IAIC Transactions on Sustainable Digital Innovation (ITSDI)
Vol. 7, No. 1, October 2025, pp. 97∼105
E-ISSN: 2715-0461 P-ISSN: 2686-6285, DOI:10.34306

Data-Driven Innovation for Circular Digital Economy in Sustainable Urban Development

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Article Info

Article history:

Submission August 25, 2025
Revised September 30, 2025
Accepted October 2, 2025
Published October 22, 2025

Keywords:

Data-Driven
Digital Economy
Sustainable
SDGs
Urban Development

ABSTRACT

The rapid advancement of digital technology has transformed how cities innovate and sustain their growth, making data-driven innovation a crucial element in achieving sustainable urban development. This study aims to examine the integration of data analytics, artificial intelligence, and Internet of Things within the framework of a circular digital economy to promote smarter, greener, and more resilient cities aligned with the Sustainable Development Goals. Using a Systematic Literature Review method, the research collected and analyzed publications from 2015 to 2024 obtained from major academic databases such as Scopus, ScienceDirect, and IEEE Xplore. **The results show** that data accessibility, interoperability, and digital infrastructure enhance efficiency in energy, mobility, and waste management, while digital tracking supports circularity and resource optimization. Governance that applies human-centered design further ensures inclusivity and transparency in urban systems. Overall, **the findings** highlight that data serves not only as a technological asset but also as a strategic driver for sustainable transformation. **The study concludes** that integrating data-driven innovation with circular economy principles strengthens collaboration among governments, industries, and communities, enabling cities to achieve long-term sustainability and contribute effectively to global goals such as innovation, responsible consumption, sustainable cities, and climate action.

DOI: https://doi.org/10.34306/itsdi.v7i1.710

1. INTRODUCTION

The rapid advancement of digital technology has revolutionized urban governance, making Data-Driven Innovation (DDI) a central component in driving sustainable city development. As cities face increasing pressure to meet SDGs like SDGs 11 (Sustainable Cities and Communities) and SDGs 13 (Climate Action), the integration of AI, IoT, and Circular Digital Economy (CDE) models offers a promising pathway [1].

However, existing studies have largely examined these frameworks independently, missing the potential synergies when combined [2]. This study bridges this gap by offering a comprehensive analysis of how DDI and CDE together can transform urban sustainability practices [3]. The integration of these technologies promotes not only environmental efficiency but also social equity and economic resilience, addressing an urgent need for smart cities to meet both local and global sustainability goals.

This study bridges the gap by offering a comprehensive framework for integrating DDI with CDE, an approach that has been underexplored in the context of urban sustainability. By focusing on the synergies between these two frameworks, this research offers new insights into how smart, data-driven technologies can enhance the circularity of urban systems [4, 5, 6, 7]. This work is novel in its focus on how cities can leverage both DDI and CDE simultaneously to not only increase efficiency but also support long-term sustainability goals. By leveraging AI, IoT, and data analytics, cities can transition from linear consumption models to regenerative systems. This transformation is essential for achieving SDGs 12 (Responsible Consumption and Production), which emphasizes minimizing resource extraction and reducing waste [8, 9]. Through digital tracking and predictive analytics, cities can enhance their resource management practices, making them more efficient and sustainable.

1.1. Literature Review

This section discusses previous studies related to data-driven innovation, circular digital economy, and sustainable urban development. The discussion aims to build a clear theoretical foundation, highlight the intersection among these three domains, and identify existing research gaps in relation to the Sustainable Development Goals (SDGs) [10, 11, 12].

1.2. Data-Driven Innovation in Sustainable Systems

Data-driven innovation (DDI) is increasingly recognized as a critical enabler of sustainable transformation across industries and cities. It refers to the systematic use of data analytics, Artificial Intelligence (AI), and digital technologies to enhance performance, decision-making, and environmental efficiency [13, 14, 15]. A research emphasize that DDI enables organizations to turn large volumes of raw data into meaningful insights that support proactive and evidence-based actions.

- **Optimizing Urban Systems:** In the context of urban management, data-driven innovation helps optimize energy systems, reduce waste, predict infrastructure needs, and design policies that align with sustainability goals [16]. This aligns closely with SDGs 9 (Industry, Innovation, and Infrastructure), which promotes resilient infrastructure and sustainable industrialization. DDI plays a significant role in optimizing resource utilization, fostering more sustainable urban systems [17].

- **Transparency and Accountability:** Moreover, the integration of DDI fosters transparency and accountability in public systems, ensuring that innovation contributes not only to efficiency but also to social and environmental well-being. This is especially crucial in achieving SDGs 12 (Responsible Consumption and Production), as data-driven systems can track resource flows, minimize waste, and optimize consumption patterns [18, 19].

1.3. Circular Digital Economy

The Circular Digital Economy (CDE) combines two transformative paradigms: the circular economy's resource regeneration model and digital transformation's technological advancement. A researchs define CDE as a digitally enabled system that supports material reuse, recycling, and extended product lifecycles [20, 21]. Digital tools such as IoT, blockchain, and cloud computing allow real-time tracking of resources and promote transparency across supply chains.

- **Resource Regeneration and Digital Tools:** CDE supports SDGs 12 (Responsible Consumption and Production) by encouraging companies and governments to transition from linear "take-make-dispose" models toward closed-loop systems that minimize resource extraction and emissions. Technologies like IoT and blockchain provide the necessary infrastructure for these systems by offering transparency and tracking capabilities that can monitor product lifecycles [22].

- **Promoting Circularity Through Data:** Data-enabled circularity ensures that urban economies transition from linear models to regenerative systems, minimizing waste while maximizing material reuse [23]. These strategies contribute directly to SDGs 12 by promoting efficient resource utilization and enabling sustainable production cycles. This also aligns with SDGs 9 (Industry, Innovation, and Infrastructure) by fostering technological innovation and new sustainable business practices.

1.4. Data-Driven Urban Sustainability

Urban sustainability has become a critical global challenge, with cities responsible for over 70% of global carbon emissions. The application of data-driven systems offers new possibilities for addressing this issue through smarter and more adaptive urban governance. A research note that smart city initiatives, powered by IoT and AI, have transformed urban management from intelligent transportation systems to efficient energy grids and waste reduction programs [24].

- **Smart City Implementation:** Smart city initiatives, powered by AI and IoT, support SDGs 11 (Sustainable Cities and Communities) by enhancing livability, reducing pollution, and improving resource efficiency. These initiatives allow cities to better manage urban challenges such as congestion, waste, and energy consumption, all while fostering a sustainable environment [25].

- **Evaluation and Dynamic Adjustments:** Integrating data-driven innovation with circular principles amplifies these benefits. For instance, cities can use sensor data to monitor waste flows, support urban recycling loops, and guide citizen behavior toward more sustainable lifestyles. Furthermore, data analytics allows policymakers to evaluate the effectiveness of sustainability programs and adjust interventions dynamically. This ensures that urban systems can remain adaptable to changing environmental and social needs [26].

2. METHODOLOGY

This study employs a Systematic Literature Review (SLR) approach, a widely recognized method for synthesizing research in an evidence-based manner. The review follows a structured process: identification, screening, and synthesis. Relevant publications were collected from databases such as Scopus, ScienceDirect, and IEEE Xplore, using keywords such as ”data-driven innovation,” ”circular digital economy,” and ”urban sustainability.” Only peer-reviewed articles published between 2015 and 2024 were included.

2.1. Research Design

The review process consisted of three main stages: identification, screening, and synthesis. In the identification stage, relevant publications were collected from major academic databases such as Scopus, ScienceDirect, and IEEE Xplore. Several combinations of keywords were used, including data-driven innovation, circular digital economy, smart city, urban sustainability, and sustainable development goals. Boolean operators (AND, OR) were applied to refine the search results and focus on studies closely related to the topic.

Table 1. Research Stages and Activities

Research Stage	Description of Activities	Purpose	Output
Literature Identification	Define key terms such as data-driven innovation, circular digital economy, and urban sustainability across databases including Scopus, ScienceDirect, and IEEE Xplore.	To collect relevant publications aligned with the research focus.	Initial list of potential articles (2015–2024).
Preliminary Screening	Review titles, abstracts, and full texts to assess topic relevance and publication quality.	To ensure that the selected studies are consistent with digital innovation and sustainability themes.	Set of articles passing the initial screening.
Eligibility Evaluation	Assess methodological clarity, topic relevance, and contribution to SDGs [27, 28].	To maintain the validity and quality of selected sources.	Final set of articles for in-depth analysis.
Data Extraction	Extract key information from each study, including objectives, methods, findings, and implications.	To build a comprehensive research database for thematic analysis.	Literature data matrix.
Thematic Analysis	Categorize findings into three main dimensions: (1) Data-Driven Innovation, (2) Circular Digital Economy, and (3) Urban Sustainability.	To identify recurring patterns and relationships between key concepts.	Thematic mapping of literature findings.
Synthesis and Discussion	Integrate the analytical results with the framework of SDGs and sustainable smart city concepts.	To construct theoretical interpretations and derive meaningful insights.	Synthesized findings and discussion outcomes.
Conclusion and Recommendations	Summarize key findings and provide directions for future research.	To highlight academic and practical implications.	Final conclusions and recommendations.

In Table 1, the process stages used in the literature review for identifying, screening, and synthesizing research related to data-driven innovation and circular digital economy in the context of sustainable development are presented. The process is divided into five main stages, starting with Literature Identification, where keywords related to data-driven innovation, circular digital economy, and urban sustainability are gathered from major academic databases such as Scopus, ScienceDirect, and IEEE Xplore. Next, in the Preliminary Screening stage, the titles, abstracts, and full texts of articles are reviewed to assess the relevance of the topics

and the publication quality. In Eligibility Evaluation, articles that pass the initial screening are selected based on methodological clarity, topic relevance, and their contribution to the SDGs. Data Extraction focuses on extracting key information from each study, including objectives, methods, findings, and implications. The final stage, Thematic Analysis, categorizes the findings into three main dimensions: (1) Data-Driven Innovation, (2) Circular Digital Economy, and (3) Urban Sustainability, and aims to identify recurring patterns and relationships between key concepts. In Table 1, the Purpose and Output columns describe the objectives of each stage and the expected outcomes, such as the Literature data matrix obtained after data extraction and the Final set of articles following the eligibility evaluation. This table provides a clear overview of the steps taken to filter and analyze the literature relevant to this research topic.

Material Flow Analysis (MFA) is a technique used to track the movement of resources in a system, allowing for the identification of inefficiencies and waste. It plays a crucial role in circular economy models, where resource optimization is key. This method was used in the review to identify how data-driven systems can optimize material use in urban contexts [29].

During the screening stage, all retrieved articles were carefully examined by reading their titles, abstracts, and full texts to ensure alignment with the research focus [30]. Only peer-reviewed journal articles and conference papers published between 2015 and 2024 were included, as they represent the most recent and relevant developments [31]. Studies that lacked methodological clarity or had no connection to sustainability or urban innovation were excluded. In the synthesis stage, the extracted data were grouped thematically according to three main dimensions:

- Data-Driven Innovation
- Circular Digital Economy, and
- Urban Sustainability

This process allowed for the identification of recurring patterns and relationships between key concepts, as well as gaps in the existing literature. To maintain research credibility, all selected papers were assessed based on clarity, relevance, and methodological rigor. The evaluation ensured that each study provided sufficient evidence and meaningful insights that contributed to the topic. Only high-quality publications with well-defined objectives and sound analytical frameworks were retained for synthesis.

The synthesis process focused on identifying relationships and trends among data-driven innovation, circular digital economy, and sustainable urban development. Rather than summarizing results, the review emphasized how the integration of digital technologies and circular principles can strengthen sustainability practices [32]. The analysis also highlights how these intersections contribute to achieving the Sustainable Development Goals (SDGs 9, SDGs 11, SDGs 12, and SDGs 13), particularly in promoting innovation, responsible resource use, and resilient urban systems [33].

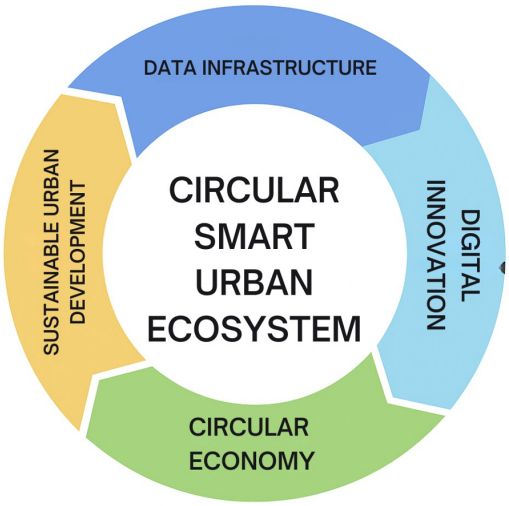

Figure 1. Smart Urban Ecosystem Model

This model in Figure 1 illustrates the interaction between data-driven innovation, circular digital economy, and sustainable urban development within the context of achieving relevant SDGs (9, 11, 12, and 13) [34, 35]. The circular structure emphasizes the continuous feedback loop between data generation, innovation processes, and sustainable outcomes [36, 37].

3. RESULTS AND DISCUSSION

The integration of data-driven innovation (DDI) and circular digital economy (CDE) offers profound implications for urban sustainability. The study identifies three key dimensions where these frameworks intersect: (1) data integration and digital infrastructure, (2) circularity and resource efficiency, and (3) governance and human-centered design.

3.1. Data Integration and Digital Infrastructure

Data-driven innovation fosters the development of robust digital infrastructures that enable cities to optimize energy use, enhance waste management, and improve mobility systems. This alignment with SDGs 9 (Industry, Innovation, and Infrastructure) is particularly crucial as cities continue to invest in IoT networks and open data platforms that can enhance the efficiency and resilience of urban systems. The ability to track resource consumption in real-time provides valuable insights that allow for the optimization of urban processes, ensuring that cities can operate more sustainably [38, 39, 40].

3.2. Circularity and Resource Efficiency

The second dimension focuses on the intersection of DDI with CDE principles, particularly around resource optimization and waste minimization. Data analytics and IoT technologies are central to enhancing circularity by enabling real-time tracking of resources, promoting recycling, and extending product lifecycles. These data-enabled circular practices contribute to SDGs 12 (Responsible Consumption and Production), helping to transition from linear ”take-make-dispose” models to closed-loop systems. The study shows that cities using both DDI and CDE principles achieve significant reductions in resource consumption and environmental impact, demonstrating the transformative potential of these integrated frameworks.

3.3. Governance and Human-Centered Design

Effective governance frameworks are critical for integrating DDI and CDE in urban systems. The study highlights the importance of participatory decision-making processes and transparent governance models that empower citizens and stakeholders. Human-centered design principles ensure that these technological systems are inclusive and equitable, addressing the social dimensions of sustainability. This approach aligns with SDGs 11 (Sustainable Cities and Communities) and SDGs 13 (Climate Action), reinforcing the need for policies that not only promote technological innovation but also ensure that these innovations contribute to the well-being of all urban residents.

3.4. Integrated Discussion

The integration of data-driven innovation within a circular digital economy represents a transformative approach to sustainable urban growth. The synergy between these frameworks enables cities to become adaptive, efficient, and inclusive. However, successful implementation requires cross-sector collaboration among governments, industries, and academic institutions. The transition also depends on the ethical management of data, emphasizing privacy, security, and equitable access. Future research should focus on developing measurable indicators to evaluate how circular digital models contribute to long-term urban resilience and sustainability.

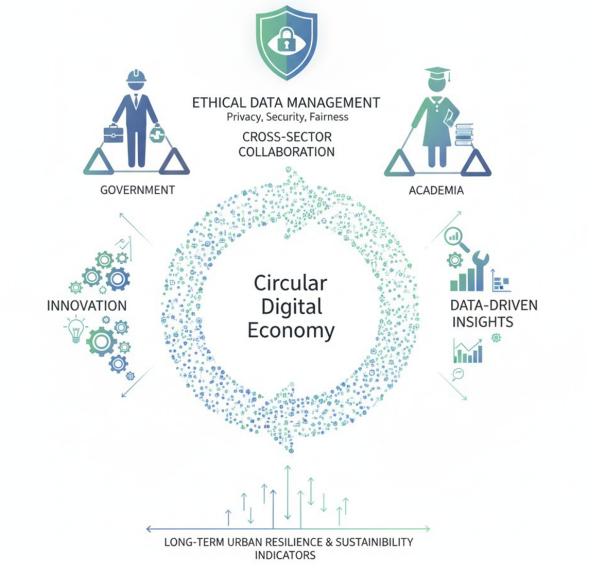

Figure 2. Synergy of Data-Driven Innovation and the Circular Digital Economy

The integration of data-driven innovation into the circular digital economy is a transformative approach towards sustainable urban growth. The synergy between these frameworks allows cities to become adaptive, efficient, and inclusive. Figure 2 presents an integrated workflow metaphor between Data-Driven Innovation and the Circular Digital Economy, supported by Cross-Sector Collaboration (Government, Industry, Academia) and grounded in Ethical Data Management. However, successful implementation necessitates cross-sector collaboration between government, industry, and academic institutions. This transition also relies on ethical data management, emphasizing privacy, security, and fair access. Future research should focus on developing measurable indicators to evaluate how circular digital models contribute to long-term urban resilience and sustainability.

4. MANAGERIAL IMPLICATIONS

The integration of Data-Driven Innovation (DDI) and Circular Digital Economy (CDE) presents significant opportunities for urban managers and policymakers to enhance the sustainability and efficiency of city systems. By adopting these frameworks, cities can optimize resource use, reduce waste, and improve urban infrastructure resilience. Managers should focus on developing and implementing digital infrastructures that support real-time data collection, predictive analytics, and resource tracking. Furthermore, incorporating circular economy principles into urban planning and policy-making will not only foster environmental sustainability but also drive economic growth through resource efficiency and innovation, ultimately contributing to the achievement of key Sustainable Development Goals (SDGs).

5. CONCLUSION

This study highlights the essential role of data-driven innovation (DDI) in accelerating the transition toward a circular digital economy that supports sustainable urban development. By integrating data analytics, IoT, and digital infrastructure, cities can enhance efficiency in energy, mobility, and waste management while fostering innovation-led growth. The findings emphasize that data serves not only as a technological asset but also as a strategic enabler for achieving the Sustainable Development Goals (SDGs), particularly SDGs 9 (Industry, Innovation, and Infrastructure), SDGs 11 (Sustainable Cities and Communities), and SDGs 12 (Responsible Consumption and Production).

The convergence of data-driven practices and circular economy principles offers a new paradigm in how urban ecosystems operate. This study is novel in its approach to integrate these two transformative frameworks, offering new insights into how urban areas can become more resilient and resource-efficient. Cities that adopt circular digital models can shift from resource depletion to regeneration, supported by transparent governance and citizen-centered design. The integration encourages collaboration between government, industry, and society, ensuring that digital transformation aligns with ecological sustainability and social inclusivity.

Future research should focus on developing quantitative frameworks and performance indicators to evaluate how data-driven circular models contribute to long-term sustainability outcomes. Further exploration is needed to assess the ethical, regulatory, and social implications of digital technologies in urban systems. Expanding this research across different cultural and geographical contexts can enhance the global understanding of sustainable innovation, helping policymakers design evidence-based strategies for smarter, greener, and more human-centered cities.

6. DECLARATIONS

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6.2. Author Contributions

Conceptualization: CL; Methodology: FP, TH and ML; Software: ML and TH; Validation: CL and FP; Formal Analysis: CL and FP; Investigation: FP, TH and ML; Resources: CL; Data Curation: FP; Writing Original Draft Preparation: FP, TH and ML; Writing Review and Editing: CL, FP, TH and ML; Visualization: ML; All authors, CL, FP, TH and ML, have read and agreed to the published version of the manuscript.

6.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.4. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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