Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/GC03.20260105
Published: February 2, 2026

National Waste Digital Platform (NWDP): A Digital Supply-Chain Backbone for Circular MSW in Saudi Arabia

Bandar S. Aljabri
Industrial Engineering Department
King Saud University
Riyadh, Saudi Arabia
bandarsalim@hotmail.com

Mohamed S. Alkahtani
Industrial Engineering Department
King Saud University
Riyadh, Saudi Arabia
moalkahtani@ksu.edu.sa

Abstract

Saudi Arabia's waste management system is severely challenged. It is contending with more than a fair share of waste generation per capita, sporadic peaks during religious festivals, and a lengthy history of dependency on landfills. In its pursuit of a sustainable circular economy, Saudi Arabia has established the National Waste Digital Platform (NWDP). The platform is an integrated digital platform that links citizens, municipal staff, contractors, sorters, and regulators through data-driven operations. The NWDP realizes its goals by leveraging various technologies, including smart bins with IoT, stream processing, AI/ML routing, blockchain for document tracking, and ESG dashboards. This setup connects real-time data to systems, enhancing the capability to track performance and accountability throughout the supply chain. The operation process is sequential, starting with source segregation and asset registration, proceeding to optimized collection, computerized sorting, and a proven marketplace, all supported by performance-based incentive systems. The NWDP should improve recycling recoveries, significantly reduce landfill use, and minimize environmental pollution. It further encourages participatory citizenship and facilitates verification of ESG standards. By consolidating various waste services into a single circular supply chain, the platform facilitates more efficient planning and operations. The NWDP is a key national database. It enables evidence-based policy-making, carbon emissions tracking, and investment planning for green circular economy activities in the Kingdom.

Keywords
Municipal solid waste (MSW), Digital supply chain, National Waste Digital Platform (NWDP), ESG

1. Introduction
The World Bank reports that the generation of municipal solid waste (MSW) is increasing worldwide. It was 2.0 billion tons annually in 2018. The United Nations Environment Program (UNEP) projects that it will be 2.3 billion tons in 2023 and 3.8 billion tons in 2050, based on current trends. Urbanization results in waste that many cities struggle to collect and recycle. This results in rampant waste, environmental degradation, financial losses, and health risks (**World Bank, 2018; UNEP, 2024**). Accelerated urbanization, changing consumption habits, and population growth during religious festivities contribute to wasted generation in Saudi Arabia.

The country handles millions of tons of municipal waste annually. Recycling levels are low, and most waste ends up in landfills, according to national research and market reports. Municipal waste systems that are ineffectively coordinated and data sharing limitations across agencies hinder the installation of new waste sorting plants and the development of the recycling sector. The NWDP offers an electronic system that promotes waste tracking and cost savings. It also supports season trend planning and helps market growth (trade.gov; Almansour, 2024). Contemporary viewpoints recognize that waste management is essential to achieving sustainable supply chains, both within the supply chain and for the government, not just for waste disposal. To convert waste into useful circular inputs, physical and information management systems must be integrated.

Such collaboration promotes improved material quality, increased market liquidity, and the recycling of materials in supply chains (Singh et al., 2023). The supply chain model illustrates how digital platforms and DPPs transform uncertain waste streams into available secondary industrial materials through reliable tracking and data analysis (Liu et al., 2022; Zhang and Seuring, 2024). To meet its economic and environmental goals, Saudi Arabia's waste management infrastructure requires a shared digital platform as its foundation. The sector is currently fragmented, as separate systems and landfills manage most of the work. Proper waste diversion requires solid infrastructure and institutional support, as local and national studies have indicated.

The proposed National Waste Digital Platform (NWDP) will receive data from municipalities, trucks, smart bins, sorting facilities, treatment facilities, and market transactions. NWDP will enable dynamic routing, seasonal forecasting, transparent trust through DPP/blockchain, and verifiable ESG dashboards. Further, NWDP's marketplace features and reward incentives will convert tracking data into tangible economic value. This method positions Saudi Arabia's waste flows to be investible and transparent, with the country embracing the circular economy. The National Waste Digital Platform (NWDP) is unique in its integration of various datasets for operational, spatial, and temporal purposes, utilizing an end-to-end system for data collection. It conducts digital twin technology-powered spatial and temporal analysis and GIS integration, aggregating data from various sources. This facilitates seasonable planning, economic assessments of secondary materials, and fleet route optimization. The approach converts volatile waste streams into uniform, investment-grade supply streams.

With IoT sensors, real-time analytics, AI systems, and blockchain records, it builds a national marketplace for secondary materials. It makes waste management quantifiable and sustainable for the environment. The NWDP's waste flow forecasting system translates big data into a strategic policy tool. Policymakers can utilize this evidence to propel the circular economy and enhance ESG performance. The platform collects huge volumes of data, including municipal waste tonnage, truck route timestamps, smart bin weight, sorting results, facility performance, and market data. The data enable spatial-temporal analysis to predict peak periods during pilgrimages, which is applied in policy and investment modeling. ESG dashboards also guide regulators and investors.

2. Literature Review

Municipal solid waste (MSW) management has been a key priority area in recent research on circular economy and sustainable supply chain systems during the past decade. Contemporary research suggests that waste management involves more than just collecting waste, as it encompasses transforming waste streams into valuable resources through integrated physical and information systems that monitor materials, forecast usage, and promote the utilization of recycled products. The combination of digital technologies, including IoT sensors, AI predictive systems, dynamic routing systems, blockchain, and Digital Product Passports (DPPs), has been proven to be efficient in enhancing material quality and marketability, as noted by Singh et al. (2023) and Kirchherr et al. (2023).

Provenance and DPP studies show that blockchain technology shows promise for secure batch origin tracking, quality tracking, and service authentication. The research demonstrates that blockchain technology in waste management is promising; however, it faces operational issues, including scalability concerns, high application costs, privacy concerns, and limited nationwide deployments and field tests. Jiang et al. (2023) presented an extensive review of the applications of blockchain in waste management, demonstrating how blockchain systems can be integrated with IoT sensors and LCA systems. However, they noted a few examples of nationwide blockchain deployment. The DPP study demonstrates the possibility of connecting DPPs to high-quality information and secondary material markets; however, economic advantages depend on standardized passport designs and harmonized purity measurement systems (Psarommatis and May, 2024; Voulgaridis et al. 2024). Two researchers have developed dual storage systems with access controls to provide data visibility while ensuring privacy levels and system usability (Bułkowska et al. 2023).

IoT smart bin deployment in waste collection operations equals measurable operational performance improvement. The combination of fill-level and weight telemetry data, as demonstrated through simulation and in practice, demonstrates that it eliminates unnecessary collections and optimizes collection scheduling, resulting in reduced operational costs and environmental emissions (Zoumpoulis et al., 2024; Hussain et al., 2024). The field deployment of sensors is faced with operational reliability issues and extended sensor deployment costs, requiring extensive research on municipal cost-effectiveness and performance analysis.

Vehicle routing and dynamic routing algorithm development have witnessed the development of models with real-time bin data and multi-compartment vehicle capacity and time window constraints that have reported cost savings and distance reduction in simulated, as well as in-field, testing (Priyadarshi et al. 2023; Mohammadi et al. 2023; Bouleft and Elhilali Alaoui 2023). The main challenge is in scaling to city or national levels of operational reliability by leveraging performance gains from small pilots and controlled simulations in changing operating conditions.

The application of artificial intelligence through computer vision and deep learning algorithms has immense potential to transform automated sorting operations in material recovery facilities, resulting in improved sorting accuracy and reduced contamination in the materials sorted. The improved quality of recyclables achieved through these advances amounts to a higher market value and enables DPP metadata enrichment through precise purity measurements. According to the literature, two primary challenges exist in deploying sorting systems on an industrial level, primarily due to the lack of large annotated datasets and the difficulty of model transferability under varying lighting conditions, camera types, and material conditions (Nafiz et al., 2023).

Digital twins and spatial analysis (GIS-integrated digital twins) are also effective platforms for evaluating various planning options, such as MRF facilities, route optimization, and peak demand management. Digital twins have been proven to minimize environmental footprints and maximize profitability for various types of waste, including construction and demolition waste, through research conducted by Campana et al. (2025) and Kaewunruen et al. 2025. There are two principal obstacles to the effective implementation of digital twins with operational data feeds: establishing operational connections and determining institutional frameworks for decision-making based on the outputs of twin findings.

Institutional, regulatory, and economic tools, such as Extended Producer Responsibility (EPR), incentive programs for citizens, and market mechanisms for secondary materials, are theoretically and empirically justified for achieving systemic circularity in the implementation of technological solutions. The literature states that regulatory support and standardization of data practices are essential requirements for digital platforms to establish operational secondary material markets (Kirchherr et al. 2023).

The review of existing research highlights some important gaps in knowledge that need to be addressed. The majority of existing research focuses on prototypes, pilot studies, and simulation models because digital backbone systems that coordinate households with collection fleets, MRFs, and markets at national scales are yet to be realized (Jiang et al. 2023; Bułkowska et al. 2023). The lack of empirical studies to date on the effect of DPPs and blockchain on secondary market prices and liquidity necessitates that researchers conduct controlled market experiments. The current research lacks sufficient data on governance models tested and data-privacy architectures for national platforms, which calls for further studies to determine feasible solutions that balance operational transparency and personal privacy protections (Wilson, 2024; Jiang et al. 2023). The current research has a limited number of studies on developing a fair digital system for informal waste pickers. The current use of AI-driven sorting has two major limitations: it requires standardized benchmark datasets, and its models exhibit low transferability to novel environments. The current research lacks sufficient financial and economic evaluations for investments in national platforms.

The research has to give importance to five areas such as testing integrated platforms like NWDP in multiple cities and at a national scale for analyzing operational and financial and behavioral and governance effects and undertaking controlled market experiments for measuring DPP standardization effects on secondary material prices and market liquidity and developing hybrid data governance systems providing privacy assurances while facilitating auditing and creating open standardized datasets for AI model training and increasing model transferability and carrying out overall techno-economic analysis to guide public-private investment choices. The literature to date demonstrates the potential of digital technologies for enhancing waste management and circular supply chains through technical and theoretical frameworks. However, researchers must conduct large-scale evidence-based studies across multiple areas to determine the operational, market, and policy feasibility of the technologies. The National Waste Digital Platform (NWDP)

addresses these requirements through its integrated, data-driven backbone, from which researchers can tackle many unanswered research issues while delivering policy-ready insights to decision-makers.

3. Methods

Conceptual development and implementation design were the research approach used in the present study. The study utilized supply chain principles to transform municipal solid waste (MSW) management into a material and information flow system. Platform architecture design emerged from technology mapping, which assigned IoT and AI/ML to sensing, prediction, and routing functions, and blockchain and Digital Product Passports (DPPs) to provenance and marketplace trust, as well as GIS/digital twins to planning and system-level integration. A data architecture was created to organize important datasets, including waste amounts, truck telemetry data, sorting results, market transactions, and environmental sustainability metrics, thereby converging physical and digital data in a unified national system. The research approach gave NWDP a firm theoretical foundation while demonstrating its potential to serve as a strategic instrument for Saudi Arabia's circular economy development.

4. Results and Discussion

4.1 The National Waste Digital Platform (NWDP)

The National Waste Digital Platform (NWDP) serves as a unified digital system that integrates Saudi Arabian municipal solid waste (MSW) management operations, encompassing collection, recycling, and energy recovery. The platform connects all stakeholders, including citizens, municipalities, contractors, sorting facilities, recycling companies, and regulatory bodies, to create a data-driven system that enhances operational efficiency, maintains transparency, and improves ESG performance. The following section explains the platform's design approach, workflow structure, technological foundation, and projected outcomes and effects (Figure 1).

Stakeholder Ecosystem

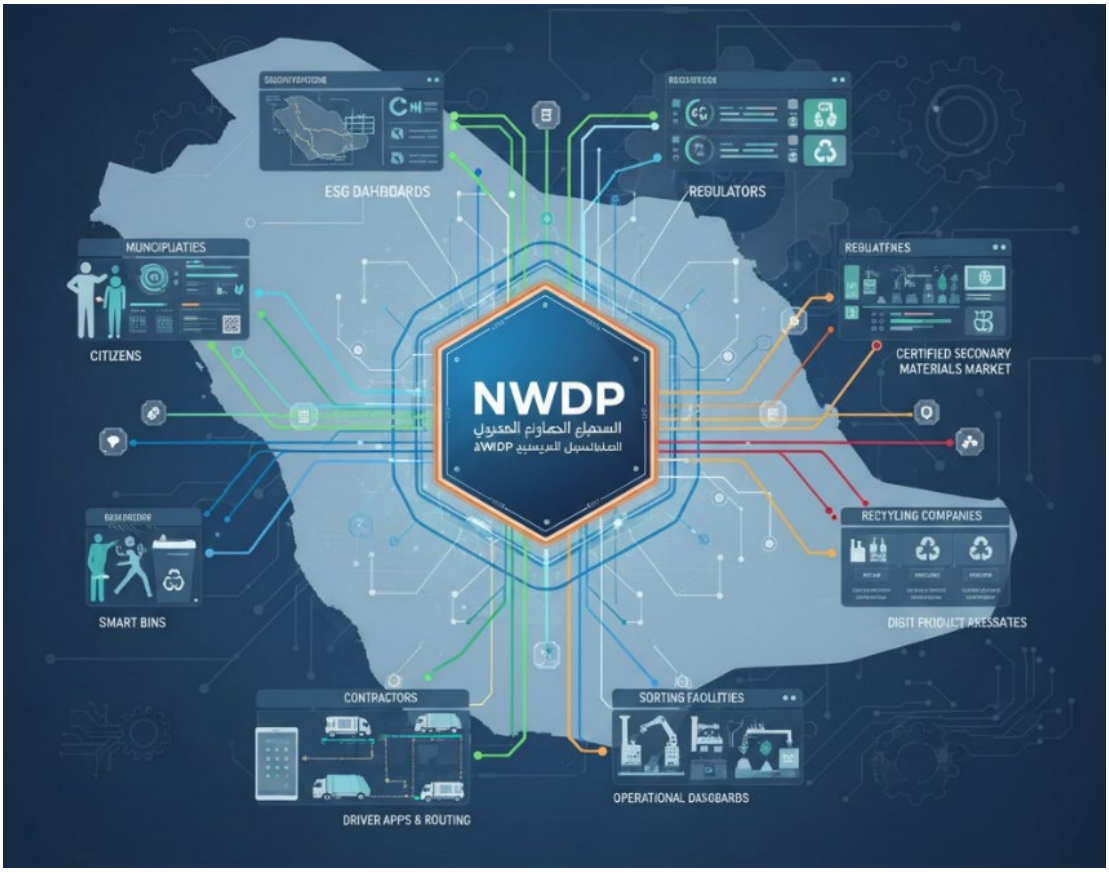

Figure 1. National Waste Digital Platform (NWDP) — Integrated Architecture

Figure 1 illustrates that the National Waste Digital Platform (NWDP) serves as a unified digital platform that connects all participants through real-time data exchange, operational dashboards, and ESG reporting interfaces, facilitating seamless communication between citizens and smart bins, contractors and sorting facilities, recycling companies, and regulatory bodies. The system enables proof-of-custody and digital product passports, while optimizing collection routes and schedules, to create a trusted platform for trading secondary materials. This results in higher recycling rates, decreased landfill waste, and reduced environmental emissions.

NWDP solves waste management system fragmentation by providing separate digital interfaces tailored to each stakeholder segment. The system enables citizens to use mobile apps and smart bins for interaction, while municipalities monitor operations through ESG dashboards and contract management tools, and contractors access driver apps and routing portals, and sorting facilities use operational consoles and industrial interfaces, and recycling companies access a verified secondary-materials marketplace, and regulators monitor compliance through dashboards with carbon accounting functions. The platform offers comprehensive supply chain visibility through its well-organized system of connections.

4.2 Platform workflow

Platform workflow integrates physical and information flows into a step-by-step process from waste generation to re-entry into the market:

a) Onboarding & Asset Registration
Every asset, from trucks and bins to weighbridges and sorting robots, is assigned a digital identity by the system and placed in a GIS environment for geo-tagging purposes. The system establishes a platform for tracking goods and contracts.

b) Source Segregation
The waste collection system utilizes smart bins equipped with sensors to track weight readings, fill levels, and contamination levels. The deposit system for waste is linked to citizens' accounts, allowing them to participate in reward programs. The initial stage optimizes the sorting of waste materials at the source, as it is a significant factor in achieving the high material quality of the later processing stages.

c) IoT Data Collection & Stream Processing
The platform's data backbone receives secure sensor information from bins and trucks, enabling real-time analysis to identify critical events, such as contamination alerts, vehicle anomalies, and bin overflow accidents. The system creates automatic notices that trigger collection operations, maintenance activities, and regulatory responses.

d) Dynamic Collection & Routing
The system utilizes vehicle routing algorithms to generate optimized collection routes depending on bin status, fleet capacity, and live traffic conditions. The system provides optimized routes for drivers and tracks their real-time compliance status. The system minimizes fuel usage and emission rates in addition to reducing the duration of waste collection operations.

e) Proof of Service & Custody Records
The system also records collection events by time stamps, location identifiers, weight readings, and photo capture. The system also maintains an irrevocable record of all custody transfers among bins and trucks, as well as among trucks and facilities, which prevents fraudulent activity.

f) Transportation Monitoring
The system tracks trucks via GPS and geo-fencing technology, along with weighbridge activities, to ensure the accurate measurement of materials entering and exiting facilities. The system automatically identifies all cases of unauthorized dumping and unauthorized route taking.

g) Sorting & Processing
The sorting plant utilizes computer vision technology, assisted by robots, to sort waste materials into plastics and metals, paper and organics, and residuals, while measuring their purity levels and batch weights. The

measured data serve as the foundation for Digital Product Passports (DPPs), which verify the quality and source of products.

h) Digital Product Passport (DPP) Creation
The authentication procedure issues tamper-proof certificates that use blockchain-based technology for verification. The Digital Product Passport contains information on material name, purity grade, weight, country of origin, and processing plant details, all of which are linked via QR codes.

i) Secondary Materials Marketplace
The digital marketplace enables recycling businesses to conduct smart contract-based transactions for bulk purchases across a nationwide platform. The mechanism involves quality checks, delivery processes, and payment terms through smart contracts, hence minimizing business risks and enhancing the market's liquidity for recyclables.

j) Incentives & Payments
It rewards citizens with digital tokens for disposing of their waste properly, and contractors receive payment based on the success of their Key Performance Indicators. Carbon rewards are also provided to facilities that produce energy recovery credits. The program ties financial reward to sustainability success in its reward system.

k) ESG Dashboards & Reporting
The system collects all data available to generate dashboards that monitor recycling performance, carbon savings, service response times, and participation levels. Regulators and municipalities can access detailed information about specific districts and contractors through the system, facilitating informed decision-making based on data for policy formulation and budget allocation.

The platform integrates various electronic elements to consolidate waste management activities into an information-based supply chain system. The collection process utilizes IoT-enabled smart bins that give instant details about their fill levels, weight measurements, and contamination levels. The use of stream processing combined with AI/ML code enables anomaly detection, waste forecasting, and routing optimization for collections. The coupling of computer vision systems and robotic sorting in facilities yields higher material purity levels, as the accuracy of sorting and operational efficiency are enhanced. Applying blockchain technology with Digital Product Passports (DPPs) generates immutable records for secondary material markets, based on verifiable material certificates, to build trust. It supports spatial and temporal planning through digital twins and GIS services, enabling users to run simulation models that enhance logistics and infrastructure optimization. The system receives input from all components through dashboards and open APIs, providing valuable insights to governance bodies, regulatory bodies, and policy-making groups.

4.3 Expected Results and Impacts

NWDP produces many quantifiable ESG results, which are:

1. The system produces three major environmental benefits, including improved recycling performance, reduced landfill utilization, and quantifiable reductions in greenhouse gas emissions through optimized routing and improved recovery techniques.
2. The system optimizes social benefits through its incentive structures, mutual engagement of citizens, and generation of new employment opportunities in the recycling and ICT service sectors, as well as the provision of fair access to improved waste collection services.
3. The system provides policy support for Carbon Accounting and ESG reporting schemes, as well as Extended Producer Responsibility (EPR), which provides auditable information to decision-makers to inform budget allocation, project investments, and design incentives. The system enables the formalization of informal actors in waste collection for inclusive digital waste management.

4.4 Layered Architecture of the National Waste Digital Platform (NWDP)

Figure 2 presents the nine-layer architecture, which indicates the overall operation of the National Waste Digital Platform (NWDP), ranging from sensor-based fill level and weight, and contamination sensing in the perception layer to core microservices business logic and data management/Lakehouse aggregation of real-time and historical data, and permissioned blockchain security for proof-of-custody data and Digital Product Passports (DPPs). The system begins with AI and digital twin processing for simulation, representation, and analytics, and then proceeds to a shared

API gateway, ultimately culminating in applications and dashboards that present results to municipalities, regulators, and citizens. The system architecture will strive for three key outcomes, including transparent tracking, operational optimization, and improved environmental, social, and governance (ESG) outcomes.

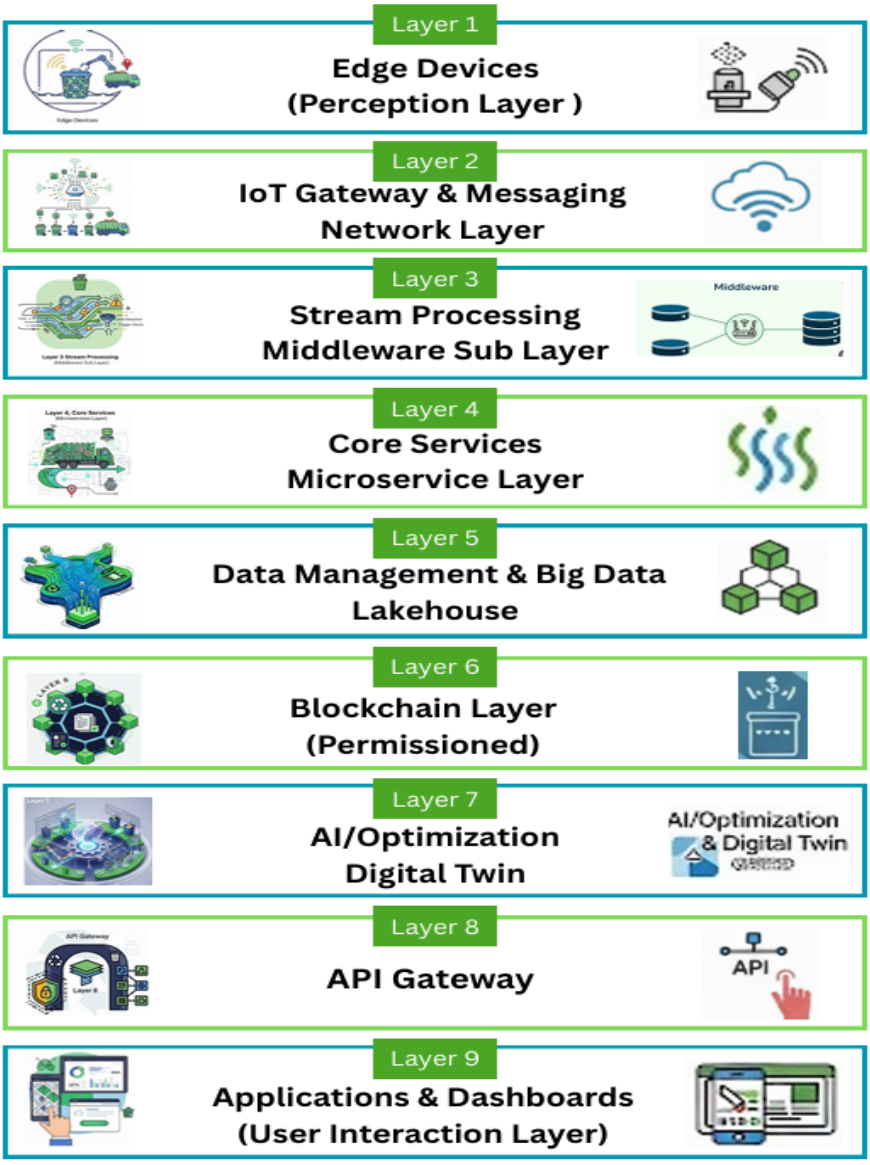

Figure 2. Detailed Layered Architecture of the National Waste Digital Platform (NWDP)

Table 1 establishes connections between the NWDP's nine layers and their fundamental technologies, as well as predicted ESG outcomes, through edge sensors/robots, which deliver precise data while protecting workers and minimizing waste leaks. Additionally, it highlights the use of IoT gateways, which employ LoRaWAN/NB-IoT/MQTT protocols for energy-efficient and reliable data integrity. The stream processing system enables real-time analytics, which helps detect anomalies early and speeds up response times. The core microservices handle routing and incentives, device management to achieve lower fuel consumption, reward citizens, and maintain accountability. The system utilizes time-series and big-data management for recycling trend analysis, public reporting, and evidence-

based governance. Blockchain technology enables smart contracts and tokenization, providing traceability, fair incentives, and unalterable records. The combination of AI and digital twin technology through ML, optimization, and simulation methods delivers predictive efficiency, creates new technology jobs, and enables policy testing. The API gateway uses OAuth2/OIDC and API management to enable scalable, controlled data sharing. The applications and dashboards section includes mobile apps and ESG dashboards, which increase recycling participation rates, enhance citizen involvement, and provide clear KPI performance metrics (Table 1).

Table 1. Layered Architecture of (NWDP) with key Technologies and ESG Outcomes

Layer	Key Technologies	ESG Outcomes
1. Edge Devices	IoT sensors, GPS, Robotics	E: Reduced waste leakage, S: Safer worker environment, G: Accurate data collection
2. IoT Gateway & Messaging	LoRaWAN, NB-IoT, MQTT/HTTP	E: Energy-efficient communication, S: Reliable connectivity, G: Data integrity
3. Stream Processing	Real-time analytics engines	E: Early anomaly detection, S: Faster service response, G: Transparent alerts
4. Core Microservices	Routing, incentives, device mgmt	E: Optimized fuel use, S: Citizen reward systems, G: Performance-based accountability
5. Data Management	Time-series DB, relational DB, big data	E: Trend analysis for recycling, S: Public insights reports, G: Evidence-based governance
6. Blockchain	Smart contracts, tokenization	E: Traceable recycling flows, S: Fair incentive distribution, G: Immutable records
7. AI & Digital Twin	ML, optimization, simulations	E: Predictive efficiency gains, S: Job creation in tech, G: Scenario testing for policy
8. API Gateway	OAuth2/OIDC, API management	E: Scalable integrations, S: Open access for apps, G: Controlled data sharing
9. Applications & Dashboards	Mobile apps, ESG dashboards	E: Higher recycling participation, S: Citizen engagement, G: Transparent KPI reporting

5. Conclusions and Recommendations

The National Waste Digital Platform (NWDP) is an example of digital integration as a solution to enhance municipal solid waste management in Saudi Arabia. The platform combines IoT sensors with AI/ML forecasting and routing, blockchain Digital Product Passports, digital twins, and ESG dashboards into a single circular supply chain from separate waste management logistics. The platform enhances recycling performance, operational efficiency, and transparency by establishing robust data assets for policy-making. The system fosters long-term operational sustainability through its single data-driven platform that seamlessly connects citizen reporting with contractor tracking and regulatory oversight.

The platform requires proper implementation and institutional support to achieve its future goals. Makkah and other cities with variable populations must establish testing programs to demonstrate the platform's ability to operate at full capacity without compromising operational stability. The system should provide direct access to regulatory requirements, including national regulations, ESG reporting requirements, and Extended Producer Responsibility schemes, for digital records. The platform requires cutting-edge data protection measures that safeguard privacy rights while enabling secure system interconnectivity, thereby fostering trust among citizens, municipalities, and private operators.

The platform requires the building of human capacities, in combination with strong institutional support, to thrive. There is a need for training programs to equip municipal workers, contractors, and recyclers with the skills to utilize digital tools and adopt harmonized application strategies for effective implementation. A secondary materials market with standardized DPPs will attract investment opportunities, thereby building buyer confidence and improving the financial sustainability of recycling businesses. The NWDP platform enables Saudi Arabia to build a data-driven circular economy while developing a blueprint for other nations to establish sustainable waste management systems.

References

Almansour, M., An environmental assessment of municipal solid waste management strategies in Riyadh, Saudi Arabia: A comparative life cycle analysis, *Sustainability*, vol. 16, no. 20, p. 9111, 2024. https://doi.org/10.3390/su16209111.

Bouleft, Y. and Elhilali Alaoui, A., Dynamic multi-compartment vehicle routing problem for selective and intelligent waste collection, Algorithms, vol. 6, no. 1, p. 30, 2023. https://doi.org/10.3390/asi6010030.

Bułkowska, K., Implementation of blockchain technology in waste management, Energies, vol. 16, no. 23, p. 7742, 2023. https://doi.org/10.3390/en16237742.

Campana, P., et al., Artificial intelligence and digital twins for sustainable systems, Applied Sciences, vol. 15, no. 11, p. 6337, 2025. https://doi.org/10.3390/app15116337.

Hussain, I., Elomri, A., Kerbache, L. and El Omri, A., Smart city solutions: Comparative analysis of waste management models in IoT-enabled environments using multiagent simulation, *Sustainable Cities and Society*, vol. 103, p. 105247, 2024. doi: https://doi.org/10.1016/j.scs.2024.105247.

Jiang, P., Zhang, L., You, S., Fan, Y. V., Tan, R. R., Klemeš, J. J. and You, F., Blockchain technology applications in waste management: Overview, challenges and opportunities, Journal of Cleaner Production, vol. 421, p. 138466, 2023. https://doi.org/10.1016/j.jclepro.2023.138466.

Kaewunruen, S., Lin, Y.-H. and Guo, Y., BIM-driven digital twin for demolition waste management of existing residential buildings, Scientific Reports, vol. 15, p. 28989, 2025. https://doi.org/10.1038/s41598-025-13938-9.

Kirchherr, J., Yang, N. H. N., Schulze-Spüntrup, F., Heerink, M. and Hartley, K., Conceptualizing the circular economy (revisited): An analysis of 221 definitions, Resources, Conservation & Recycling, vol. 194, p. 107001, 2023. https://doi.org/10.1016/j.resconrec.2023.107001.

Liu, J., Quddoos, M. U., Akhtar, M. H., Amin, M. S., Tariq, M. and Lamar, A., Digital technologies and circular economy in supply chain management: In the era of COVID-19 pandemic, Operations Management Research, vol. 15, no. 1–2, pp. 326–341, 2022. 10.1007/s12063-021-00227-7.

Mohammadi, M., Rahmanifar, G., Hajiaghaei-Keshteli, M., et al., A dynamic approach for the multi-compartment vehicle routing problem in waste management, Renewable and Sustainable Energy Reviews, vol. 184, p. 113526, 2023. https://doi.org/10.1016/j.rser.2023.113526.

Nafiz, M. S., Das, S. S., Morol, M. K., Al Juabir, A. and Nandi, D., ConvoWaste: An automatic waste segregation machine using deep learning, arXiv preprint, 2023. Available: https://arxiv.org/abs/2302.02976.

Priyadarshi, M., Maratha, M., Anish, M. and Kumar, V., Dynamic routing for efficient waste collection in resource constrained societies, Scientific Reports, vol. 13, p. 2365, 2023. https://doi.org/10.1038/s41598-023-29593-x.

Psarommatis, F. and May, G., Digital product passport: A pathway to circularity and sustainability in modern manufacturing, Sustainability, vol. 16, no. 1, p. 396, 2024. https://doi.org/10.3390/su16010396.

Singh, S., Chhabra, R. and Arora, J., A systematic review of waste management solutions using machine learning, Internet of Things and blockchain technologies: State-of-art, methodologies, and challenges, Archives of Computational Methods in Engineering, vol. 31, pp. 1255–1276, 2023. https://doi.org/10.1007/s11831-023-10008-z.

U.S. International Trade Administration, Saudi Arabia — Waste Management, 2024. Available: https://www.trade.gov/country-commercial-guides/saudi-arabia-waste-management. Accessed on: 1-9-2025

United Nations Environment Programme (UNEP), Global Waste Management Outlook 2024, UNEP, 2024. Available: https://www.unep.org/resources/global-waste-management-outlook-2024, Accessed on: 1-9-2025.

Voulgaridis, K., Lagkas, T., Angelopoulos, C. M., et al., Digital product passports as enablers of digital circular economy: A framework based on technological perspective, Telecommunication Systems, vol. 85, pp. 699–715, 2024. https://doi.org/10.1007/s11235-024-01104-x.

Wilson, S., Blockchain-enabled provenance tracking for sustainable material reuse in construction supply chains, Informatics, vol. 16, no. 4, p. 135, 2024. https://doi.org/10.3390/fi16040135.

World Bank, What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050, Washington DC: World Bank, 2018. Available: https://datatopics.worldbank.org/what-a-waste/. Accessed on: 1-9-2025

Zhang, A. and Seuring, S., Digital product passport for sustainable and circular supply chain management: A structured review of use cases, International Journal of Logistics Research and Applications, vol. 27, no. 12, pp. 2513–2540, 2024. https://doi.org/10.1080/13675567.2024.2374256.

Zoumpoulis, P., Konstantinidis, F. K., Tsimiklis, G. and Amditis, A., Smart bins for enhanced resource recovery and sustainable urban waste practices in smart cities: A systematic literature review, Cities, p. 105150, 2024. https://doi.org/10.1016/j.cities.2024.105150.

Biographies

Bandar S. Aljabri is a Ph.D. in business administration and a PhD candidate in industrial operations systems and logistics at King Saud University Faculty of Engineering. Bandar Aljabri is a seasoned expert with over 20 years of experience across engineering, management, human resources, and organizational development. With certifications in MBTI and Strong Interest Inventory assessments, he is also a certified Strategic Planning Professional and a Key Performance Indicators Professional. Dr. Aljabri has been designated an engineering expert in numerous arbitration cases, demonstrating his expertise in resolving complex technical disputes. His extensive research portfolio includes publications on AI, IoT, and smart city technologies, with significant contributions to enhancing municipal operations, improving supply chain efficiency, and optimizing human resource management. He has a deep understanding of artificial intelligence, operations research, and project management, making him a key figure in both academic and professional circles. Dr. Aljabri has played a vital role in assessment centers, both as an assessor and manager, consistently utilizing his psychometric testing, training, and development skills to foster innovation and leadership in his area of expertise.

Mohammed S. Alkahtani is a Professor of Industrial Engineering and Vice-Dean of the Advanced Manufacturing Institute, King Saud University (KSU), Riyadh, Saudi Arabia. He served as the chairman of the Industrial Engineering Department at the College of Engineering, KSU, for over four years (2014-2018). He earned his B.Sc. degree in Industrial Engineering from KSU, a M.Sc. in Industrial Engineering from the University of Central Florida (Orlando, FL, USA), and a Ph.D. in Manufacturing Engineering from Loughborough University (Loughborough, UK). He has diverse expertise in the analysis, modeling, and design of manufacturing systems, supply chains, and operations management, as well as responsiveness measurement, lean manufacturing, and agility in manufacturing and supply chains.