

Operationalizing Circular Economy Principles Through Integrated
Digital Systems: An Analytical Assessment of Algeria’s National Waste
Agency Tools

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Abstract:

The study analyzes how Algeria’s National Waste Agency (AND) uses four integrated digital systems—SNID, SIG, BDI, and NDIF to support the transition to a circular economy under Law 25-02. It relies on documentary analysis of institutional and regulatory frameworks to understand how these tools jointly create informational, spatial, economic, and participatory conditions for waste valorization. The results indicate that the digital infrastructure enhances transparency, optimizes collection routes, stimulates investment in recovery, and improves service quality through citizen reporting. However, its success still depends on parallel investments in physical infrastructure, institutional capacity, enforcement, and stakeholder engagement.

Keywords: Circular Economy; Digital Transformation; Waste Valorization; Law 25-02; Algeria’s National Waste Agency; Digital Quartet (SNID, SIG, BDI, NDIF).

JEL Classification Codes: Q53, Q56, O33

1. INTRODUCTION

The global transition toward a circular economy (CE) has reframed waste from a disposal burden into a recoverable resource, yet realizing this shift requires advanced digital systems capable of ensuring real-time transparency and material flow integration. In Algeria, Law No. 25-02 (February 2025) marks a strategic turning point by embedding circular economy principles into waste management governance and mandating

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digital transformation through The National Waste Agency (Agence Nationale des Déchets—AND). To operationalize this vision, AND has deployed an integrated digital quartet SNID (Système National d'Information sur les Déchets -The National Waste Information System), BDI (Bourse des Déchets Industriels -The Waste Exchange), SIG (Système d'Information Géographique -Geographic Information System), and NDIF (mobile application) that collectively establish the informational, operational, and participatory infrastructure necessary for transitioning from linear to circular waste management. This study examines how these four systems function synergistically to operationalize Law 25-02, establish waste as an economic asset, and create enabling conditions for circular economy advancement in Algeria's waste sector.

1.1 Research Problem

1.1.1 Research Problem and Research Questions: Against this background, the central research problem addressed in this study can be articulated as follows:

How do integrated digital systems operationalize CE principles within Algeria's waste sector under Law 25-02?

1.1.2 Research Questions: To address this overarching problem, the study pursues the following sub questions:

- How do the integrated digital systems (SNID, SIG, BDI, NDIF) operationalize circular economy principles?
- What functional roles do these systems play in waste valorization and material flow management?
- To what extent do these systems support the implementation of Law 25-02?

1.3 Study Objectives

In line with this problem and hypothesis, the study pursues the following objectives:

- To assess the effectiveness of the SNID system in providing an accurate and comprehensive database that supports decision-makers and investors in designing and managing CE loops.

- To analyze the functional role of the NDIF application in tracing the trajectories of recovered resources and ensuring transparent flows that prevent the dissipation of the economic value embedded in waste.
- To examine the contribution of the SIG system to spatial and material efficiency by rationalizing waste collection and distribution routes and reducing the operational costs associated with waste valorization.
- To highlight the importance of the BDI platform as a mechanism for stimulating investment in waste recycling and for converting waste into economic assets traded through a digital marketplace.
- To explore the prospects for deeper digital integration among the four systems as a unified platform capable of acting as a strategic lever to accelerate the transition towards a CE in Algeria.

1.4 Significance of the Study:

This study addresses a notable gap in understanding how digital infrastructures can operationalize circular economy principles in emerging economies, particularly within the institutional context of Algeria's waste sector under Law 25-02. It contributes conceptually by framing waste valorization as an information-intensive and regulation-dependent process, and empirically by demonstrating how integrated digital systems (SNID, SIG, BDI, NDIF) can enhance investment efficiency, strengthen data governance, and support economic resilience while advancing circular economy objectives.

1.5 Methodology of the study :

This study adopts a qualitative, documentary-analytical methodology that relies on official AND documents, regulatory texts, and academic literature to examine how the digital systems SNID, SIG, BDI, and NDIF operationalize circular economy principles under Law 25-02. Using thematic synthesis, it analyzes each system's functional design and its role within the integrated digital quartet, without collecting primary data or testing causal hypotheses.

I. THEORETICAL FRAMEWORK : Strategic Foundations of the CE and Digital Enablement Mechanisms

1. Conceptual Foundations of the Circular Economy

The transition towards a represents a paradigmatic shift in economic thinking that extends far beyond the simple recycling of waste. It involves a fundamental re-engineering of resource flows, global material systems, and production-consumption relationships, with digitalization emerging not merely as a technical choice but as a systemic prerequisite for sustaining and integrating these circular loops over time.

1.1 Definition and Conceptualization of the CE

The CE is increasingly recognized in academic discourse as "a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops" (Geissdoerfer, Pieroni, Pigosso, & Soufani , 2020). This definition captures three distinct operational strategies: slowing loops through product durability and extended lifespan; closing loops through reuse, remanufacturing, and recycling; and narrowing loops through dematerialization and reduced material intensity.

The circular economy concept emphasizes closing the loop in production and consumption cycles by designing out waste, keeping products and materials in use for as long as possible, and regenerating natural systems. This approach contrasts sharply with the traditional "take-make-dispose" model, focusing on minimizing waste generation through innovative design, responsible consumption, and effective recovery strategies (Kotayal, 2023).

In practice, CE systems are implemented through a portfolio of strategies including long-lasting design, maintenance and repair, reuse, remanufacturing, refurbishing, and recycling each calibrated to the material type, economic context, and regulatory environment. The core principle is that materials and resources should flow continuously within industrial ecosystems, mimicking biological cycles in which waste from one process becomes feedstock for another, thus minimizing extraction of virgin resources and reducing environmental externalities.

1.2 Transition from the Linear to the Circular Model: Economic and Environmental Imperatives

The dominant economic model of the past two centuries—often termed the "linear" or "take-make-dispose" economy has generated cumulative environmental and resource pressures that now threaten the stability of production systems themselves. This model is predicated on the assumption of abundant, low-cost natural resources and unlimited assimilative capacity of ecosystems for waste and emissions.

In practice, the linear model proceeds as follows: (1) extraction of raw materials from the natural environment; (2) industrial transformation into goods; (3) use-phase consumption; and (4) disposal into landfills, incineration facilities, or diffuse environmental sinks. Each stage is economically optimized in isolation, without accounting for cascading environmental costs, resource scarcity, or supply chain vulnerabilities. The result is accelerating resource depletion, mounting waste stockpiles, accumulating persistent pollution, and destabilized global cycles of critical materials (phosphorus, rare earths, metals). (Valavanidis, 2018)

This transition is not merely aspirational; it is increasingly driven by material necessity. Resource prices are volatile and subject to geopolitical constraints; regulatory frameworks (especially in the EU and increasingly in Asia) are imposing extended producer responsibility and circular design requirements; and investors are integrating circular business models and resource resilience into risk assessment and valuation frameworks. Algeria, in particular, faces acute pressures: limited natural resource bases outside hydrocarbons, growing waste streams, imported material dependencies, and exposure to global supply chain disruptions. The CE thus represents not only an environmental imperative but also an economic resilience strategy (Organisation des Nations Unies pour le Développement Industriel, 2017).

1.3 Definition and Taxonomy of Digital Enabling Technologies

Digital enabling technologies constitute an integrated ecosystem of information, computing, and communication tools that together create a unified platform for material flow visibility, system optimization, and stakeholder coordination (Bücker, Pantel, & Geissdoerf, 2025). The principal enabling technologies include (Massari & Nacchiero, 2023):

1.3.1 Internet of Things (IoT)

IoT refers to networks of physical objects sensors, devices, waste collection containers, sorting facilities, processing units, and even end-of-life products embedded with connectivity, digital identifiers, and computational capacity. IoT enables real-time tracking and traceability of waste and recovered materials across the entire value chain, with automated data capture at key control points to reduce errors and accelerate decision-making.

1.3.2 Big Data Analytics (BDA)

BDA refers to the systematic collection, integration, and statistical analysis of very large, heterogeneous datasets generated across supply chains, production facilities, consumption patterns, and waste management systems. BDA enables pattern recognition and forecasting of waste volumes and recovery yields, optimizing capacity planning and process configurations.

1.3.3 Artificial Intelligence (AI)

AI encompasses machine learning, predictive modeling, and autonomous decision systems that can learn from historical data and adapt to new conditions. In CE applications, AI enables demand forecasting and supply planning by integrating market signals to predict material economic viability, while automated sorting via computer vision and machine learning improves recovery rates and product quality.

1.3.4 Blockchain Technology (BC)

BC constitutes a distributed, cryptographically secured ledger system that maintains immutable records of transactions, ownership changes, and material flows across a network of participants without requiring a centralized intermediary (Kirchherr, Yang, Spüntrup, Heerink, & Hartley, 2023). In CE contexts, Blockchain enables complete material traceability throughout product lifecycles and recovery cycles, creating tamper-proof chains of custody for regulatory compliance and consumer authentication.

2. The Legal and Regulatory Framework for Waste Management in Algeria

The Algerian legal system has undergone a profound transformation, whereby the legal characterization of waste has shifted from being an environmental burden requiring removal and final disposal to being regarded

as an economic resource eligible for valorization. This shift is reflected in the move away from the traditional approach established by Law No. 01-19 on the management, control and elimination of waste towards the adoption of an integrated management strategy. This legislative reform responds to international developments through the introduction of substantial amendments in 2025 by Law No. 25-02, which laid down the legal foundations of the CE model. Accordingly, the legal framework is no longer a mere technical control instrument but has become a strategic lever aimed at embedding environmental responsibility at the heart of the development process.

2.1 The Shift towards a CE in Light of Law No. 25-02

The promulgation of **Law No. 25-02 of 21 Shaaban 1446**, corresponding to 20 February 2025, amending and supplementing Law No. 01-19 of 12 December 2001 relating to the management, control and elimination of waste, marks a turning point in Algeria's waste-sector policy. This change is not a mere procedural adjustment, but rather a transition towards a strategic vision whose main pillars can be summarized as follows:

2.1.1 Adopting the CE as a strategic choice:

Enshrining the concept of the CE at the core of **Law No. 25-02** represents a fundamental recasting of the relationship between the legislative framework and economic activity in Algeria. Instead of the linear model based on depleting resources and then discarding them as waste, the legislator has established the rules of a circular model that seeks to keep materials and resources within the economic cycle for as long as possible.

2.1.2 End-of-waste status:

The legislator's recognition of this principle constitutes a qualitative leap towards closing the CE loop, as it allows the legal transition from a disposal-oriented model to a valorization-oriented model in which waste is treated as an economic resource. This transformation rests on the institutionalization of integrated management, which gives priority to recovery and recycling over engineered landfilling. The law establishes the principle of exiting waste status and converting waste into a raw material or product that can be valorized, together with a hierarchical sequence of treatment options that prioritizes recovery.

2.1.3 Integration of eco-design and extended producer responsibility (EPR):

The law adopts proactive instruments aimed at reducing negative environmental impacts throughout the product life cycle, notably through the principle of eco-design as a technical standard ensuring product durability and recyclability from the manufacturing stage. This is articulated in tandem with the principle of EPR, which shifts the financial burden of waste management from the State to the producer or importer, thereby supporting the effective transition towards a circular economy.

2.1.4 Modernization of the sanction regime as a guarantee of compliance:

To ensure field-level effectiveness of the newly introduced principles, the legislator, in **Law No. 25-02**, strengthened the sanction regime through a comprehensive revision of the penal provisions related to breaches of management standards. The objective is to enforce compliance with the new obligations concerning valorization and EPR, thus making the sanction system a mechanism that sustains the CE model and protects economic resources from waste or unlawful exploitation.

2.2. Waste Valorization in Light of Law No. 25-02

2.2.1 Definition and Types of Waste

Article 2 of Law No. 25-02 defines waste as “any residues resulting from production, transformation or use processes and, more generally, any material, product or movable object that the owner or holder disposes of or removes.” Waste is classified into the following categories:

- **Household and similar waste:** All waste generated by household activities and similar waste arising from commercial, industrial, craft and other activities.

- **Bulky waste:** All waste generated by household activities, which, due to its large size, cannot be collected together with household, and similar waste.

- **Special waste:** All waste generated by industrial, agricultural, healthcare, service and other activities which, due to its nature or the composition of the materials it contains, cannot be collected, transported and treated under the same conditions as household and inert waste.

- **Healthcare waste:** All waste resulting from diagnostic, monitoring,

preventive or curative activities in human and veterinary medicine.

- **Inert waste:** All waste resulting from quarrying and mining activities and from demolition, construction or renovation works, which does not undergo any physical, chemical or biological change when disposed of in landfills.

- **Organic waste:** All biodegradable waste of animal or plant origin.

- **Marine waste:** All waste discharged, disposed of or dumped in the marine and coastal environment, regardless of its size.

- **Final waste:** All waste, whether resulting from treatment or not, for which no further recovery is safely possible.

2.2.2 Waste Valorization

Waste valorization constitutes the essential transitional link between the linear waste management model and the CE model. It enables the shift from a logic of disposal and landfilling to a logic of valorization that closes resource loops and maximizes their economic value, thereby making it the practical cornerstone for realizing the principles of the circular economy. **According to Article 2 of Law No. 25-02**, waste valorization comprises all operations aimed at re-using waste, repairing it, reusing it, preparing it for reuse, recycling it, composting it and/or subjecting it to anaerobic digestion, or any other operation intended to obtain, from waste, materials suitable for use or energy. A distinction can be made between two main types of valorization:

2.2.2.1 Material valorization, which includes:

- **Re-use:** The re-employment of materials or products that have not been classified as waste, for a use similar to that for which they were originally designed.

- **Repair:** Restoring damaged objects that are no longer functional so that they can be used again.

- **Reuse or preparation for reuse:** Operations of inspection, cleaning or repair through which waste is prepared so that it can be reused as new products or components.

- **Recycling:** A set of stages starting from the collection of waste and its transformation into secondary raw materials obtained through recycling, up

to their integration into the manufacture of new products.

- Composting:** Any aerobic transformation process applied to fermentable organic matter under controlled conditions.

- Anaerobic digestion:** Any anaerobic transformation process applied to fermentable organic matter under controlled conditions.

2.2.2.2. Energy valorization:

Any recovery operation based on exploiting the calorific value of waste by incinerating it and recovering the resulting energy in the form of heat and/or electricity.

II. THE ANALYTICAL ASSESSMENT FRAMEWORK

3. Assessing the Functional Performance of AND Digital Tools

The effective implementation of **Law No. 25-02**, particularly its provisions concerning waste-flow traceability, assessment of valorization pathways, and the reinforcement of transparency, presupposes the existence of an integrated digital infrastructure capable of generating and harmonizing information. In this respect, AND information systems emerge as operational mechanisms for enforcing the law and as practical tools for translating CE principles from regulatory texts into field-level practices.

However, the efficiency of waste valorization, as a pivotal link in the transition towards the circular model, remains contingent upon the existence of information systems that ensure flow traceability, characterize valorization-eligible resources, and support decision-making. Accordingly, Law No. 25-02 constitutes the overarching legislative framework nurturing the CE in Algeria, while the waste sector represents its primary arena, and digitalization serves as the operational lever that guarantees the effectiveness of this transition. In concrete terms, AND has adopted a package of integrated information systems that function as the sector's sensory nerve center for monitoring and managing resources: SNID, GIS, NDIF and BDI.

3.1 The National Waste Agency in Algeria

3.1.1 Definition and Mandate of the AND

The AND was established by Executive Decree No. 02-175 of 20 May 2002. The Agency operates under the authority of the Ministry of Environment and Renewable Energies and is entrusted with the mission of

informing and raising awareness about techniques for the sorting, collection, transport, treatment, valorization and disposal of waste. It is also responsible for building and maintaining a specialized documentary repository on waste management, and for ensuring its dissemination to local authorities and the various key economic sectors (L'Agence Nationale des Déchets, 2025).

In this framework, the Agency carries out the following core missions: (L'Agence Nationale des Déchets, 2025)

A. Support to local authorities: Providing technical assistance and on-the-ground support to local communities in all aspects of waste management.

B. Data processing: Analyzing and processing data and information related to waste in accordance with scientific standards.

C. Information monitoring: Establishing and regularly updating a national waste data bank to serve as a central reference for decision-makers.

D. In the fields of sorting, collection, transport, treatment, valorization and final disposal of waste, the Agency is specifically tasked with:

- **Research and development:** Initiating and conducting scientific studies and research, or contributing to the implementation of pilot and demonstration projects that reflect state-of-the-art technologies.

- **Knowledge dissemination:** Publishing and spreading scientific and technical information in order to enrich academic and professional content in the waste management sector.

- **Strategic awareness raising:** Designing, launching and participating in awareness and information programs aimed at strengthening environmental consciousness.

- **Management of national systems:** Operating and managing national schemes for the recovery and valorization of specific waste streams, such as the public system for the recovery and valorization of packaging waste known as “ECO-JEM” (Eco-Jem / Eco-packaging scheme).

3.1.2 Strategic and Legislative Framework of the AND

Waste management policy in Algeria falls within the core priorities of the National Environmental Strategy (SNE) and the National Action Plan for the Environment and Sustainable Development (PNAE-DD). This strategic vision was concretized by Law No. 01-19 of 12 December 2001 on the

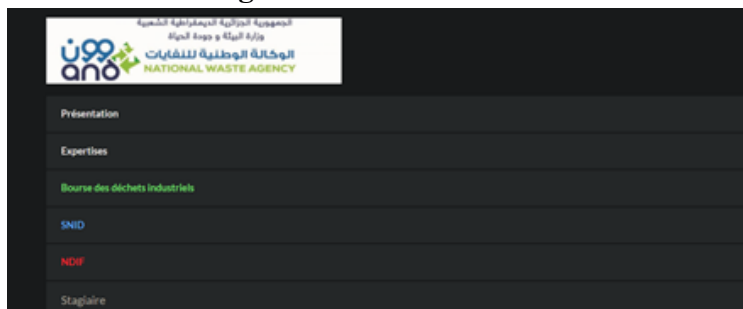
management, control and elimination of waste, which addresses the essential dimensions of waste handling based on the following guiding principles: (L'Agence Nationale des Déchets, 2025)

- **Prevention and reduction at source:** Reducing the volume of waste and lowering its level of hazardousness and toxicity from the point of generation.
- **Governance of operations:** Organizing and regulating operations of sorting, collection, transport and treatment of waste according to coherent and standardized criteria.
- **Valorization and recycling:** Strengthening waste recovery through mechanisms of reuse and recycling, with a view to reintegrating materials into the economic cycle.
- **Environmentally sound treatment:** Ensuring that waste is treated using methods that comply with stringent ecological standards, in order to minimize negative environmental impacts.
- **Community awareness and citizenship:** Establishing clear rules for informing and sensitizing citizens about the risks associated with waste and its direct effects on public health and ecosystems.

3.2 Functional and Technical Architecture of the AND System

As part of its digital transformation efforts, the Agency has structured its official web interface around a set of organized icon-based access points that enable users to navigate smoothly to its digital solutions and integrated information systems. These tools constitute the core entryway to the Agency's digital ecosystem, as illustrated in the following figure:

Fig.1. The AND Interface



Source: (L'Agence Nationale des Déchets, 2025)

3.2.1 The SNID Tool

SNID is an effective decision-support tool for all stakeholders involved in waste management, as it enables the transition from raw databases to an integrated dashboard comprising multiple indicators related to waste management, while ensuring a high level of data security. The system can be accessed via the link (snid.and.dz) and is essentially composed of: (L'Agence Nationale des Déchets, 2025)

Input interface: A set of electronic forms tailored to the various branches and specializations of waste management.

- Database:** Hosted at the data center of the National Waste Agency.

- Dashboard:** Displaying performance indicators in the form of statistics, charts and interactive maps.

SNID thus constitutes a central tool for steering and monitoring, designed to achieve the following strategic objectives (L'Agence Nationale des Déchets, 2025):

- Real-time information exchange:** Enabling instantaneous data sharing as an alternative to traditional means (paper forms, fax, email) characterized by slow procedural flows.

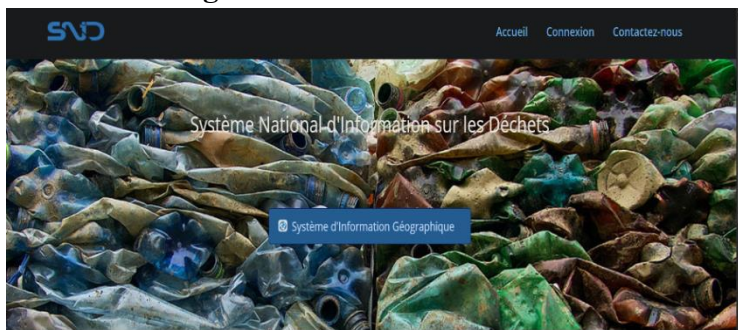
- Big data management:** Providing the technical capacity to collect, store and process large volumes of environmental data efficiently.

- Inter-institutional connectivity:** Establishing a digital communication network between geographically dispersed institutions and operators (National Waste Agency, provincial environmental directorates, public entities managing sanitary landfills, cleaning and collection companies, fisheries directorates, municipalities and private operators).

- Support for strategic foresight:** Contributing to the development of a forward-looking vision for the waste sector in the medium and long term.

The following figure presents the main interface of the system, which can be accessed either via the above-mentioned link or through a dedicated icon available on the homepage of the National Waste Agency's website:

Fig.2. Main Interface of SNID



Source: (L'Agence Nationale des Déchets, 2025)

The data entered by the various stakeholders through the platform are subject to automatic and regular processing, whereby they are converted into statistical indicators and periodic reports that diagnose the state of waste management at both local and national levels. The effectiveness of the SNID is not limited to data processing; it also extends to the harmonization of conceptual frameworks among the different actors in the waste value chain, through a glossary of terms that standardizes technical and legal meanings and reduces conceptual inconsistencies in data entry. This enhances the reliability and quality of information and helps avoid semantic discrepancies between waste producers, collectors and valorization operators. The glossary is structured around five main axes (L'Agence Nationale des Déchets, 2025):

- General terminology: Includes basic definitions of waste, producer, operator and related concepts.
- Waste classification: Technical designations of different waste types (household, inert, special, hazardous special, healthcare activities, etc.).
- Waste management branches: Terms related to recycling pathways (sorting, collection, transport, storage, valorization, recycling, etc.).
- Waste treatment facilities: Terms specific to engineered landfills, sorting centers and composting plants.
- Waste and climate: Terminology linking waste management to greenhouse gas emissions.

3.2.2 The SIG Tool

SIG is an information system designed to collect, store, process, analyze, manage and display all types of spatial data and indicators related to

waste management, through an interactive dashboard and mapping interface. It is essentially composed of four main portals by municipality (L'Agence Nationale des Déchets, 2025):

- A portal dedicated to household and similar waste generation.
- A portal dedicated to the status of master plans;
- A portal dedicated to the collection of household and similar waste;
- A portal dedicated to the treatment of household and similar waste

The following figure presents the main interface of this system:

Fig. 3. Main Interface of the SIG



Source: (L'Agence Nationale des Déchets, 2025)

Within the SNID architecture, the SIG serves as the cartographic component, whose function is to transform the raw figures and data collected by SNID into interactive maps and geospatial information that show the locations of landfills, collection routes and “black spots”. It provides a web-based solution for displaying and analyzing geographic information, and is regarded as an effective steering tool that supports decision-making for all stakeholders involved in waste management, by enabling the following (L'Agence Nationale des Déchets, 2025):

- Organizing and monitoring integrated waste management.
- Displaying and analyzing geographic information via the internet.
- Strengthening management and planning tools.
- Tracking and sharing information through dynamic and interactive maps and a dashboard containing all key indicators.
- Making data available to the public online to ensure data exchange with all categories of users.

3.2.3. The “NDIF” Application

As part of the digital transformation pursued by AND, the NDIF application was launched on 14 July 2019 and is available on mobile devices via the Play Store. This application aims to promote environmental citizenship by providing citizens with a direct communication channel enabling them to report various environmental violations, such as the spread of illegal dumps, the emergence of black spots, irregularities in waste collection schedules, or shortages in containers. It can be downloaded via the following link (Play Store download link provided by AND) (L'Agence Nationale des Déchets(2025)).

Fig. 4. Main Interface of the NDIF Application



Source: (L'Agence Nationale des Déchets, 2025)

The application operates by enabling citizens to submit reports, supported with photographic evidence, on the state of waste across the entire national territory, while benefiting from geolocation functionality that allows precise identification of the spatial coordinates of the reported issue. The National Waste Agency acts as a technical and institutional intermediary, whereby the platform automatically redirects these reports to the relevant local authorities to ensure on-the-ground follow-up and treatment of the reported problems. In this way, citizens actively contribute to this monitoring and oversight process.

3.2.4. The BDI Tool

BDI is the electronic platform created by AND on 5 June 2015, to function as a national virtual marketplace connecting industrial waste producers with recovery and valorization operators in Algeria. The platform provides an interactive environment that enables registered users to manage offers and requests, consult technical data sheets of waste and their current

market prices, thereby directly contributing to structuring the value chains for recyclable waste.

Its functional interface also allows users to access a database of economic operators specialized in household and similar waste, in addition to offering advertising space dedicated to companies wishing to promote their presence in this field. In this way, the Exchange serves as a practical tool for digitizing commercial intermediation and transforming waste from an environmental burden into an economic resource available for trade and recycling (L'Agence Nationale des Déchets, 2025)The following figure illustrates the main interface of this platform:

Fig.5. BDI Main Interface



Source: (L'Agence Nationale des Déchets, 2025)

3.3. The Roles of the Digital Quartet as a Lever for the Transition to a Circular Economy

The digital tools deployed by the National Waste Agency (SNID, SIG, BDI, NDIF) form an integrated system that not only collects data but also acts as a strategic engine for operationalizing the CEmodel through the following roles:

A.Role of SNID in resource transparency: SNID serves as the operational instrument for comprehensive national inventory, providing a structured database on waste quantities and categories. Its functional importance lies in transforming waste from neglected residues into statistically documented secondary raw materials, thereby enabling investors to accurately identify valorization opportunities. This informational transparency activates CE loops by substituting recovered resources for primary raw materials, which in turn ensures efficient resource use and reduces material waste.

B. Role of the SIG: SIG is the technical tool for managing the spatial flows of waste. It enables geographic modelling of collection and transport operations and improves the configuration of flows by identifying optimal locations for sorting stations and recycling facilities based on proximity criteria. This leads to reduced transport distances and lower emissions associated with vehicle movements.

C. Role of the BDI in creating value and economic benefit: BDI is a strategic mechanism for digitizing intermediation between waste producers and recovery operators. Its effectiveness as a lever for the transition to a CE lies in its ability to stimulate investment in secondary raw materials, thus reducing the import bill for primary resources and supporting local manufacturing industries. In this way, the Exchange ensures the closure of material loops by reintegrating waste into the production cycle, thereby reducing reliance on the linear extract–produce–dispose model; in other words, it is an electronic marketplace that brings waste “back to life” as an economic asset.

D. Role of the NDIF application in activating environmental citizenship: NDIF is the technical tool for regulating material flows by involving citizens in monitoring field-level irregularities. Its operational function is to generate real-time data that allow immediate spatial tracking of waste, thereby preventing valorization-eligible materials from leaking into informal dumpsites and ensuring that they remain within the recycling loop. The application also helps limit qualitative degradation of materials by enabling the reporting of black spots, which accelerates their recovery and reintegration into the production cycle and thus supports circular transition objectives.

4. Key Findings and Analysis

The four integrated digital systems SNID, SIG, BDI, and NDIF create a synergistic architecture that operationalizes circular economy principles through data transparency, spatial optimization, market formalization, and participatory accountability. SNID documents waste as secondary raw materials; SIG optimizes collection and facility locations; BDI establishes a digital marketplace for secondary materials; and NDIF mobilizes citizens for real-time monitoring. These systems operate through functional

interdependence: SNID data inform SIG analyses and BDI intelligence; SIG optimization enhances market accessibility; NDIF citizen reports validate official data; and BDI pricing signals guide material prioritization. This integration strengthens material traceability, enhances regulatory compliance monitoring, and supports investment planning for valorization infrastructure. However, while this digital architecture provides critical enabling conditions for circular economy transitions under Law 25-02, its effectiveness ultimately depends on complementary investments in physical infrastructure, institutional capacity, regulatory enforcement, stakeholder engagement, and favorable market conditions.

5. CONCLUSION

The analysis reveals that digital transformation in Algeria's waste sector has evolved into a strategic enabler of circular economy transitions under Law 25-02, fundamentally reframing waste as an alternative economic resource. The coherent integration of SNID, SIG, BDI, and NDIF establishes foundational conditions for systemic circular material flows by bridging statistical documentation, spatial planning, commercial intermediation, and citizen participation. The synergistic effects generated through this integration extend beyond individual system functions. The functional interdependence creates positive reinforcement cycles where SNID prioritization guides BDI pricing mechanisms, which in turn inform investment decisions for SIG optimized facility locations. This systemic coherence strengthens investment planning for valorization infrastructure and enhances regulatory oversight mechanisms. However, translating these informational and organizational possibilities into tangible circular economy outcomes remains contingent upon parallel investments in physical infrastructure, institutional capacity building, rigorous regulatory enforcement, and the cultivation of stakeholder commitment to circular principles.

5.1 Policy Recommendations:

The study proposes establishing mandatory regulatory frameworks for systematic stakeholder data reporting; integrating the four systems into a unified platform enabling real-time waste lifecycle tracking; linking state financial incentives to digital compliance and circular economy metrics;

formalizing the BDI as the primary institutional mechanism for secondary material markets; and implementing educational initiatives strengthening participatory citizenship through digital monitoring channels. These complementary measures are essential for actualizing the transformative potential of the digital quartet and advancing sustainable waste management aligned with circular economy objectives.

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