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Circular Economy Practices for Data Management †

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Abstract: Data waste presents a growing challenge in the digital era, characterized by redundant, outdated, and underutilized data that contributes to inefficiencies, increased costs, and environmental concerns. This paper explores how circular economy (CE) principles—reduce, reuse, recycle, repair, and rethink—can be adapted to optimize data usage, minimize waste, and ensure responsible data handling throughout its lifecycle. Applying CE concepts to data management can enhance sustainability, improve operational efficiency, and support responsible digital transformation. This study examines key strategies and challenges in implementing circular data management, emphasizing data reuse, lifecycle management, and policy frameworks. Furthermore, real-world examples and case studies demonstrate the impact of CE principles in reducing data waste and improving efficiency. Notably, AI-driven data minimization strategies have led to 30% reductions in storage costs, while centralized data-sharing initiatives have improved operational efficiency by 20%. These findings underscore the necessity of structured data governance in the digital economy.

Keywords: circular economy; data management; sustainability; digital transformation; data lifecycle

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1. Introduction

The rapid expansion of digital data has transformed industries, enhancing operational efficiency and innovation [1]. However, this exponential growth has also led to significant data waste, characterized by unstructured, obsolete, and redundant information that burdens storage systems, increases energy consumption, and raises security concerns [2]. As data accumulates without proper governance, organizations face escalating financial and environmental costs, underscoring the need for sustainable data management practices [2,3].

One critical challenge in digital data management is infobesity, which refers to the excessive accumulation of digital information, much of which remains underutilized or redundant [3,4]. Infobesity leads to inefficiencies in storage, increased processing costs, and security vulnerabilities. Addressing this issue requires structured data governance that integrates principles of reduction, reuse, and optimization to enhance data sustainability.

The circular economy (CE) model, originally developed for physical resource management, presents a promising framework for addressing these challenges in data management. By applying CE principles—reducing, reusing, recycling, and optimizing resources—organizations can minimize unnecessary data accumulation, enhance efficiency, and promote sustainable data governance. CE principles align well with digital ecosystems, ensuring that data remains valuable, accessible, and responsibly handled throughout its lifecycle.

This paper explores the integration of circular economy principles into data management strategies, particularly in domains such as transportation systems, where efficient data utilization is critical for safety, operational efficiency, and environmental sustainability. We examine key practices such as data minimization, reuse, sharing, quality assurance, and lifecycle management to propose a sustainable approach to digital resource governance. Through this analysis, we highlight both the benefits and challenges of implementing circular data management strategies, providing insights into how businesses and institutions can optimize data utilization while reducing environmental and financial costs.

While existing studies have examined CE principles within broader sustainability contexts, limited research has specifically addressed their role in optimizing data lifecycle management and enhancing storage efficiency. This study bridges this gap by presenting a structured framework for integrating CE strategies into digital data governance, particularly in transportation systems. Through real-world case studies and practical implementations, this research lays a foundation for CE-based data management, connecting sustainability objectives with digital transformation. Furthermore, AI-driven predictive analytics have been shown to significantly reduce data redundancy and enhance operational efficiency in the transportation sector [5]. By aggregating data from multiple sources, such as traffic patterns and weather conditions, AI systems can minimize redundancy and support real-time adaptability in decision making [6].

Despite the potential benefits of circular economy principles in data management, organizations continue to struggle with an overwhelming influx of digital information. This phenomenon, often referred to as infobesity, arises from the excessive accumulation of data—much of which remains underutilized, redundant, or obsolete. To fully leverage CE principles, it is essential to first understand the challenges posed by infobesity and the role of effective data management in mitigating its impact.

2. Data Management and Infobesity

The rapid growth of digital data presents both opportunities and challenges [1,2]. While data drives decision making and innovation, unchecked accumulation leads to infobesity—excessive, unstructured data that overwhelms organizations, increasing redundancy, inefficiencies, and storage costs [2,3]. Without effective management, data becomes a burden rather than an asset [7,8].

A sustainable approach is essential. The circular economy (CE) model [9], traditionally used for physical resources, offers a framework to optimize data usage, minimize waste, and enhance efficiency. By integrating CE principles such as reducing, reusing, recycling, and optimizing, organizations can lower costs and environmental impact [10].

Key CE-aligned strategies for managing data include the following:

- Data minimization: Reducing unnecessary data collection and storage.
- Data reuse: Repurposing existing datasets across applications.
- Data recycling: Converting outdated data into usable formats.
- Data sharing: Encouraging collaboration to prevent duplication.
- Data quality and standardization: Ensuring accuracy and structured formats for better integration.
- Data lifecycle management: Overseeing data from acquisition to disposal.
- Data privacy and security: Implementing encryption, anonymization, and compliance measures.

- Data governance and compliance: Defining policies for ethical and regulated data use.

By applying these principles [10], organizations can transition from inefficient accumulation to a structured, sustainable data governance model. Treating data as a reusable resource reduces the risks and costs of infobesity [7,8]. The next section explores strategies for making this transition.

3. Research Methodology

This study employs a mixed-methods research approach, integrating qualitative and quantitative methodologies to analyze the impact of circular economy (CE) principles on data management, as illustrated in Figure 1.

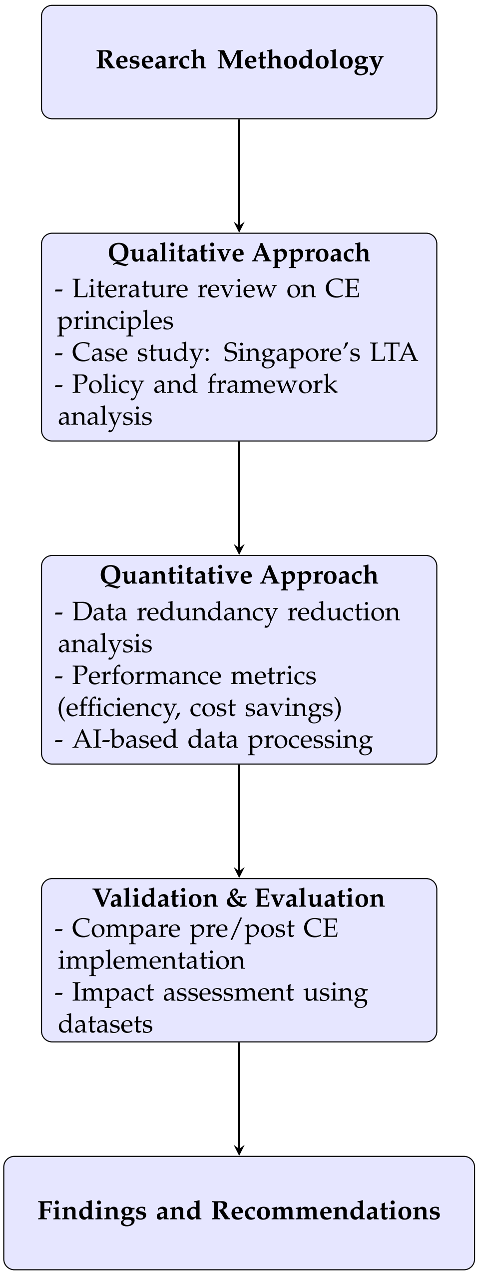

Figure 1. Research methodology flowchart outlining qualitative and quantitative approaches applied in this study.

3.1. Qualitative Approach: Theoretical Framework and Case Study

The qualitative aspect of this study involves an in-depth literature review and a case study analysis. The literature review examines existing research on CE principles in data management, focusing on strategies such as reduce, reuse, recycle, repair, and rethink. Additionally, a case study on Singapore's Land Transport Authority (LTA) is conducted to demonstrate real-world applications of CE in transportation data management.

3.2. Quantitative Approach: Data Analysis and Impact Assessment

The quantitative component involves a statistical analysis to assess the effectiveness of CE-based data management strategies. Key performance indicators include data redundancy reduction percentage, improvements in operational efficiency, and estimated cost savings. The data sources include government reports, industry publications, and AI-driven analytics applied to transportation data.

3.3. Validation and Evaluation

To validate the findings, a comparative analysis is conducted using real-world datasets, measuring changes before and after CE implementation. Metrics such as data storage efficiency, retrieval speed improvements, and overall system performance enhancements are analyzed to provide a comprehensive evaluation of the proposed framework.

4. Key Strategies for Circular Data Management

To effectively implement the principles of the circular economy (CE) in data management, organizations must adopt structured strategies that optimize data collection, storage, reuse, and governance. By applying these circular economy strategies, transportation authorities can improve sustainability, reduce operational costs, and improve overall data efficiency. These approaches align with broader sustainability goals by reducing unnecessary digital storage while optimizing data utility.

4.1. Data Minimization and Optimization

Uncontrolled data accumulation leads to inefficiencies, increased storage costs, and security risks. Organizations must prioritize collecting and retaining only essential data. Techniques such as automated data retention policies define storage durations and automatically delete obsolete information. Compression algorithms reduce data size without compromising integrity and reduce storage demands. Deduplication techniques identify and remove redundant datasets, freeing up storage space. AI-driven data classification uses machine learning to automatically categorize and eliminate irrelevant or outdated data. Integrating these strategies reduces data waste and improves storage efficiency while maintaining accessibility [11].

Organizations must focus on collecting and maintaining only essential data to maximize efficiency and business growth. High-quality data is a key driver of revenue, profitability, and operational effectiveness, with companies leveraging data analytics seeing a 5–10% increase in revenue and 6% growth in EBITDA margins [12,13]. Data-driven B2B strategies further enhance financial performance, contributing to 15–25% EBITDA gains. Moreover, automation powered by AI and Big Data eliminates up to 80% of manual tasks, leading to improved strategic decision making (69%), enhanced consumer insights (52%), and 10% cost reductions [14,15]. On the other hand, poor data quality results in inefficiencies, wasted resources, and missed opportunities, highlighting the need for structured data management. Techniques such as automated retention policies, compression algorithms, and deduplication play crucial roles in optimizing storage usage while ensuring data remains valuable and actionable [16,17].

4.2. Enhancing Data Reuse

Maximizing the value of existing data assets is essential for sustainable data management. A notable example is the European Union's Open Data Initiative, which has successfully enabled cross-sector data sharing, leading to a 20% increase in operational efficiency for businesses that adopt standardized metadata [18,19]. Implementing similar practices can enhance interoperability across industries. Reusing data across multiple applications prevents unnecessary duplication and optimizes resource utilization. Standardized data formats ensure compatibility between different systems, facilitating seamless integration. Metadata tagging enhances searchability and retrieval. Open data initiatives encourage public and private entities to share non-sensitive data for broader applications. Data-sharing agreements establish policies that enable inter-organizational data exchange while maintaining privacy and compliance. Implementing these approaches extends the usability of collected data, reducing redundancy and increasing efficiency [20].

4.3. Data Recycling for Enhanced Utility

Legacy data have significant potential for repurposing in modern applications. In the transportation sector, repurposing historical data into AI-driven predictive models has led to significant improvements in operational efficiency. For instance, a study demonstrated that machine learning algorithms could accurately forecast traffic speeds with a 93% accuracy rate and flow rates with 86% accuracy, utilizing historical speed and flow data from Berlin [21].

Similarly, another case study highlighted the application of AI in predicting vehicle emissions. By analyzing onboard diagnostics data, researchers developed a physics-aware AI model that improved predictive accuracy by approximately 65% compared to traditional methods [22].

These examples underscore the value of recycling historical transportation data to enhance predictive capabilities and operational efficiency. Data recycling strategies leverage historical datasets to extract new insights and enhance decision making. Advanced analytics apply statistical models and AI to uncover patterns in archived data. Cloud-based storage solutions provide scalable platforms for repurposing old datasets into AI training models and predictive analytics. Data warehouses consolidate diverse datasets into centralized repositories for retrospective analysis and operational optimization. Repurposing historical data unlocks untapped value while reducing environmental and financial costs associated with storage [23].

4.4. Data Repair and Quality Assurance

Ensuring data accuracy and integrity is crucial for reducing waste and improving usability. The Land Transport Authority (LTA) of Singapore has implemented centralized data-sharing systems to enhance traffic management efficiency. By integrating real-time data collection technologies, such as sensors and control systems, LTA monitors and manages traffic flow effectively, leading to improved road network efficiency and safety. This is illustrated by the integration having resulted in a 30% reduction in redundant data storage and a 15% improvement in real-time traffic management [24,25]. Poor-quality data leads to errors, inefficiencies, and increased operational costs. Organizations should implement data validation tools to automate the detection of inconsistencies and errors. Regular audits maintain data integrity and compliance. Machine learning for anomaly detection identifies outliers and inconsistencies that may indicate corrupted or redundant data. Governance frameworks define clear data stewardship roles and responsibilities to ensure accountability in data management. A structured approach to data quality assurance prevents data-related inefficiencies and fosters a more reliable data ecosystem [26].

4.5. Sustainable Data Governance and Compliance

A robust governance framework is fundamental to enforcing CE principles in data management. Effective governance promotes accountability, security, and ethical data use. Key components include regulatory compliance, adhering to data protection laws such as the General Data Protection Regulation (GDPR) to ensure responsible data handling. Standardized protocols establish clear guidelines for data access, ownership, and sharing. Privacy and security measures, including encryption, anonymization, and controlled access mechanisms, safeguard sensitive information. Ethical data usage ensures practices align with ethical considerations, preventing misuse and ensuring transparency. Integrating these governance principles enhances data sustainability while building trust with stakeholders and regulatory bodies [27].

5. Challenges in Implementing a Circular Data Economy

Despite the numerous benefits of adopting CE principles in data management, organizations face several challenges that hinder implementation. Addressing these challenges is critical to the successful implementation of the principles of circular economy in data management. By strengthening privacy measures, improving interoperability, promoting cultural change, upgrading technology infrastructure, and fostering collaboration, organizations can transition to a more sustainable and efficient data governance model.

5.1. Data Privacy and Security

Ensuring data privacy and security is paramount, especially when sharing sensitive information among multiple stakeholders. Open data initiatives and data-sharing agreements necessitate robust protection measures to prevent unauthorized access and data breaches. Compliance with regulations like the General Data Protection Regulation (GDPR) is crucial in CE-based data governance. Organizations should implement encryption techniques to secure data at rest and in transit, establish access control mechanisms to restrict data access to authorized entities, and conduct regular security audits to identify and mitigate vulnerabilities. A study by Chowdhury et al. [28] discusses the use of blockchain technology to enhance data security and privacy in circular economy applications, highlighting its potential to ensure secure and ethical data management.

5.2. Interoperability Issues

The absence of standardized data formats and system compatibility poses significant challenges in implementing a circular data economy. Many organizations utilize proprietary data structures, hindering seamless data exchange. To overcome these interoperability issues, adopting open data standards ensures system compatibility; utilizing application programming interfaces (APIs) facilitates smooth data integration; and fostering cross-agency collaboration aligns data management frameworks.

Research by Eshghie et al. [29] proposes a role-based token management scheme on the Algorand blockchain to achieve fine-grained and scalable component management, facilitating seamless data exchange in circular economy applications.

5.3. Resistance to Change

Organizations often hesitate to transition from traditional data management practices to circular models due to perceived complexity and implementation costs. To mitigate this resistance, conducting training programs educates stakeholders on the advantages of circular data management, demonstrating cost savings and operational efficiencies achieved through circular data models, and presenting successful case studies of CE-based data governance to gain executive buy-in.

A comprehensive review by Saidani et al. [30] provides a taxonomy of circular economy indicators, offering insights into effective implementation strategies and highlighting the benefits of adopting CE principles.

5.4. Technological Constraints

Implementing circular data management necessitates infrastructure capable of supporting efficient data storage, retrieval, and analysis. Many organizations rely on legacy systems not optimized for data sharing and recycling. Addressing these technological constraints involves investing in cloud storage solutions for scalable and secure data management, utilizing AI-driven data processing to automate classification and reuse of information, and upgrading legacy systems to support real-time data access and cross-agency integration.

Zocco et al. [31] discuss the development of a computer-vision-enabled material measurement system to enhance material management efficiency, illustrating technological advancements that support circular data practices.

5.5. Lack of Collaboration

Effective circular data management requires active cooperation among various stakeholders, including government agencies, private sector organizations, and technology providers. However, competing interests and regulatory barriers often impede collaboration. To foster a cooperative environment, establishing multi-stakeholder governance models aligns interests and creates shared data policies; promoting public–private partnerships drives innovation and investment in circular data management; and advocating for policy frameworks facilitates secure and ethical data-sharing practices.

An exploratory study by Van Capelleveen [32] identifies the need for collaborative approaches across the value chain to overcome barriers in data management for the circular economy, emphasizing the importance of stakeholder cooperation.

6. Case Study: Circular Economy in Transportation Data Management

Transportation systems generate vast amounts of data from IoT sensors, GPS tracking, surveillance cameras, and traffic monitoring systems. Managing this data efficiently is crucial for optimizing operations, enhancing safety, and reducing environmental impact. However, traditional data management approaches often lead to redundancy, data silos, and inefficiencies. Applying circular economy (CE) principles in transportation data management can transform how data is collected, stored, shared, and utilized to create more sustainable and efficient urban mobility systems.

6.1. Implementing Circular Data Strategies in Transportation

By leveraging CE strategies, transportation authorities can optimize data usage while minimizing waste. Key implementations include the following:

- Optimizing traffic management: Shared data platforms enable real-time traffic monitoring and congestion mitigation. For example, Google's Wazepartners with city governments through its Connected Citizens Program, allowing authorities to access crowd-sourced traffic data for better urban planning.
- Reducing redundant data storage: Integrated data-sharing systems among agencies prevent duplication. In Singapore, the Land Transport Authority (LTA) consolidates public transit, traffic, and pedestrian flow data to improve transportation planning and reduce inefficiencies.
- Predictive maintenance using AI: AI-driven analytics utilize sensor data to predict vehicle and infrastructure failures, reducing downtime and maintenance costs. Deutsche

Bahn, Germany's national railway, employs predictive maintenance on trains, leveraging IoT sensors to detect mechanical issues before failures occur.
- Enhancing environmental impact assessments: Improved data integration supports sustainability efforts. London's Ultra Low Emission Zone (ULEZ) monitors real-time vehicle emissions using roadside sensors and ANPR (automatic number plate recognition) cameras, enforcing policies to reduce urban air pollution.

Figure 2 illustrates the conceptual framework for applying circular economy (CE) principles to transportation data management. At the center of the model is the circular data economy in transportation, which promotes sustainable and efficient data usage.

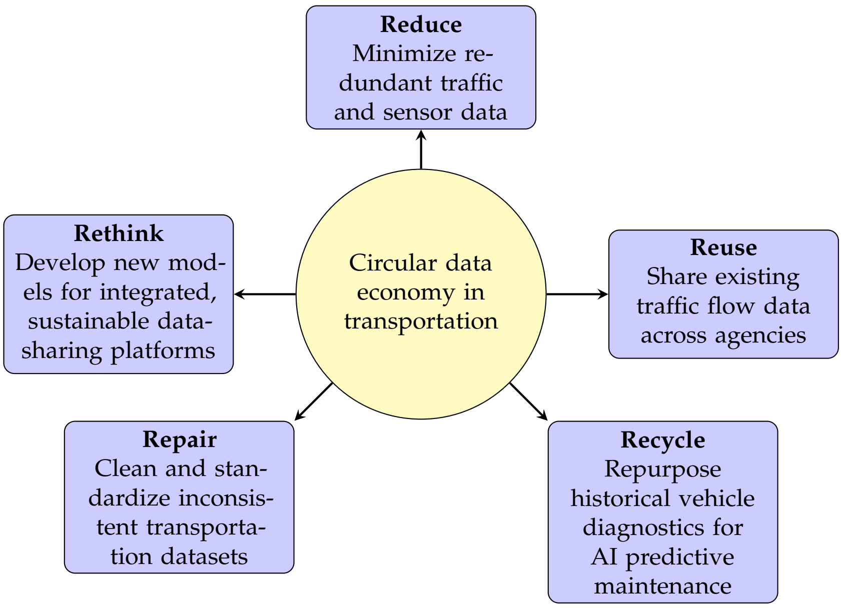

Figure 2. Conceptual framework: Circular data economy in transportation.

Surrounding this core concept are five key CE principles guiding sustainable transportation data management.Reduce minimizes redundant traffic and sensor data to optimize storage and processing. Reuse enhances coordination by sharing traffic flow data across agencies. Recycle repurposes historical vehicle diagnostics for AI-driven predictive maintenance. Repair improves data quality through cleaning and standardization. Rethink fosters innovative, integrated data-sharing platforms for efficiency and collaboration.

These principles create a circular approach to data governance, reducing waste while maximizing the value of transportation data. By adopting them, agencies enhance efficiency, lower environmental impact, and support data-driven decision making.

6.2. Case Study: Singapore Land Transport Authority (LTA)

A practical example of CE-based data strategies is found in the Singapore Land Transport Authority (LTA) system. The following structured steps illustrate how the CE principles have been applied in the system:

- Step 1: Data collection and reduction—the LTA identified redundant and obsolete data sources, consolidating essential transportation records while removing unnecessary duplicates. This process led to a 30% reduction in redundant data storage [24].
- Step 2: Data reuse and integration—GPS and sensor data were shared across multiple agencies, enabling real-time monitoring and predictive analytics to optimize traffic flow [24].
- Step 3: Data recycling and repurposing—archived transport data was repurposed for AI-driven predictive modeling, enhancing congestion management and route optimization.

- Step 4: Standardization and interoperability—data formats were standardized across platforms to ensure seamless integration and accessibility for multiple stakeholders [24].
- Step 5: Evaluation and impact—the integration of CE principles resulted in a 15% improvement in real-time traffic management and significant cost savings in data storage [24].

These structured steps demonstrate the effectiveness of CE principles in optimizing data management, improving efficiency, and reducing waste in transportation systems.

Table 1 illustates the real-world applications that highlight the tangible benefits of integrating circular economy principles into data management.

Table 1. Application of circular economy (CE) principles in transportation data management.

CE Principle	Application in Transportation Data Management	Impact
Reduce	Eliminating redundant traffic data	20% storage savings
Reuse	Sharing GPS and sensor data across agencies	Improved efficiency
Recycle	Repurposing archived transport data for AI models	Better predictions
Repair	Standardizing data formats for integration	Enhanced interoperability
Rethink	Developing innovative data-sharing platforms	Cross-sector collaboration

6.3. Challenges in Adopting Circular Data Management

Despite the benefits, several challenges hinder the adoption of CE-based transportation data management:

- Data privacy and security: Sharing transportation data raises privacy concerns, particularly with GPS tracking and surveillance data. Regulations such as GDPR impose strict requirements on data handling.
- Interoperability issues: Integrating data from various stakeholders (e.g., traffic management, public transport, logistics) requires standardized formats and compatible systems, which remain a challenge in many cities.
- Stakeholder collaboration: Effective circular data management requires coordination between government agencies, private companies, and technology providers, which can be difficult due to differing priorities and regulations.

7. Discussion

The integration of circular economy (CE) principles into transportation data management presents both opportunities and challenges. While CE strategies enhance data efficiency, minimize redundant storage, and promote sustainability, several obstacles hinder adoption, including privacy concerns, interoperability issues, and resistance to new governance models. Ensuring data security while fostering reuse requires advanced governance frameworks and technological innovation [33].

Figure 3 illustrates the Improved Circular Data Governance Model, which integrates CE principles into transportation data governance. The model consists of three interconnected layers: the circular data economy core, the data process layer, and the stakeholder layer. These elements work together to establish a more efficient, sustainable, and collaborative framework for data governance [34].

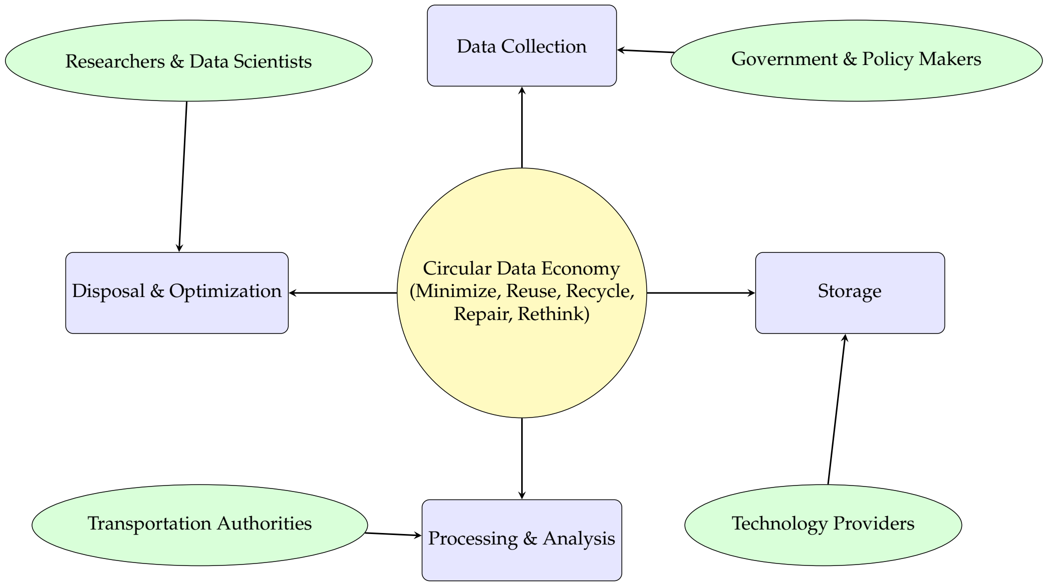

Figure 3. Improved circular data governance model. The yellow circle represents the core principle of the circular data economy. The blue rectangles represent data lifecycle stages (e.g., collection, storage, processing). The green ellipses indicate the key stakeholders involved in each stage.

7.1. Circular Data Economy Core

At the center, the circular data economy core applies the five CE principles: Minimize, reuse, recycle, repair, and rethink. These principles guide transportation data management by reducing redundancy, optimizing resource allocation, and ensuring long-term sustainability [35].

7.2. Data Process Layer

Encircling the core, the data process layer consists of four inter-related operations that ensure a circular approach to transportation data governance. The process begins with data collection, where transportation data is gathered from multiple sources, including IoT sensors, GPS tracking, and traffic monitoring systems. This data is then securely stored using cloud solutions and cross-agency platforms, reducing redundancy and improving accessibility. The processing and analysis stage applies advanced analytics, AI-driven insights, and predictive modeling to extract valuable information that supports urban mobility planning and infrastructure optimization. Finally, the **disposal and optimization** phase ensures responsible data lifecycle management through techniques such as data minimization, deduplication, and automated deletion policies. These interconnected processes align with CE principles by promoting efficient data utilization and reducing unnecessary digital waste [36].

7.3. Stakeholder Layer

The outermost layer, the stakeholder layer, includes key actors who facilitate circular data management. Government and policymakers establish regulatory frameworks like GDPR to ensure compliance and support circular data strategies. Technology providers develop AI-driven analytics tools and cloud storage solutions to enhance efficiency. Transportation authorities use these technologies to optimize urban mobility and traffic management. Researchers and data scientists analyze datasets to improve predictive maintenance and congestion forecasting. Their collaboration fosters a well-governed data-sharing ecosystem aligned with circular economy principles [34].

The Improved Circular Data Governance Model demonstrates how circular economy principles can be applied to transportation data management. By promoting data reuse, minimizing waste, and fostering cross-sector collaboration, the model enhances operational efficiency, environmental sustainability, and decision making. This structured approach provides a roadmap for policymakers, organizations, and researchers to transition from traditional linear data management to a more resilient, circular system.

7.4. Comparison of Traditional and Circular Data Management

The transition from traditional data management to a circular data economy model represents a fundamental shift in how organizations handle, utilize, and govern digital resources. Table 2 provides a comparative analysis of key aspects that differentiate the two approaches.

Table 2. Comparison of traditional data management and circular data economy model.

Aspect	Traditional Data Management	Circular Data Economy Model
Data storage	Siloed, redundant storage	Shared, optimized storage with deduplication
Data utilization	Limited reuse, frequent data loss	Maximized reuse and recycling for new applications
Governance approach	Compliance-focused, rigid policies	Flexible, sustainability-driven governance
Environmental impact	High energy consumption due to excess storage	Reduced digital carbon footprint through efficiency
Decision making	Reactive data analysis	Proactive AI-driven insights

Traditional data management is characterized by siloed storage systems, leading to inefficiencies, redundant datasets, and frequent data loss. In contrast, the circular data economy prioritizes optimized storage, deduplication, and shared data resources, ensuring greater efficiency and sustainability [35]. From a governance perspective, conventional models focus on compliance and rigid policies, whereas circular data governance fosters adaptability and sustainability-driven policies, facilitating cross-sector collaboration and ethical data sharing [36]. The environmental impact of traditional data storage is substantial, with high energy consumption due to excess data processing. A circular approach mitigates this by minimizing redundant storage and enhancing processing efficiency, thereby reducing the digital carbon footprint [33]. Finally, decision making in traditional models remains reactive, relying on retrospective data analysis. The circular model, however, leverages AI-driven analytics and predictive modeling to enhance real-time decision making and proactive resource optimization [34].

Adopting a circular data economy model offers organizations the opportunity to enhance efficiency, sustainability, and decision making. By shifting from rigid, siloed data management practices to an optimized, collaborative framework, businesses can unlock the full potential of their digital resources. Finally, collaboration between policymakers, transportation authorities, and technology providers will be essential in addressing these challenges and fostering a transition toward a more sustainable and efficient transportation data ecosystem.

8. Conclusions and Future Directions

This research highlights the transformative role of circular economy (CE) principles in transportation data management, emphasizing efficiency, sustainability, and smarter decision making. By adopting circular data practices—such as reuse, optimization, and predictive analytics—transportation systems can minimize redundancy, enhance collaboration, and reduce their digital carbon footprint. Future advancements in AI, blockchain, and machine learning will further accelerate the transition toward a circular and intelligent transportation ecosystem, ensuring long-term resilience and sustainability.

The key contributions of this study include the introduction of a structured framework for applying circular economy (CE) principles to digital data management. The research demonstrates real-world benefits through a transportation data case study, providing strategies for reducing data waste and enhancing sustainability. Additionally, this study identifies key challenges in implementing CE-based data governance and proposes viable solutions. Looking ahead, the findings highlight the potential of AI-driven automation to further optimize sustainable data use, ensuring a more efficient and responsible digital ecosystem.

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References

1. Elete, T.Y.; Nwulu, E.O.; Erhueh, O.V.; Akano, O.A.; Aderamo, A.T. Digital transformation in the oil and gas industry: A comprehensive review of operational efficiencies and case studies. *Int. J. Appl. Res. Soc. Sci.* **2024**, *6*, 2611–2643. [CrossRef]
2. Desai, B.C. The state of data. In Proceedings of the 18th International Database Engineering and Applications Symposium, Porto, Portugal, 7–9 July 2014; pp. 77–86. [CrossRef]
3. Jackson, T. Is there a role for knowledge management in saving the planet from too much data? *Knowl. Manag. Res. Pract.* **2023**, *21*, 427–435. [CrossRef]
4. Bawden, D.; Robinson, L. Information Overload: An Introduction. In *Oxford Research Encyclopedia of Politics*; Oxford University Press: Oxford, UK, 2020. [CrossRef]
5. Hu, C.; Wen, H. The Studies Based on the Application of Predictive Analytics Models. *Adv. Econ. Manag. Political Sci.* **2024**, *140*, 98–103. [CrossRef]
6. Arinze, C.A.; Agho, M.O.; Eyo-Udo, N.L.; Abbey, A.B.N.; Onukwulu, E.C. AI-Driven Transport and Distribution Optimization Model (TDOM) for the downstream petroleum sector: Enhancing sme supply chains and sustainability. *Magna Sci. Adv. Res. Rev.* **2025**, *13*, 137–153. [CrossRef]
7. Kathuria, A.; Verma, A.; Sen, A.S. How Technology Use Drives Infobesity: An In-Depth Look at ERP Systems. In Proceedings of the Pacific Asia Conference on Information Systems (PACIS), Dubai, United Arab Emirates, 20–24 June 2021; pp. 1–14.
8. Kathuria, A.; Verma, A.; Sen, A.S. Unravelling the Origins of Infobesity: The Impact of Frequency on Intensity. In Proceedings of the 55th Hawaii International Conference on System Sciences, Maui, HI, USA, 4–7 January 2022; pp. 1–10.
9. Yap, N.T. Towards a Circular Economy. *Greener Manag. Int.* **2005**, *50*, 11–24 . [CrossRef]
10. Kristoffersen, E.; Aremu, O.O.; Blomsma, F.; Mikalef, P.; Li, J. Exploring the Relationship Between Data Science and Circular Economy: An Enhanced CRISP-DM Process Model. In *Digital Transformation for a Sustainable Society in the 21st Century*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 177–189.

11. Mulam, V.R. Data-Driven Decision-Making in Transportation Management Using AI. *Int. J. Sci. Res. Comput. Sci. Eng. Inf. Technol.* **2024**, *10*, 383–389. [CrossRef]
12. Consumer Goods Technology. Available online: https://consumergoods.com/research-shows-how-cgs-are-prioritizing-data-analytics-sales-marketing (accessed on 7 June 2023).
13. Maximize Business Growth With Data-Driven Decision-Making. Available online: https://www.forbes.com/councils/forbestechcouncil/2024/08/01/maximize-business-growth-with-data-driven-decision-making/ (accessed on 31 March 2023).
14. Big Data and AI Are Driving Business Innovation. Available at: https://www.brainforge.ai/blog/big-data-and-ai-are-driving-business-innovation (accessed on 3 January 2023).
15. How does data analysis influence business decision making?. Available online: https://www.sage.com/en-us/blog/how-does-data-analysis-influence-business-decision-making/ (accessed on 3 January 2023).
16. Sargiotis, D. Future Trends in Data Governance: Preparing for Tomorrow. In *Data Governance: A Guide*; Springer: Berlin/Heidelberg, Germany, 2024; pp. 365–390.
17. Southekal, P. *Data Quality: Empowering Businesses with Analytics and AI*; John Wiley & Sons: Hoboken, NJ, USA, 2023.
18. Borgogno, O.; Colangelo, G. Data sharing and interoperability: Fostering innovation and competition through APIs. *Comput. Law Secur. Rev.* **2019**, *35*, 105314. [CrossRef]
19. What Is Open Data. 2020. Available online: https://data.europa.eu/en/dataeuropa-academy/what-open-data (accessed on 23 March 2025).
20. Zannat, K.E.; Choudhury, C.F. Data Reuse Methods for Transportation Planning in Small and Medium-Sized Towns. *J. Urban Plan. Dev.* **2019**, *145*, 04019020. [CrossRef]
21. Abduljabbar, R.; Dia, H.; Liyanage, S.; Bagloee, S.A. Applications of artificial intelligence in transport: An overview. *Sustainability* **2019**, *11*, 189. [CrossRef]
22. Selvam, H.P.; Li, Y.; Wang, P.; Northrop, W.F.; Shekhar, S. Vehicle Emissions Prediction with Physics-Aware AI Models: Preliminary Results. *arXiv* **2021**, arXiv:2105.00375.
23. Zhang, W.; Li, M.; Wang, J. Exploration of an Intelligent Decision-making System for International Freight Transportation. In Proceedings of the 2023 International Conference on Transportation Information and Safety (ICTIS), Xi'an, China, 4–6 August 2023; pp. 1–6.
24. Land Transport Authority. Intelligent Transport Systems. Available online: https://www.lta.gov.sg/content/ltagov/en/getting_around/driving_in_singapore/intelligent_transport_systems.html (accessed on 23 March 2025).
25. Achar, T.E.; Rekha, C.; Shreyas, J. Smart automated highway lighting system using IoT: A survey. *Energy Informatics* **2024**, *7*, 76. [CrossRef]
26. Alsolbi, I.; Shavaki, H.F.; Agarwal, R.; Bharathy, K.G.; Prakash, S.; Rasad, M. Big Data Optimization and Management in Supply Chain Management. *Artif. Intell. Rev.* **2023**, *56*, 123–145. [CrossRef]
27. Osaba, E.; Sanchez-Medina, J.; Vlahogianni, E.I.; Yang, X.S. Data-Driven Optimization for Transportation Logistics and Smart Mobility Applications. *IEEE Intell. Transp. Syst. Mag.* **2020**, *12*, 6–9. [CrossRef]
28. Chowdhury, M.J.M.; Hassan, N.U.; Tushar, W.; Niyato, D.; Saha, T.; Poor, H.V.; Yuen, C. Blockchain-enabled Circular Economy—Collaborative Responsibility in Solar Panel Recycling. *arXiv* **2024**, arXiv:2403.09937. [CrossRef]
29. Eshghie, M.; Quan, L.; Kasche, G.A.; Jacobson, F.; Bassi, C.; Artho, C. CircleChain: Tokenizing Products with a Role-based Scheme for a Circular Economy. *arXiv* **2022**, arXiv:2205.11212.
30. Saidani, M.; Yannou, B.; Leroy, Y.; Cluzel, F.; Kendall, A. A taxonomy of circular economy indicators. *arXiv* **2018**, arXiv:1901.02709. [CrossRef]
31. Zocco, F.; McLoone, S.; Smyth, B. Material Measurement Units for a Circular Economy: Foundations through a Review. *arXiv* **2021**, arXiv:2103.01997. [CrossRef]
32. van Capelleveen, G. The anatomy of a passport for the circular economy: A conceptual definition, vision and structured literature review. *Resour. Conserv. Recycl. Adv.* **2023**, *17*, 200123. [CrossRef]
33. Bressanelli, G.; Perona, M.; Saccani, N. Exploring How Usage-Focused Business Models Enable Circular Economy Through Digital Technologies. *Sustainability* **2018**, *10*, 639. [CrossRef]
34. *Implementing Data Governance at Transportation Agencies*; Technical Report; National Academies Press: Washington, DC, USA, 2023.
35. Nolan, L.; Simanjuntak, A.; Newell, H.; Tan, W. X. Opportunities and Challenges in Implementing Circular Economy within Digital Platforms. *International Transactions on Education Technology (ITEE)* **2025**, *3*, pp. 125–133. [CrossRef]
36. *Improving Safety Data Programs Through Data Governance and Data Business Planning*; Technical Report; National Academies Press: Washington, DC, USA, 2015.