143 and 05-495) illustrate a classical source-control approach through the establishment of limit values for major industrial pollutants such as $SO_2$, NOx and VOCs. The inclusion of specific standards for ambient air quality reinforces this approach by imposing contextualised environmental monitoring in industrial zones. This regulatory architecture ensures convergence with international requirements relating to emission reduction and responds to public health protection imperatives.

Similarly, the regulatory framework dedicated to liquid effluents provides comprehensive coverage of the effluent management cycle. Decrees establishing discharge standards (93-160), conditions for release (04-410) and sector-specific limit values (06-141) demonstrate a clear intention to develop technical regulations aligned with international practices in water quality control. Texts relating to effluent treatment (11-219) and wastewater reuse (13-235) introduce a strategic dimension, encouraging not only compliance but also hydric footprint reduction and resource circularity. This orientation is particularly relevant in a country facing increasing pressure on water availability.

The most significant development within the regulatory framework concerns recent legislation on waste management and the circular economy. While Law 01-19 was mainly limited to requirements relating to sorting, storage and traceability, later regulations—particularly Decree 20-293 and Law 25-02—mark Algeria's shift towards a circular flow logic. The introduction of concepts such as Better Input Consumption (MCI), Smart Consumption (CFI) and Extended Producer Responsibility (EPR) signals a transition towards a model integrating eco-design, material and energy recovery, and waste reduction at the source. Combined with the National Waste Valorization Programme (PNVD), this framework reflects growing ambitions to structure recycling channels and optimise the management of industrial by-products.

Finally, the texts governing classified installations and risk management (Law 03-10 and Decrees 06-198/06-199) reinforce the regulatory system by mandating environmental impact assessments and major risk analyses. This preventive orientation, based on impact and hazard studies, aligns with international standards for risk control and constitutes an essential mechanism for anticipating environmental pressures associated with industrial activities.

Overall, this regulatory corpus exhibits the characteristics of a coherent, modernised normative system aligned with international sustainable development principles. Key provisions—such as pollution prevention, discharge control and incentives for circularity—reflect the orientations of major international frameworks, including the United Nations 2030 Agenda (SDGs 6, 12 and 13), the European Industrial Emissions Directive 2010/75/EU (IED) and the Waste Framework Directive 2008/98/EC, which establishes the waste hierarchy and the principle of Extended Producer Responsibility. The structuring of Algerian environmental law around mechanisms such as eco-design, source reduction and waste valorization also mirrors the global dynamic driven by the European Circular Economy Package (2015–2020). Through the density and complementarity of its instruments, this normative framework provides a clear indication of the strategic direction adopted by Algeria, in coherence with contemporary international environmental policy standards.

**Table 1. Algerian Regulatory Framework on Environmental Protection, Waste Management and Circular Economy.**

| Domain | Regulatory Reference | Purpose | Main Requirements / Limits |
|---|---|---|---|
| Atmospheric emissions | Decree 07-144 (2007) | Industrial atmospheric emissions. | Limit values for $SO_2$, NOx, VOCs, total suspended dust. |
| | Decree 07-143 (2007) | Ambient air quality | Standards for $NO_2$, $SO_2$, $O_3$, CO, $PM_{10}$ |
| | Decree 05-495 (2005) | Sector-specific emissions | Specific emission limit values by industrial sector |
| Liquid effluents & water | Decree 93-160 (1993) | Protection of aquatic environments | Limits for COD, $BOD_5$, TSS and heavy metals |
| | Decree 04-410 (2004) | Discharge conditions | Pretreatment, discharge authorisation, compliance with receiving environment |
| | Decree 06-141 (2006) | Effluent limit values | Parameter-specific standards for industrial effluents |
| | Decree 11-219 (2011) | Treated wastewater | $BOD_5 \leq 30$ mg/L; COD $\leq 120$ mg/L |
| | Decree 13-235 (2013) | Wastewater reuse | Quality criteria depending on intended use |
| Waste management & circular economy | Law 01-19 (2001) | Waste management | Sorting, storage, traceability requirements |
| | Decree 04-199 (2004) | Hazardous waste | Labelling, transport and storage obligations |
| | Decree 06-104 (2006) | Waste nomenclature | Classification and codification of waste streams |
| | Decree 09-336 (2009) | Tax on polluting activities | Fiscal charges on pollutant emissions and non-valorised waste |
| | Decree 20-293 (2020) | Circular economy | MCI, CFI, material and energy recovery |
| | Decree 24-61 (2024) | Recyclable products and incentives | Exemptions and tax reductions for recyclable materials |
| | PNVD | National waste strategy | Recycling, composting, energy recovery |
| | Law 25-02 (2025) | Circular economy | EPR, eco-design, source reduction |
| Classified installations & risks | Law 03-10 (2003) | Environmental protection | Prevention, compliance, polluter-pays principle |
| | Decree 06-198 (2006) | Environmental impact assessment | Assessment of effects and mitigation measures |
| | Decree 06-199 (2006) | Hazard study | Analysis of incident scenarios and major risks |

COD = Chemical Oxygen Demand; $BOD_5$ = Biochemical Oxygen Demand (5-day); TSS = Total Suspended Solids; MCI = Integrated Circularity Mechanisms; CFI = Integrated Functional Circuits; PNVD = National Waste Valorization Programme; EPR = Extended Producer Responsibility.

**3.2. Institutional Responsibilities in Algerian Waste Management and Valorization.**

The synthesis presented in Table 2 highlights a formally structured institutional framework in which responsibilities for waste management and valorization are distributed across multiple territorial

levels. Municipalities are positioned as the primary operational actors, whereas wilayas and the Wali exercise supervisory, planning and enforcement functions. The regulatory instruments further attribute specialised technical and monitoring roles to the Directorate of Environment, particularly regarding hazardous and industrial waste. This multi-layered architecture demonstrates that the Algerian system is designed to rely on coordinated local governance mechanisms. However, the articulation of these roles suggests a high degree of interdependence between institutions, implying that effective implementation depends not only on the clarity of legal mandates but also on the capacity of local structures to interact and operationalize these responsibilities.

**Table 2. Main Regulatory Instruments Defining Institutional Responsibilities for Waste Management and Valorization in Algeria**

| Regulatory Instrument | Institutions Concerned | Institutional Responsibilities Defined |
|---|---|---|
| Law No. 01-19 (2001) on the management, control and elimination of waste | - Municipality (APC)<br>- Wilaya<br>- Wali | - Responsible for daily waste management operations (collection, transport and local organisation).<br>- Development and implementation of the Wilaya Waste Management Plan (PWGD).<br>- Oversight of regulatory enforcement, including issuing warnings and applying sanctions. |
| Executive Decree No. 04-199 (2004) on hazardous waste management | - Directorate of Environment of the Wilaya (DEW) | - Inspection of hazardous waste generators.<br>- Control of collection, transport, storage and treatment operations.<br>- Verification of traceability documents and technical monitoring. |
| Executive Decree No. 09-336 (2009) on the management of special industrial waste | - Directorate of Environment of the Wilaya | - Monitoring and control of producers of special industrial waste.<br>- Conducting technical assessments and issuing environmental authorizations. |
| Executive Decree No. 20-293 (2020) promoting the circular economy | - Local authorities<br>- Enterprises | - Promotion and facilitation of circular economy practices at the territorial level.<br>- Support for local valorization initiatives. |
| Law No. 25-02 (2025) establishing Extended Producer Responsibility (EPR) | - Producers<br>- Local authorities | - Shared responsibility for the management of waste derived from marketed products.<br>- Financial and operational contribution to recycling and valorization systems. |

### 3.3. Evaluation of By-Product Management and Valorization Practices in the Agri-Food Industry.

#### 3.3.1 Valorization of Waste in the Cereal Industry

The strategic importance of the cereal sector in Algeria extends far beyond its economic contribution: it constitutes one of the major pillars of national food security. With 263 flour mills and 135 semolina-processing units, the national processing capacity exceeds 110 million quintals per year (Bessaoud, 2018), generating substantial quantities of milling by-products. This potential is all the more significant given the country's high dependency on wheat imports, estimated at 7 to 8 million tonnes per year according to recent assessments (FAO, 2022; USDA, 2023). In this context, the management and valorization of cereal co-products represent a central issue for the transition towards a circular bioeconomy.

Internationally, numerous studies published since 2020 highlight that cereal-processing by-products such as husks, bran, screening residues and spent grains—should no longer be regarded as waste streams to be discarded, but rather as high-value matrices. For example, *Skendi et al. (2020)* demonstrated that wheat bran is an exceptional source of polyphenols, insoluble fibres and micronutrients, making it highly suitable for functional food applications. Similarly, Ilhan-Ayisigi,and *al*., 2020 showed the feasibility of extracting antioxidant compounds from grain husks, paving the way for their incorporation into innovative food formulations. In parallel, studies by Bai *and al., (2019)* confirm the potential of lignocellulosic cereal residues for producing advanced biofuels, including bioethanol and biogas. In the field of materials, research by Berthet and *al*, (2015) demonstrates that these residues can be used in the manufacture of biocomposites, biodegradable films and bio-based packaging. Furthermore, recent studies such as those by Rumbold *and al. (2009)* underline the effective use of cereal by-products as substrates for fermentation, edible mushroom cultivation or as sources of bioactive polysaccharides.

However, the analysis of data from Algerian cereal-processing companies (Figure 1) reveals a significant discrepancy between these scientific advances and national practices. Grain husks, produced by 77.78% of companies, are valorised by only 44.44%, primarily for animal feed, fertilisation or incorporation into low-value-added products. Screening residues, generated by 44.44% of units, are valorised by just 22.22%, again mainly for livestock feed. These uses remain far below the high-value valorization pathways identified by Jimenez-Lopez and *al.*, (2020), Li and *al.*, (2021). Wastewater, produced by 55.56% of companies, receives no valorization, despite several studies (such as Kumar and *al.*, 2021; Hao and *al.*, 2020) demonstrating its potential for biogas production or nutrient recovery following appropriate treatment. Packaging waste, generated by 66.67% of companies, is recycled by only 33.33%, although international experiences have shown the feasibility of valorising films, bags and cardboard through structured recycling channels (Da silva and *al.*, 2023).

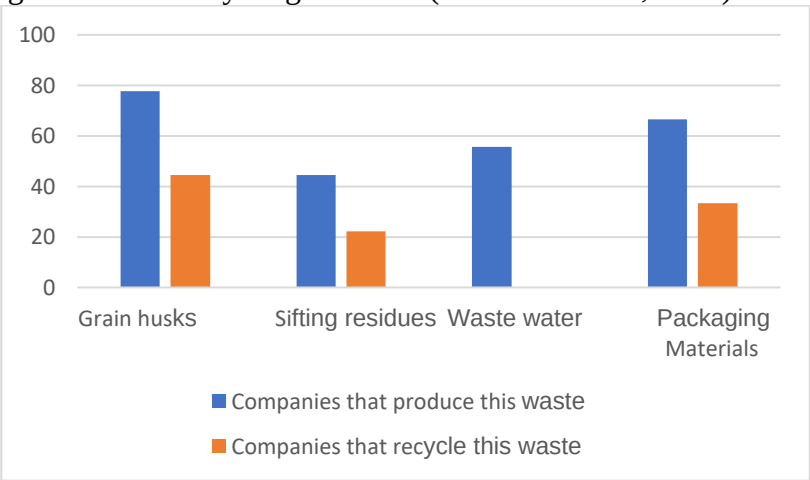


**Figure 1. Production and valorization of waste in the cereal industry in Algeria**

### 3.3.2 Valorization of By-Products in the Dairy Industry

The dairy industry is one of the most dynamic branches of the Algerian agri-food sector, with 778 enterprises recorded by the CNRC National Trade Register Centre in 2016, illustrating its economic and strategic weight. This sector, however, generates considerable volumes of by-products whose management remains problematic, despite recent literature emphasising their potential within a modern circular bioeconomy.

As highlighted by Buchanan (2023) and Tunick, Renye & Garcia (2025), dairy residues—particularly whey, buttermilk and permeate—are now regarded as matrices rich in bioactive compounds that can be converted into functional ingredients, antimicrobial molecules or immunomodulatory agents through innovative fermentation and biotransformation processes.

The results obtained from Algerian dairy companies (Figure 2) nonetheless reveal very limited valorization of the main by-products. Buttermilk, produced by 5.26% of enterprises, is not valorised by any of them, even though recent studies highlight its nutritional and technological potential, notably for the extraction of phospholipids and bioactive peptides (Dissanayake and *al.*, 2022). Downgraded products, generated by 21.05% of companies, also remain unvaporized despite their suitability for directed fermentations or incorporation into food formulations, as demonstrated by Pagioro and *al.*, (2020) and Hameed and *al.*, (2023).

Permeate, produced by 5.26% of companies, is not valorised in any unit, although recent studies by Teixeira and *al.*, (2022) and Smithers (2020) highlight its increasing use in the manufacture of dairy beverages, lactose production, and as a substrate for producing lactulose and other prebiotic compounds. Cream separator sludge, produced by 26.31% of companies, also remains unexploited, despite documented applications in anaerobic digestion and animal feed reported by Casal and *al.*, (2021).

Whey represents the most significant by-product: although 47.36% of companies produce it, only 10.52% valorise it, primarily in cheese production. However, recent literature points to whey as a strategic resource. According to Yadav and *al.* (2022) and Buchanan (2023), whey can be transformed into bioactive peptides, functional fermented beverages, bioplastics, fermentation media, antimicrobial compounds and biostimulants. Recent findings by Tunick (2025) even demonstrate its conversion into immunoregulatory compounds via microbial fermentation, reinforcing its relevance within the advanced bioeconomy. Algerian contributions (Belhout and *al.*, 2015; Setouti & Beggar, 2017; Dahache & Messaoudi, 2019…) also confirm the technological feasibility of multiple valorization pathways, though their industrial implementation remains limited.

Wastewater presents another critical issue: produced by 73.68% of companies and valorised by only 10.52%. Despite recognised potential for anaerobic digestion, nutrient recovery or biogas production—as demonstrated by Hao and *al.*, (2021) and Dragone and *al.*, (2022) valorization remains marginal. The Algerian regulatory framework, particularly Executive Decree No. 09-209, imposes very strict $BOD_5$ and COD thresholds, whereas effluents such as whey largely exceed these values ($BOD_5$: 20–50 g/L; COD: 60–80 g/L), highlighting the need for alternative valorization strategies. Finally, packaging waste, although produced by 89.47% of companies, is recycled by only 31.57%, despite promising prospects reported by Da silva and *al.*, (2023) and Müller and *al.*, (2021) regarding bioplastics and bio-based materials.

Overall, the results demonstrate a significant gap between the opportunities documented in recent scientific literature and the practices currently observed within Algerian dairy industries.

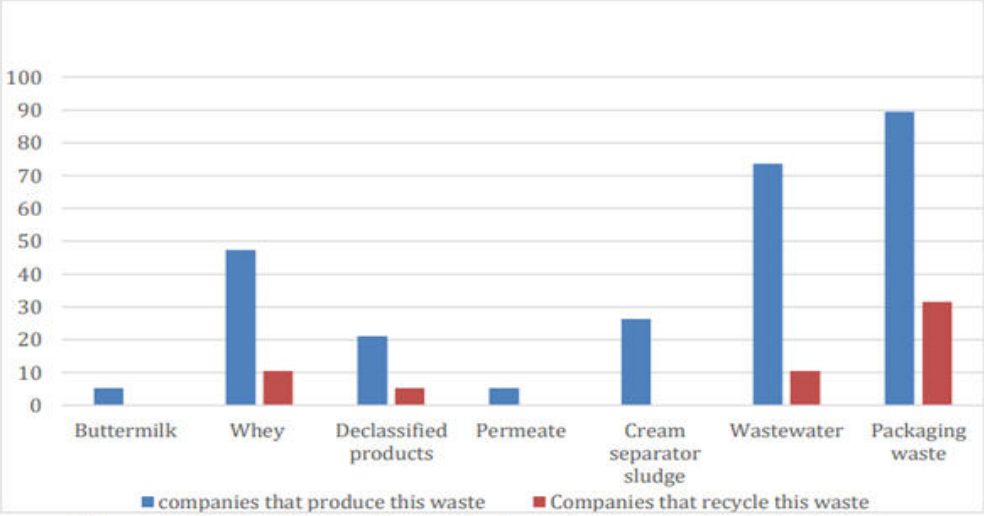


**Figure 2. Production and valorization of waste in the dairy industry**

### 3.3.3 Valorization of By-Products in the Fruit and Vegetable Processing Industry.

The fruit and vegetable processing sector occupies a strategic position within the Algerian agri-food industry, owing to the large volumes of raw materials handled annually and the diversity of by-products generated. Analysis of the data in Figure 3 shows a notable production of organic waste within companies. Indeed, 41.66% of units report generating downgraded vegetables, of which 33.33% are valorised, mainly through resale. Peels and pulps, produced by 33.33% of enterprises, are valorised at the same rate, primarily as animal feed, fertilisers, or ingredients incorporated into other food formulations. Screening residues, generated by 16.66% of units, are valorised by only 8.33%, despite representing an organic resource rich in fibres. Sludges, also produced by 16.66% of enterprises, are exclusively used as fertilisers. Wastewater, which is highly prevalent (83.33% of units), is valorised in only 25% of cases, typically after internal treatment. Finally, packaging waste, generated by 83.33% of companies, is valorised at 25%, often through recycling or reuse.

These figures indicate that valorization within the sector remains dominated by traditional uses (fertilisers, animal feed, resale), consistent with the observations of Dilucia et *al.*, (2020), who report that, in many countries, fruit and vegetable waste is still mainly composted or directed towards animal feed. However, recent literature highlights far wider potential. Studies by Nirmal, (2023) and Martínez-Ramos and *al.*, (2020) show that plant-based by-products—such as pulps, peels, seeds and pomace are rich in dietary fibres, polyphenols, carotenoids, vitamins and aromatic compounds, opening the way to high-value valorization pathways. Saini and *al.*, (2020) and Panzella (2021) demonstrate the relevance of these co-products as sources of bioactive compounds for nutraceuticals, antioxidant extracts and natural pigments. Peels and skins, which are minimally valorised in Algeria despite their potential, can be used to produce nutritional powders, edible films or biomaterials, as confirmed by Garcia-Amezquita and *al.*, (2022) and Zhu and *al.*, (2021).

Seeds and pits, which were not valorised in the surveyed units, could nevertheless be exploited for the extraction of vegetable oils rich in polyunsaturated fatty acids, tannins and polyphenols, as demonstrated by Saavedra and *al.*, (2021) and Mahato and *al.*, (2022). Wastewater—still very underutilised constitutes a promising stream for microbial fermentation, biogas production or nutrient recovery, according to Dragone and *al.*, (2022) and Kumar and *al.*, (2023). Finally, packaging waste, which remains underexploited in Algeria, can be transformed into bioplastics or composite materials incorporating plant fibres, in line with recent findings by Da silva and *al.*, (2023) and Müller and *al.*, (2021).

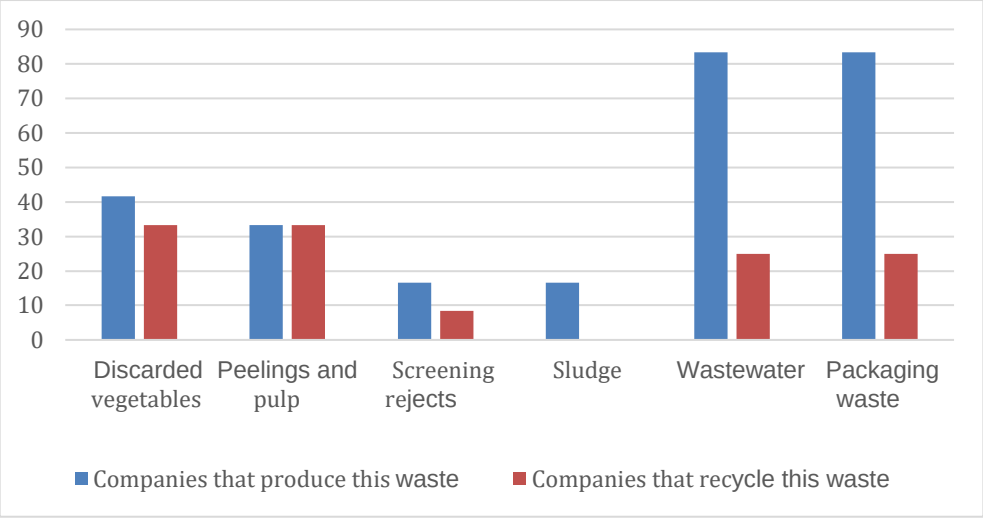


**Figure 3. Production and valorization of waste in the fruit and vegetable processing industry in Algeria.**

### 3.3.4 Valorization of By-Products in the Meat Industry

The meat industry generates substantial quantities of solid animal by-products (SAP) and slaughterhouse wastewater (SWW). Globally, meat production—estimated at nearly 250 million tonnes in 2020 produces up to 375 million tonnes of SAP and 2,250 million m³ of wastewater, illustrating the significant environmental pressure exerted by this sector (Food Systems Group, 2021). As highlighted by Pérez-Camargo and *al.*, (2022) and Nath and *al.*, (2023), these by-products contain biomass rich in proteins, lipids, minerals and keratin, yet they are often disposed of through unsustainable practices such as incineration, landfilling or conventional rendering, which exacerbate environmental and sanitary impacts.

In Algeria, the data collected (Figure 5) show that most by-products generated by companies are not valorised. Specifically, 15.38% of enterprises produce tallow and fat, 7.69% generate bones, 38.46% produce poultry carcass residues, and 92.3% generate wastewater yet none of these streams are valorised. However, recent literature indicates that animal fats can be converted into bio-lubricants and bio-oils (Xu and *al.*, 2023), bones can be transformed into hydroxyapatite or calcium phosphate for biomaterial applications (Lee & Kim, 2022), and slaughterhouse wastewater can serve as a substrate for anaerobic digestion, enhancing biogas production (Bohdziewicz and *al.*, 2021).

Some valorization opportunities are nevertheless implemented in Algeria. Poultry feathers, generated by 84.61% of enterprises, are valorised into animal protein, a practice consistent with the findings of Dersseh and *al.*, (2022) and Mullen and *al.*, (2021), who highlight the relevance of transforming feathers into keratin-rich meals or functional materials. Bristles, produced by 38.46% of units, are used in textile fibre production, in line with Sharma and *al.*, (2023), who describe the increasing valorization of animal fibres for technical textiles. Packaging waste, meanwhile, is recycled by only 15.38% of enterprises, although recent studies (Da silva and *al.*, 2023; Müller and *al.*, 2021) demonstrate its potential use in bioplastic and composite material production.

At the international level, several advanced valorization pathways are documented. SAP constitute a resource for producing biogas, protein hydrolysates, bioactive peptides, collagen, gelatine, biofertilisers, amino acids and even biodegradable films (Caruso and *al.*, 2023; Ashraf and *al.*, 2024). Thermochemical conversion through pyrolysis or hydrothermal processing yields biochar, bio-oils and mineral ashes that can be valorised (Lopez and *al.*, 2021). Several studies, including Dersseh and *al.*,

(2022), also show that meat-processing residues are used worldwide for manufacturing fertilisers, animal feed, adhesives and leather products. Overall, the meat sector in Algeria presents considerable valorization potential, which remains largely underexploited.

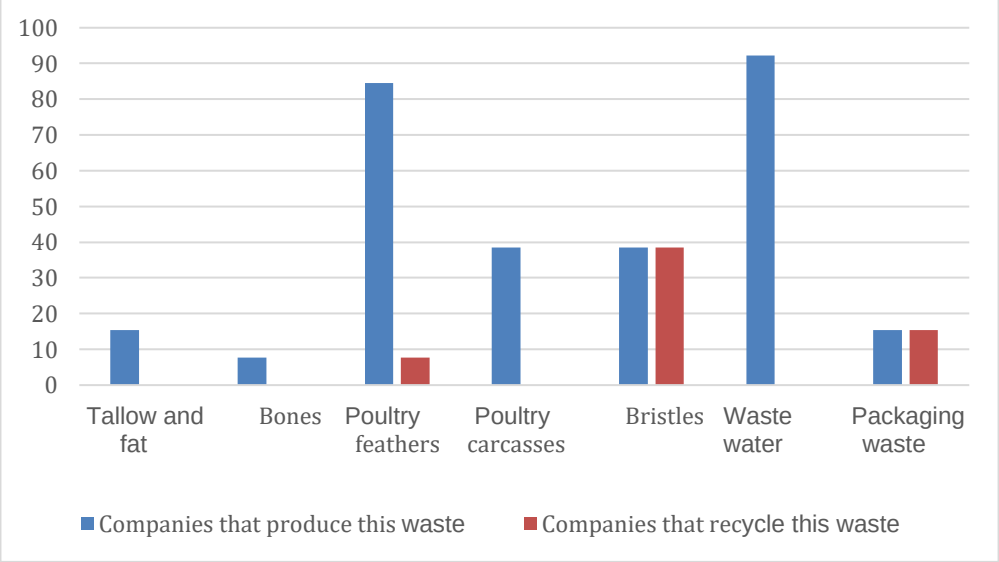


**Figure 4. Production and valorization of waste in the meat industry in Algeria**

### 3.3.5 Valorization of By-Products in the Sugar Industry

The examination of practices observed in Algerian sugar-processing units highlights a highly contrasted management of the various by-products generated during processing. Molasses, produced only in certain facilities, is most often directed toward a single outlet: the manufacture of ethyl alcohol. Conversely, wastewater is systematically treated and reused by all companies, representing one of the few processes applied consistently across the sector. Decantation residues, however, receive no form of exploitation, while packaging waste constitutes the only stream benefitting from widespread recycling.

This overall picture reveals a sector engaged in some environmental management practices, yet still largely confined to conventional and relatively undiversified valorization pathways.

International literature presents a markedly different vision of the potential of the sugar industry. Over recent years, the sector has increasingly been conceptualised as an integrated system indeed, a form of biorefinery in which co-products such as bagasse, molasses, vinasse and press-mud are treated as valuable resources for bioenergy, fertilisers, bio-based materials or high-value molecules (Singh and *al.*, 2022; Hassan and *al.*, 2019). Molasses illustrates this diversification particularly well: beyond ethanol production, it can serve as a substrate for synthesising organic acids, developing industrial yeasts and enzymes, producing microbial biomass or even formulating animal feed (Bernard, 1991; Boucherba, 2015; Fandi, 2024). Press-mud is used as an organic soil amendment or as a source of industrially exploitable bioactive compounds (Mohan and *al.*, 2021). Bagasse plays a central role in cogeneration systems and in the development of renewable materials (Singh and *al.*, 2022; Ntunka and *al.*, 2025). These studies collectively reflect a high degree of technological diversification, in sharp contrast with national practices.

In Algeria, the sugar industry is highly concentrated around a few major operators, including Cevital, Berrahal, Sorasucre and La Belle–Cristal Union (Sekhane, 2017). Although these companies generate substantial volumes of co-products, valorization remains limited to a few targeted applications: ethanol production, wastewater treatment and packaging recycling (Figure 5). Yet, several studies carried out in the country demonstrate that more diversified valorization pathways are technically

feasible. Zerouali and Hamami (2019), for example, examined the optimisation of molasses fermentation to enhance bioethanol production, while other research (Fennouche, 2017; Fandi, 2024) explored the generation of organic acids or microbial metabolites from the same substrate. These findings underline a genuine potential that, for the moment, remains confined to experimental settings.

At the African level, certain regions exhibit a far more advanced structuring of valorization chains. In South Africa, bagasse feeds cogeneration plants, vinasse is used as a substrate for bioenergy production, and press-mud is incorporated into organic fertiliser formulations (Pachón et al., 2018; South African Sugar Association, 2023). Analyses conducted by United Nations Industrial Development Organization UNIDO (2025) further highlight the strategic importance of valorising sugar-sector co-products to reduce reliance on imported inputs and energy costs priorities for many African countries. In comparison, the Algerian sugar industry appears to be at an intermediate stage: solid foundations exist, yet diversification of uses remains limited.

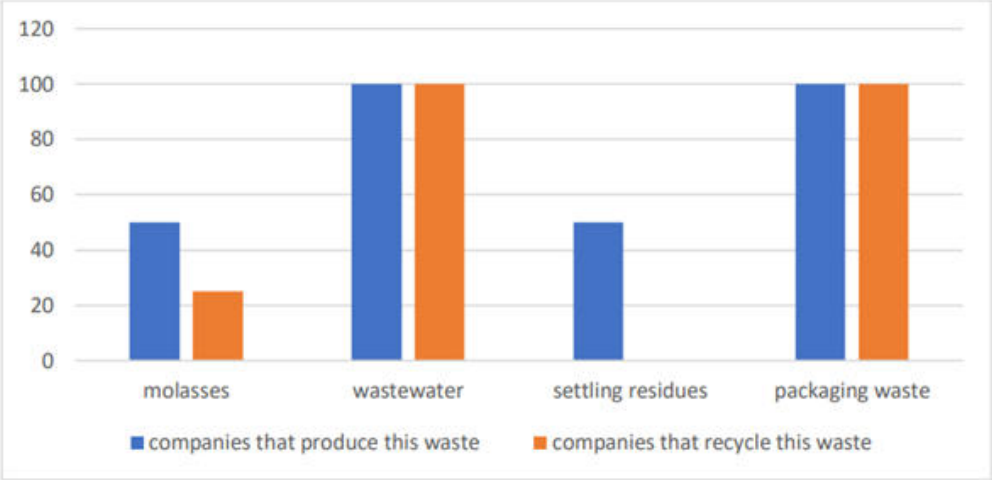


**Figure 5. Production and valorization of waste in the sugar industry**

### 3.4 Waste Valorization Profile by Category in the Agri-Food Industries

Figure 6 provides a synthetic overview of waste flows within the surveyed industries, revealing a pronounced asymmetry in which the volume of waste generated does not correspond to an equivalent level of valorization. Organic and aqueous waste streams constitute the most abundant categories, yet remain poorly integrated into valorization processes. This pattern, documented in several African contexts, has been described by the FAO (2019) and by Adekoya and Olanrewaju (2020), who emphasise that the absence of technological infrastructure, structured collection systems and institutional incentives limits the conversion of these flows into economic resources. These observations are consistent with analyses by Kanoktanaporn (2019) and the Ellen MacArthur Foundation (2020), which note that circularity is difficult to establish in the absence of consolidated technical value chains.

In Algeria, several sector-specific studies confirm this trend. Research conducted on cereal, citrus and brewery by-products (Hamdouche & Kettou, 2015), as well as on agro-industrial effluents (Karef et al., 2014; Messrouk and *al.*, 2014), shows that the mere availability of potentially valorizable resources is insufficient to give rise to operational value chains. The profile revealed by the radar diagram thus reflects a structural configuration in which waste categories lacking appropriate technical or institutional mechanisms exhibit near-zero valorization levels.

The contrast with packaging waste is particularly striking. Its market value and the presence of a secondary recovery market explain its more frequent integration into recycling streams, a trend also observed in other middle-income economies (D'Adamo and *al.*, 2022). However, studies conducted in

Algeria (Guermoud and *al.*, 2009; Lamri, 2022; Cheniti and *al.*, 2024) show that, despite this relatively favourable position, actual recovery remains far below its theoretical potential, with landfilling remaining the dominant practice.

International comparisons further illuminate these results. In regions that have adopted ambitious circularity policies—particularly in Europe under the European Green Deal—organic and aqueous waste streams are integrated into mature value chains such as anaerobic digestion, industrial composting or biorefinery systems (Pfaltzgraff & Clark, 2014; Mirabella and *al.*, 2014). In Latin America and Asia, similar valorization processes increasingly encompass agricultural and dairy by-products (Bastos et and *al.*, 2020; Zhang and *al.*, 2021). This panorama shows that the performance of a valorization system depends less on the intrinsic characteristics of the waste than on the consolidation of infrastructures, institutional mechanisms and regulatory frameworks.

Furthermore, Figure 6 illustrates that current valorization practices only partially align with the principles of the circular economy, notably the maintenance of material flows in successive cycles, the reduction of losses and the maximisation of added value.

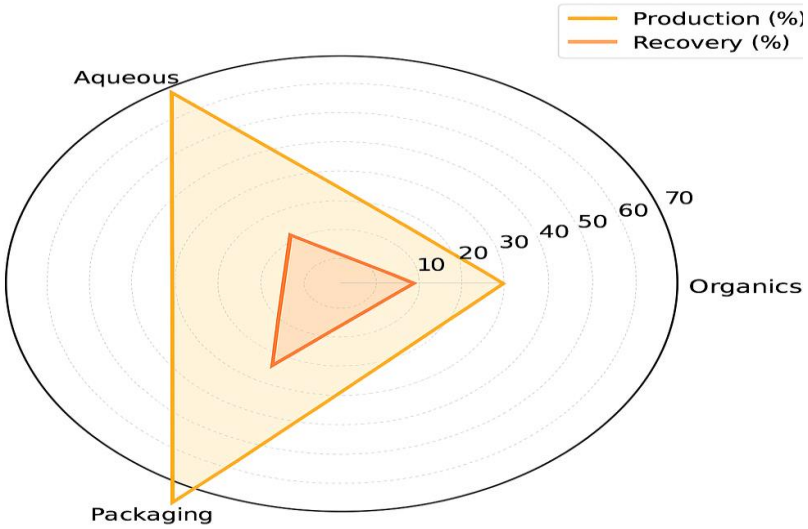


**Figure 6**: *Production and Valorization According to Waste Types in the Agri-food Industries in Algeria.*

### 3.5. Relationship Between Regulation and Waste Valorization

The analysis of the relationship between the regulatory framework and the actual valorization of waste in Algeria reveals a situation characterized by a persistent gap between legal obligations and industrial practices. Although the country has a dense regulatory architecture—including Law 01-19, decrees on liquid discharges, Decree 04-199 on hazardous waste, Decree 20-293 on the circular economy, and the more recent Decrees 24-61 (2024) and 09-336 (2009)—the levels of valorization observed remain low, particularly for organic waste and effluents. This divergence is confirmed by national studies by Agha-Benamrouche & Hezil (2024), which show that despite the proliferation of legal instruments, valorization remains marginal in several industrial sectors. Similarly, Dahmane et *al.*, (2024) note that actual performance in recycling and composting remains far below regulatory ambitions, due to a lack of infrastructure and enforcement mechanisms.

A crucial dimension of this divergence lies in the institutional architecture governing waste management in Algeria. Law 01-19 designates local authorities—particularly the municipality and the wilaya as central actors in the operational management of waste, with the Wali responsible for oversight and enforcement actions. Decrees 04-199 (hazardous waste) and 09-336 (special industrial waste)

further assign technical control and inspection duties to the Direction of Environment at the wilaya level. However, as highlighted by Hassaine & Abrika (2024), the distribution of tasks and responsibilities among these actors remains only partially defined in practice, which weakens the capacity of local institutions to translate regulatory obligations into effective valorization measures. This lack of clarity, also noted by Benouali (2019) and Moussaoui (2020), contributes directly to the limited adoption of circular practices, as enterprises operate within a regulatory environment where enforcement is uneven and institutional guidance insufficient.

A comparison with neighboring Maghreb countries shows similar trends, but with some nuances. In Morocco, the study by Dahchour et *al.,* (2021) highlights that the country has strengthened its regulatory framework and deployed sorting and valorization strategies, yet the recycling rate remains below the targets set in the national waste policy. Analyses by Campitelli et *al.,* (2023) confirm that circularity remains limited due to reliance on landfilling, despite a more operationally effective legal framework than that observed in Algeria. In Tunisia, studies by the World Bank (2023) also show that although legal texts regulating waste management and energy valorization have been in place for several years, their implementation remains fragmented, primarily due to financial constraints and unstable recovery channels. A recent review by Hemidat et *al.,* (2022) highlights the same issue: while the Tunisian legal framework anticipates circularity, actual recovery rates remain modest.

At the African level, systematic reviews by Hemidat (2022) and Tesfaye et *al.,* (2025) indicate that several countries have adopted laws and strategies promoting waste valorization and reduction. However, concrete implementation faces structural obstacles: infrastructure deficits, low private investment, and a lack of local technical expertise. These findings suggest that the MENA region and sub-Saharan Africa share the same challenge: regulation is advancing faster than actual valorization capacities.

The situation differs significantly in several European countries. In the European Union, regulations related to the circular economy—particularly the Circular Economy Action Plan (CEAP) and the revised waste directives have led to structural transformations, resulting in considerably higher valorization rates. The review by Geissdoerfer et *al.,* (2017) shows that European success is based on a combination of strict regulatory frameworks, economic incentives, and high-performing infrastructures. Additionally, Mirabella et *al.,* (2014) and Pfaltzgraff & Clark (2014) demonstrate that European agri-food industries are increasingly incorporating by-products into biorefineries, biotechnological processes, and high-value ingredient production chains a dynamic that is still rare in Algeria or the Maghreb region.

Globally, recent reviews by Yaashikaa et *al.,* Pinheiro (2022), and others (2025) show that valorization is progressing in countries that have made significant investments in technological ecosystems, particularly in East Asia (China, Japan, South Korea) and South America (Brazil, Chile). In these contexts, regulations are accompanied by heavy investments in innovation, integrated industrial chains, and binding waste reduction targets, leading to far superior results than those seen in the Maghreb.

Overall, international comparisons indicate that Algeria is in an intermediate phase: the regulatory framework is now robust and aligned with international circular economy principles, but valorization remains limited due to technical, economic, and institutional constraints. Unlike several European and Asian countries, where legal obligations are supported by operational infrastructures and strict enforcement mechanisms, Algerian industries remain predominantly locked in a linear model. This analysis clearly shows that the success of valorization depends not only on the law but on the system's ability to make regulation actionable, profitable, and technically feasible

## 4. Conclusion

This study shows that agri-food by-product valorization in Algeria remains very limited, despite the existence of a comprehensive regulatory framework aligned with circular economy principles. The findings indicate that, although the legal and institutional architecture is well established, its implementation at the territorial level remains insufficient to effectively support valorization in the agri-food sector**.** Strengthening local governance capacities and improving enforcement mechanisms therefore appear essential to bridge the gap between regulatory ambition and actual practice.

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