Mathematical and Computational Applications

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Review

IoT-Driven Transformation of Circular Economy Efficiency: An Overview

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Abstract: The intersection of the Internet of Things (IoT) and the circular economy (CE) creates a revolutionary opportunity to redefine economic sustainability and resilience. This review article explores the intricate interplay between IoT technologies and CE economics, investigating how the IoT transforms supply chain management, optimises resources, and revolutionises business models. IoT applications boost efficiency, reduce waste, and prolong product lifecycles through data analytics, real-time tracking, and automation. The integration of the IoT also fosters the emergence of inventive circular business models, such as product-as-a-service and sharing economies, offering economic benefits and novel market opportunities. This amalgamation with the IoT holds substantial implications for sustainability, advancing environmental stewardship and propelling economic growth within emerging CE marketplaces. This comprehensive review unfolds a roadmap for comprehending and implementing the pivotal components propelling the IoT's transformation toward CE economics, nurturing a sustainable and resilient future. Embracing IoT technologies, the authors embark on a journey transcending mere efficiency, heralding an era where economic progress harmonises with full environmental responsibility and the CE's promise.

Keywords: internet of things (IoT); circular economy; supply chain efficiency; resource optimisation; circular business models; sustainability; consumer engagement; market opportunities; economic transformation; sustainable commerce

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Citation: Turskis, Z.; Šniokienė, V. IoT-Driven Transformation of Circular Economy Efficiency: An Overview. *Math. Comput. Appl.* **2024**, *29*, 49. https://doi.org/10.3390/mca29040049

Academic Editor: Oliver Schütze

Received: 29 March 2024
Revised: 25 June 2024
Accepted: 26 June 2024
Published: 28 June 2024

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1. Introduction

The challenges of unsustainable environmental practices in a competitive business environment have spurred a global push for advancements in resource performance. Manufacturing organisations seeking international prominence recognise sustainability as crucial. Integrating sustainability into supply chains involves reassessing practices through lean, green, and circular economies. Data play a pivotal role in this shift, enabling predictive decision-making and leading to the emergence of intelligent manufacturing characterised by self-aware and self-predictive systems.

Companies are exploring ways to reuse materials, extend product life, and mitigate the adverse effects of the linear economic model (take–use–discard). The Industrial Internet of Things (IIoT) supports complex manufacturing ecosystems and predictive decision-making. With the adoption of IoT technologies, the integration of machine learning (ML) and big data (BD) enhances data management.

Technological advances can significantly improve CE-oriented supply chains by reducing carbon emissions, enhancing recycling, and optimising logistics. The CE emphasises creating closed-loop supply chains with restorative practices to eliminate harmful substances. The intersection of the IoT and CE is transforming sustainable manufacturing.

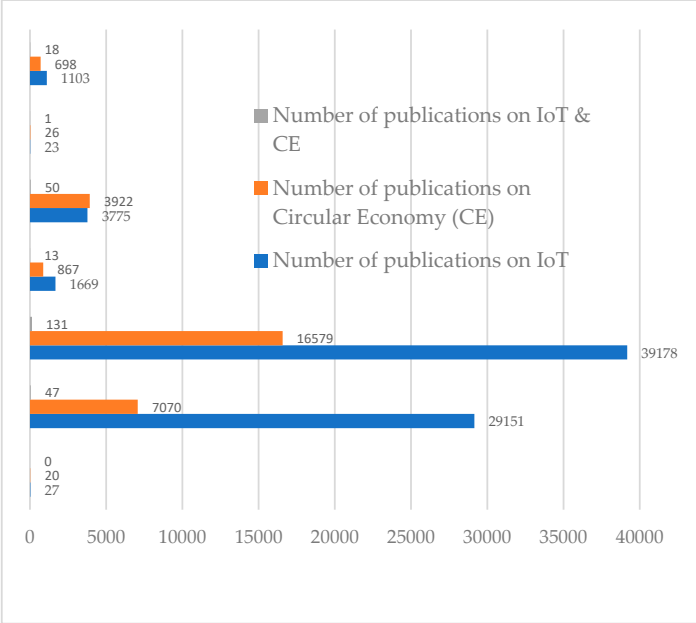
This study examined the Web of Science Core Collection database to compile data for this review, focusing on articles mentioning "IoT" and "circular economy". This study

identified 112,694 publications on the IoT, 28,869 on the CE, and 243 addressing both. These publications were categorised by type and year, revealing a steady increase in research output, especially since 2015, indicating growing interest in these fields.

Furthermore, this study analysed the distribution of publications across different years to discern temporal trends and patterns. Table 1 showcases the distribution of publications by type across all years, highlighting the prevalence of highly cited articles, review articles, and other publication categories within each field. Meanwhile, Table 2 provides a breakdown of publications by year, illustrating variations in research output over time.

Table 1. Distribution of published articles by type (all years).

Articles by Type	Number of Publications on		
	IoT	CE	IoT and CE
Highly cited papers	1103	698	18
Hot papers	23	26	1
Review articles	3775	3922	50
Early access	1669	867	13
Open access	39,178	16,579	131
Enriched cited references	29,151	7070	47
Open publisher-invited reviews	27	20	0



This article synthesises the scientific literature on the IoT and CE, highlighting the dynamic nature of research in these areas. The CE has gained attention in the last thirty years due to the detrimental impacts of linear models on the environment, such as climate change and biodiversity loss. Advocates stress the need for the CE to integrate economic and social considerations for sustainable development.

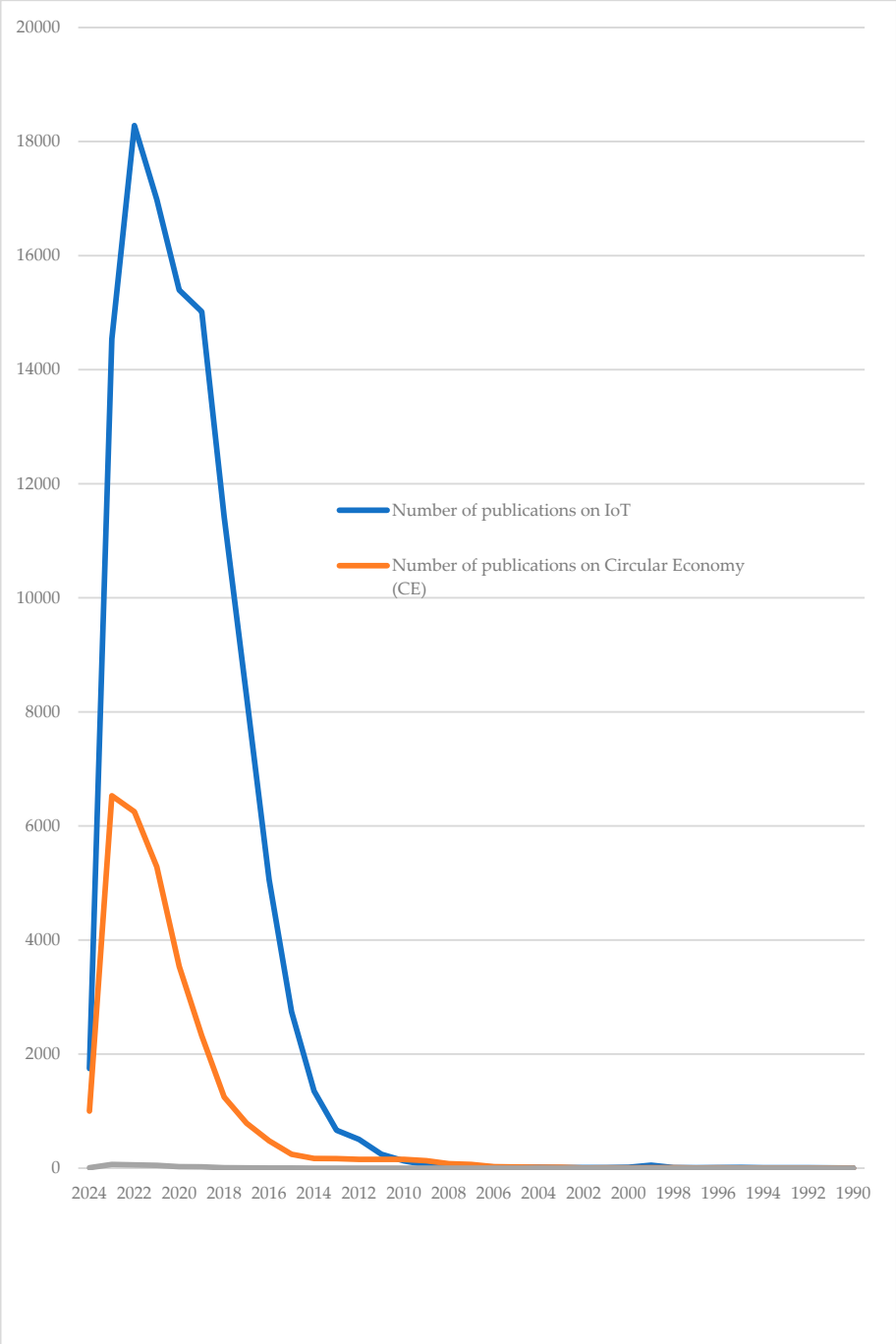
Efforts to connect everyday objects to the Internet began in the 1980s, with John Romkey's Internet-controlled toaster in 1990 [1] and Paul Saffo's [2] vision of sensor integration in 1997. The IoT concept, introduced by Ashton in 1999, has since evolved, transforming fields like inventory control and home automation.

The International Telecommunication Union (ITU) recognised the IoT's significance in 2005 [3,4]. Technologies like Huawei's Harmony OS illustrate progress in IoT infrastructure, expanding its use while reducing dependency on single processors or storage units.

IoT technologies are central in reshaping business operations within circular economic frameworks amidst environmental concerns and resource scarcity. The CE, known for its resource efficiency, aims to reduce waste by designing products for longevity, repair, and multiple lifecycles. The success of the CE hinges on the effective management, redistribution, and repurposing of products and materials, where the IoT plays a pivotal role.

Table 2. Year-wise breakdown of published articles.

Year	Number of Publications on		
	IoT	CE	IoT and CE
2024	1747	999	8
2023	14,537	6532	65
2022	18,281	6249	58
2021	16,985	5284	49
2020	15,397	3537	26
2019	15,016	2321	24
2018	11,419	1247	6
2017	8270	788	5
2016	5056	480	1
2015	2742	243	1
2014	1350	170	0
2013	665	167	0
2012	504	155	0
2011	244	153	0
2010	129	153	0
2009	57	130	0
2008	52	77	0
2007	30	66	0
2006	20	25	0
2005	14	21	0
2004	16	15	0
2003	11	15	0
2002	11	3	0
2001	11	4	0
2000	14	4	0
1999	51	6	0
1998	10	7	0
1997	6	2	0
1996	9	5	0
1995	13	3	0
1994	7	2	0
1993	6	3	0
1992	7	2	0
1991	4	1	0
1990	3	0	0



This review explores the economic transformation driven by the IoT within the CE, examining applications in supply chain management, real-time tracking, data analytics, and automation to enhance efficiency and minimise waste. It also investigates the IoT's role in circular business models like product-as-a-service and sharing economies, which extend

product lifecycles and create economic opportunities. Additionally, this review considers the impact of the IoT on consumer engagement and its financial implications.

The IoT's integration with the CE has significant sustainability implications, intertwining commerce and environmental stewardship. This integration can lead to job creation and economic growth, particularly in emerging CE markets. This review invites scholars, practitioners, and policymakers to explore the transformative synergy between the IoT and CE economics, highlighting technology's role in promoting economic sustainability and resilience.

The IoT transforms the manufacturing, construction, services, and supply chain logistics industries. It facilitates effective control, monitoring, and optimisation through interconnected objects and sensors managed via various systems. This interconnectedness supports innovative applications through web activation and automation, enhancing supply chain visibility and control and fostering efficiency, innovation, and sustainability.

Despite its potential, widespread IoT adoption in the CE faces challenges such as structured data needs, interoperability issues, and technical limitations. Numerous studies have explored IoT applications in the CE, offering insights into closed-loop product lifecycle management, recycling optimisation, and sensor-integrated 3D-printed products. Further research is needed to address implementation challenges and barriers.

The CE has gained attention as a sustainable alternative to linear economic systems, promoting reuse, remanufacturing, and recycling. Digital technologies are crucial for transforming production systems and overcoming implementation challenges. The convergence of advanced technologies with economic paradigms emphasises sustainability, prompting a re-evaluation of practices through lean, green, and circular economies.

Businesses are exploring methods to reuse materials and product components, extending their value and mitigating the linear economy's adverse effects. The IIoT complements predictive decision-making through the IoT, machine learning, and extensive data integration, promoting CE-based supply chains by reducing carbon emissions, improving remanufacturing processes, and optimising logistics operations.

The CE concept represents a shift towards a closed-loop system that minimises resource waste and emission leakages. It draws from various schools of thought, including cradle-to-cradle, ecology laws, looped and performance economy, regenerative design, and industrial ecology, aiming to eliminate waste and preserve product value through recycling and sustainable consumption.

This review emphasises the IoT's role in the CE, examining its economic dimensions, applications in supply chain management, and impact on circular business models. It highlights the potential for job creation and economic growth in emerging CE markets, envisioning a future where economic progress aligns with environmental responsibility.

The growing literature on the IoT's potential for the CE must be more comprehensive. While some reviews highlight the IoT's importance for efficiency and productivity, others overlook its role in the CE transition. This research gap underscores the need for a review that explicitly examines the IoT's significance in transitioning towards the CE, addressing critical research questions and emerging topics in academic discourse.

2. Materials and Methods

The authors chose a systematic review for its interdisciplinary insights and focused answers to research questions. It synthesises previous research, identifies emerging issues, and guides future efforts. This study, a novel contribution to the IoT and the CE, involved two researchers collaborating to select and review relevant articles.

By synthesising prior findings, this study advances the understanding of IoT-driven CE efficiency, building on established approaches.

The systematic literature search methodology ensures a comprehensive approach, summarising existing research to address specific scientific questions. This method enables a thorough synthesis of past work, providing well-supported conclusions that can inform policy-making and business strategies in the IoT and the CE.

This research operationalised the literature review process based on a primary question and objectives, focusing on relevant publications in the CE and IoT fields since 2020.

This study, by synthesising previous research findings, presents advancements in understanding the IoT-driven transformation of CE efficiency, aligning with the approaches adopted in prior studies.

Literature Review Methodology

Databases: Web of Science, Scopus;

Key terms: "Internet of things" AND "stakeholder", "Stakeholder" AND "circular economy", "Industry 4.0" AND "stakeholder", "Industry 4.0" AND "circular economy", "Digital technologies" AND "circular economy";

Article types: journal articles and review articles;

Inclusion criteria: published articles and literature reviews from any country addressing the circular economy;

Exclusion criteria: book reviews, conference proceedings, articles in the press, and editorial reviews;

Period: 2020–2023.

The IoT-driven transformation of circular economy economics relies on several essential technologies and techniques, particularly in supply chain efficiency and resource optimisation. These tools and methods enable the seamless integration of the IoT within the CE framework. They are the building blocks for implementing IoT-driven transformation in the CE, particularly in supply chain efficiency and resource optimisation. Combining these tools and methods enables businesses to create more sustainable, efficient, and resilient CE practices.

Initially, this research reviewed Web of Science articles focusing on IoT technologies and their integration into CE frameworks. To ensure the credibility and reliability of findings, the prioritised sources were peer-reviewed journals, conferences, and renowned experts in the field. The selection process aimed to identify the predominant technologies and methodologies frequently discussed in the context of IoT-driven advancements within the CE.

The investigation identified the practical significance of 17 *technologies and approaches for enhancing supply chain efficiency and resource optimisation within circular economic models*. Articles were selected based on their relevance, credibility, and contribution to comprehensively understanding the IoT-enabled economic transformation within CE paradigms. Here are the essentials identified, presented in descending order of importance:

- *IoT devices and sensors*: Bansal and Kumar [5] and Cui [6] emphasised the pivotal role of interconnected devices and sensors for collecting real-time data in IoT ecosystems.
- *Data analytics and big data*: Koot et al. [7], Li et al. [8], and Li et al. [9] pointed out the importance of robust data analytics tools for processing and extracting valuable insights from IoT-generated data.
- *Connectivity technologies*: Chaudhari et al. [10] and Nurelmadina et al. [11] investigated various connectivity options for efficient data transmission in IoT systems.
- *Cloud computing*: Nguyen et al. [12], Alam [13], and Mishra and Tyagi [14] highlighted the role of cloud platforms in storing, processing, and analysing IoT data.
- *Edge computing*: Alli and Alam [15], Sankaranarayanan et al. [16], and Yu et al. [17] emphasised the importance of edge computing for real-time decision-making in IoT systems.
- *Blockchain technology*: Kouhizadeh et al. [18], Kamble et al. [19], and Esmaeilian et al. [20] investigated the use of blockchain for transparent and secure data sharing within supply chains.
- *Artificial intelligence (AI) and machine learning*: Woschank et al. [21], Andronie et al. [22], and Sharma et al. [23] explored the role of AI and machine learning in optimising supply chain processes.
- *Automation and robotics*: Ben-Daya et al. [24] and Verma et al. [25] emphasised the importance of IoT-driven automation in optimising resource use and supply chain efficiency.

- *Digital twins*: Rasheed et al. [26] and Javaid and Haleem [27] highlighted using digital twins in modelling and simulating supply chain operations.
- *RFID and NFC technology*: Elbasani et al. [28] and Tan and Sidhu [29] investigated the use of RFID and NFC technology for tracking and tracing products within supply chains.
- *Predictive maintenance*: Ayvaz and Alpay [30] and Zonta et al. [31] emphasised the role of IoT in implementing predictive maintenance strategies.
- *Cybersecurity measures*: Hassan et al. [32] and Li and Liu [33] highlighted the importance of cybersecurity measures in protecting IoT systems.
- *Data privacy and compliance*: Ullah and Babar [34], Karale [35], and Nurgalieva et al. [36] emphasised the importance of adhering to data privacy regulations in IoT applications.
- *Supply chain mapping*: de Oliveira et al. [37], Allen et al. [38], Dossa et al. [39], and Calzolari et al. [40] investigated techniques such as supply chain mapping for visualising and understanding material flow in CE systems.
- *Circular design principles*: Sassanelli et al. [41], Hapuwatte et al. [42], and Rejeb et al. [43] explored the implementation of circular design principles in creating products aligned with CE goals.
- *Life cycle assessment (LCA)*: Nižetić et al. [44] and Ferrari et al. [45] highlighted the use of LCA in evaluating products' environmental impacts.
- *Collaborative platforms*: Rejeb et al. [46] and Tiwari [47] investigated collaborative platforms enabled by IoT for enhancing transparency and information sharing among supply chain partners.

These authors underscored the role of facilitating IoT-driven transformations within CE systems, emphasising data collection, analysis, connectivity, security, and sustainability principles.

This prioritisation underscores the role of these essential technologies and techniques in enabling IoT-driven transformations within CE systems, particularly in data collection, analysis, connectivity, security, and sustainability efforts. These tools and methods allow the integration of the IoT within the CE framework.

IoT devices and sensors provide real-time data and insights and are instrumental in addressing industry challenges. Javaid et al. [48] and Ren et al. [49] highlighted the pivotal role of IoT devices and sensors in providing real-time data and insights to organisations. This capability empowers organisations to make informed decisions, reduce costs, increase efficiency, enhance safety, and promote sustainability across various applications. The authors identified 20 critical problems addressed by IoT devices and sensors, including the following:

- *Real-time monitoring*: Subahi and Bouazza [50] and Li et al. [51] investigated IoT sensors for real-time monitoring, helping detect and mitigate issues promptly.
- *Supply chain visibility*: Helo and Shamsuzzoha [52] and Finkenstadt and Handfield [53] emphasised the role of IoT devices in enhancing supply chain visibility.
- *Environmental monitoring*: Demanega et al. [54] and Asha et al. [55] highlighted the importance of IoT sensors in environmental monitoring for ecological health assessment.
- *Energy efficiency*: Ahmad and Zhang [56] and Hossein Motlagh et al. [57] investigated how IoT sensors contribute to energy efficiency in buildings, factories, and smart grids.
- *Predictive maintenance*: Liu et al. [58] and Fernandes et al. [59] pointed out the significance of sensors in predictive maintenance in preventing costly breakdowns.
- *Asset tracking*: Khan et al. [60] and Patel et al. [61] highlighted the role of IoT devices in real-time asset tracking for optimisation and theft prevention.
- *Healthcare monitoring*: Taiwo and Ezugwu [62] and Philip et al. [63] investigated IoT sensors in healthcare for patient monitoring and remote healthcare delivery.
- *Smart agriculture*: Paul et al. [64] and Shaikh et al. [65] emphasised the contribution of IoT sensors to smart agriculture for data-driven decision-making.
- *Fleet management*: Iyer [66] and Aguiar et al. [67] pointed out the importance of IoT devices in fleet management for safer and more efficient transportation.

- *Smart cities*: Bibri [68] and Sarrab et al. [69] investigated the role of IoT sensors in smart cities for urban planning and resource utilisation.
- *Water management*: Nie et al. [70] and Bwambale et al. [71] highlighted the importance of IoT sensors in water management for efficient resource utilisation and conservation.
- *Security and surveillance*: Mocrii et al. [72] and Al-Turjman et al. [73] investigated how IoT devices support security systems, enhancing safety in homes, businesses, and public spaces.
- *Retail analytics*: Caro and Sadr [74] and Boone et al. [75] pointed out the role of IoT sensors in retail analytics for better customer experiences and inventory control.
- *Wildlife conservation*: Sandbrook et al. [76] and Petso et al. [77] emphasise using IoT sensors in wildlife conservation efforts to protect endangered species.
- *Smart homes*: Iqbal et al. [78], Metallidou et al. [79], and Tahsien et al. [80] investigated how IoT sensors in smart homes improve energy efficiency and home security.
- *Waste management*: Kang et al. [81], Nižetić et al. [82], and Wang et al. [83] highlighted the role of IoT devices in waste management for cost reduction and environmental impact mitigation.
- *Occupancy and space utilisation*: Azimi and O'Brien [84] and Valks et al. [85] pointed out how IoT sensors track occupancy in commercial spaces to optimise workspace and energy usage.
- *Agricultural drones*: Boursianis et al. [86] and Bai et al. [87] investigated IoT sensors in agriculture for crop health assessment and pest control.
- *Weather forecasting*: Ren et al. [88] and Fathi et al. [89] emphasised the contribution of IoT sensors to weather forecasting and disaster preparedness.
- *Safety and emergency response*: Alsamhi et al. [90] and Swamy and Kota [91] highlighted how IoT sensors enable quick response and damage minimisation in safety and emergencies.

The information presented above shows that IoT devices and sensors play a crucial role in addressing industry challenges. Their ability to provide real-time data and insights enables organisations to make informed decisions and promote sustainability.

Data analytics and big data: Siow et al. [92] highlighted the crucial role of data analytics and big data in addressing IoT-related problems by processing and extracting valuable insights from the vast data generated by IoT devices and sensors. These technologies transform raw IoT data into actionable insights, empowering organisations to make informed decisions, improve processes, enhance efficiency, reduce costs, and address various IoT-related challenges across industries and applications. The authors identified 14 critical problems addressed by data analytics and big data, including the following:

- *Data processing and storage*: Oussous et al. [93] and Dash et al. [94] pointed out the importance of big data technologies in efficiently managing and storing the significant volume of data generated by IoT devices.
- *Real-time analysis*: Jabbar et al. [95] and Astill et al. [96] investigated how the real-time analysis of IoT data enables organisations to make immediate decisions, such as in predictive maintenance.
- *Pattern recognition*: Amanullah et al. [97] and Adi et al. [98] emphasised the role of data analytics in identifying patterns, anomalies, and trends within IoT data, which is crucial for predictive maintenance and security.
- *Predictive insights*: Sheng et al. [99] and Kumar et al. [100] highlighted how predictive analytics based on historical IoT data can forecast future events and trends, aiding proactive planning and resource allocation.
- *Optimisation*: Aryal et al. [101], He et al. [102], and Araz et al. [103] investigated how data analytics optimises processes and resource allocations based on IoT data, such as in supply chain management.
- *Efficiency and cost savings*: Atitallah et al. [104] and Ahmad et al. [105] pointed out how IoT data analysis leads to operational efficiency, energy consumption reduction, and cost savings, such as in smart buildings.

- *Personalisation*: Grewal et al. [106] and Liu et al. [107] investigated how big data analytics personalises customer experiences by analysing behaviour and preferences derived from IoT data.
- *Data fusion*: Chen et al. [108] and Chandra Shit [109] emphasised the importance of data fusion from various IoT sources for a comprehensive view, aiding route planning and logistics.
- *Data security*: Sarker et al. [110] and Gupta et al. [111] highlighted how data analytics helps detect and respond to security threats within IoT data, essential for safeguarding IoT networks.
- *Environmental impact*: Hassan et al. [112] and Almalki et al. [113] investigated how analysing IoT data related to environmental factors promotes sustainability by understanding ecological footprints and identifying waste reduction opportunities.
- *Customer insights:* Holmlund et al. [114] and Sarker [115] investigated how organisations gain valuable insights into customer behaviour, preferences, and satisfaction by analysing customer data collected through IoT devices. This analysis allows for data-driven decision-making and improved customer experiences.
- *Regulatory compliance:* Thapa and Camtepe [116] and Lo'ai and Saldamli [117] pointed out how big data analytics can help ensure compliance with data privacy and regulatory requirements, particularly when handling sensitive IoT data.
- *Supply chain optimisation:* Bag et al. [118] and Jahani et al. [119] highlighted how data analytics helps demand forecasting, inventory management, and identifying supply chain bottlenecks or inefficiencies, contributing to better resource allocation and improved supply chain operations.
- *Waste reduction:* Kurniawan et al. [120] and Lu et al. [121] investigated how data analytics optimises collection schedules, route planning, and recycling initiatives in waste management, reducing waste and promoting resource efficiency.

Data analytics, including customer insights, regulatory compliance, supply chain optimisation, and waste reduction, is crucial in business operations. By leveraging data analytics, organisations can enhance decision-making, improve efficiency, and drive sustainable practices across different domains.

Connectivity technologies are essential in the IoT context because they provide the means for IoT devices and sensors to communicate, share data, and access cloud services. Connectivity technologies are the backbone of the IoT ecosystem, providing the means for IoT devices to communicate and share data. They are instrumental in addressing IoT-related problems by enabling data collection, real-time monitoring, remote control, scalability, and accessibility, ultimately leading to more efficient, data-driven solutions across various industries and applications. The authors identified 14 critical problems addressed by connectivity technologies, including the following:

- *Data collection and transmission*: Kassab and Darabkh [122] and Seferagić et al. [123] investigated how connectivity technologies, such as Wi-Fi, cellular networks, Bluetooth, Zigbee, and Low-Power Wide-Area Networks (LPWANs), enable data collection and transmission from IoT devices to central systems or the cloud, facilitating real-time monitoring.
- *Real-time monitoring*: Hernández-Morales et al. [124] and Wang et al. [125] pointed out how connectivity technologies enable the real-time monitoring of devices and processes, crucial for industries like manufacturing, logistics, and healthcare, where timely data are essential for decision-making.
- *Remote control*: Sharma et al. [126], and Aboubakar et al. [127] highlighted how connectivity technologies allow for remote control or management of IoT devices, enabling operators to adjust settings, apply updates, or troubleshoot issues from a distance.
- *Scalability*: Centenaro et al. [128] and Firouzi et al. [129] investigated how connectivity technologies provide the infrastructure to scale IoT solutions, supporting adding more devices or expanding geographic coverage.

- *Accessibility*: Rizvi et al. [130] and Wanasinghe et al. [131] emphasised how data accessibility from IoT devices, enabled by connectivity technologies, ensures stakeholders can access data and make informed decisions remotely.
- *Emergency response*: Ali et al. [132] explored how connectivity technologies in security and safety systems enable quick emergency responses, sending real-time alerts and notifications to authorities or responsible parties.
- *Energy efficiency*: Islam et al. [133] and Chilamkurthy et al. [134] highlighted how some connectivity technologies, like LPWANs, are designed to be energy-efficient, extending device lifespans and reducing maintenance requirements.
- *Asset tracking*: Hayward et al. [135] and Song et al. [136] pointed out how connectivity technologies, including GPS and cellular networks, facilitate asset tracking and location-based services, valuable for tracking vehicles, goods, and people in logistics, transportation, and public safety.
- *Resource optimisation*: Lv et al. [137] and Miles et al. [138] investigated how to analyse data transmitted via connectivity technologies to optimise resource usage, such as optimising irrigation in agriculture to conserve water using weather data transmitted over LPWANs.
- *Reduced downtime*: Mohan et al. [139] and Soori et al. [140] emphasised how industrial settings and connectivity technologies support predictive maintenance by transmitting data about equipment conditions, reducing downtime by enabling timely maintenance before a breakdown occurs.
- *Data aggregation*: Erhan et al. [141] and Thamilarasu et al. [142] highlighted how data aggregation over connectivity networks allows organisations to gain a holistic view of operations, identify trends, and detect anomalies by aggregating data from multiple IoT devices.
- *Remote updates*: Bauwens et al. [143] and Mugarza et al. [144] investigated how connectivity enables remote software updates for IoT devices, which is critical for improving device security, adding new features, and fixing bugs without physical access.
- *Integration*: Tavana et al. [145] and Farahani et al. [146] pointed out how connectivity technologies allow for the sharing of IoT data with enterprise software, cloud applications, and analytics platforms, facilitating comprehensive data utilisation through integration.
- *Consumer engagement*: Del Rio et al. [147] and Li et al. [148] highlighted how connectivity technologies enable users to access and control devices remotely for IoT applications in the consumer market, such as smart homes and wearables. This remote access enhances convenience and engagement, allowing users to interact with their devices from anywhere.

Connectivity technologies are the foundation of the IoT and play a crucial role in enhancing consumer engagement for IoT applications in the consumer market. They enable data collection, real-time monitoring, remote control, scalability, and accessibility. These technologies addressing IoT-related challenges empower industries to develop more efficient, data-driven solutions across diverse applications.

In the dynamic and complex arena of the IoT, where an array of interconnected devices generates vast amounts of data, multi-criteria decision-making (MCDM) methods play a crucial role in navigating complex decisions. MCDM techniques provide a structured and systematic approach for evaluating and selecting the most suitable options among multiple alternatives, considering various criteria and stakeholder preferences.

Cloud computing is essential in the IoT. Sharma and Obaidat [149] and Hamdan et al. [150] highlighted the crucial role of cloud computing in the IoT context, providing the infrastructure and capabilities to process, store, and analyse the vast amount of data generated by IoT devices and sensors. Cloud computing is indispensable for IoT solutions, offering the necessary infrastructure and tools for data management, analytics, and integration. It serves as a foundational technology, addressing IoT problems by enabling data scalability, real-time analytics, machine learning, data security, and more, thereby

enhancing the efficiency and effectiveness of IoT applications across industries. The authors identified 15 critical problems addressed by cloud computing in the IoT context:

- *Scalability:* Kumar and Agrawal [151] and Mrozek et al. [152] pointed out that cloud platforms offer scalable resources, enabling the handling of increasing data volumes generated by IoT devices. This scalability is essential for accommodating many devices and ensuring consistent performance.
- *Data storage:* Zdravevski et al. [153] and Mukherjee et al. [154] highlighted that cloud services store IoT data, ensuring data availability, redundancy, and durability. Storing data in the cloud also allows for historical data retention, which is valuable for analytics and compliance.
- *Real-time analytics:* Rahmani et al. [155] and Wolf et al. [156] concluded that cloud computing platforms support real-time data analysis, which is crucial for monitoring and responding to IoT-generated data. Real-time analytics can detect anomalies, trigger alerts, and enable immediate responses to critical events.
- *Data processing:* Krishnamurthi et al. [157] and Li [158] highlighted that IoT data often require pre-processing and transformation before using them for analytics and decision-making. Cloud computing platforms offer the computational power to process data at scale, extract insights, and generate meaningful reports.
- *Machine learning and AI:* Ahmed et al. [159] and Lazaroiu et al. [160] pointed out that cloud platforms integrate machine learning and artificial intelligence services, which are essential for developing predictive models and automating decision-making based on IoT data, particularly for applications like predictive maintenance and anomaly detection.
- *Integration:* Hashem et al. [161] and Shao et al. [162] concluded that cloud platforms facilitate the integration of IoT data with other data sources and enterprise systems, enabling comprehensive data utilisation and the creation of more holistic insights.
- *Geographic distribution:* Salaht et al. [163], Carvalho et al. [164], and De Donno et al. [165] highlighted that cloud providers have data centres in multiple geographic regions, allowing low-latency access to data and services, which makes it feasible to deploy IoT solutions globally.
- *Security and compliance:* Karie et al. [166] and Sun et al. [167] highlighted that cloud platforms offer robust security features and compliance certifications, safeguarding sensitive IoT data and ensuring that data handling aligns with industry-specific regulations.
- *Device management:* Paiva et al. [168], Rahim et al. [169], and Mavromatis et al. [170] concluded that cloud services often include device management capabilities, making it easier to provision, monitor, and manage IoT devices remotely, crucial for large-scale deployments.
- *Cost efficiency:* James et al. [171], Chowdhury et al. [172], and Centobelli et al. [173] pointed out that cloud computing allows organisations to pay only for the resources they use, reducing capital expenditures, essential for organisations seeking cost-effective IoT solutions.
- *Reliability:* Xing [174] and Berger et al. [175] concluded that cloud providers offer high availability and redundancy, ensuring that IoT data are accessible and recoverable even during hardware failures or disasters.
- *APIs and SDKs:* Song et al. [176] and Kristiani et al. [177] highlighted that cloud providers typically offer application programming interfaces (APIs) and software development kits (SDKs) that simplify the development of IoT applications and the integration of IoT data into other systems.
- *Remote access:* Barros et al. [178], Werning and Spinler [179], and Mboli et al. [180] pointed out that cloud platforms enable remote access to IoT data and services, enabling the monitoring and management of IoT systems from anywhere with an Internet connection.

- *Collaboration:* Jäger-Roschko and Petersen [181] and Chavez et al. [182] concluded that cloud platforms facilitate data sharing and collaboration among stakeholders and departments, which is valuable for organisations leveraging IoT data for various purposes.
- *Innovation:* Hallioui et al. [183] and Gaiardelli et al. [184] highlighted that cloud providers continuously innovate by adding new features and services, keeping IoT solutions up to date and capable of addressing evolving business needs.

Cloud computing is the backbone of IoT solutions, enabling many benefits such as scalability, real-time analytics, machine learning integration, security, and cost-efficiency. By leveraging cloud platforms, organisations can effectively harness IoT technologies to drive business growth, enhance operational efficiency, and meet the evolving needs of their stakeholders.

For several reasons, ***edge computing is critical for the IoT***. Rejeb et al. [43] and Cui et al. [185] highlighted that edge computing is essential for the IoT, addressing latency, bandwidth, data privacy, security, resilience, and real-time control challenges. Nain et al. [186] and Liu et al. [187] concluded that edge computing provides solutions that enhance the efficiency, security, and effectiveness of IoT applications across various industries and use cases. The authors identified 15 critical problems addressed by edge computing in the IoT context:

- *Reduced latency*: Fraga-Lamas et al. [188] and Almalki et al. [113] pointed out that edge computing reduces latency in IoT applications, which is crucial for real-time responses in areas like autonomous vehicles and industrial automation.
- *Bandwidth optimisation*: Jahanbakht et al. [189] and Rizi and Seno [190] investigated how edge computing reduces the need for vast data transmission to central servers, optimising bandwidth by processing data locally at the edge.
- *Data privacy and security*: Khan et al. [191], Ranjbari et al. [192], and Kumar et al. [193] highlighted that edge computing addresses privacy concerns by processing sensitive data locally, reducing the risk of data breaches.
- *Resilience*: Javed et al. [194], Bhuiyan et al. [195], and Mehmood et al. [196] pointed out that edge computing enhances system resilience, ensuring business continuity during network outages or cloud disruptions.
- *Offline operations*: Rao and Deebak [197] and Botín-Sanabria et al. [198] concluded that edge computing allows devices to operate offline, which is crucial for IoT applications in remote or challenging environments.
- *Real-time control*: Li et al. [199], Khan and Ali [200], and Escolar et al. [201] highlighted that edge computing enables the real-time control of devices and processes, which is essential for immediate responses in industrial automation and robotics.
- *Scalability*: Shammar and Zahary [202], Fraga-Lamas et al. [188], and Ray and Kumar [203] pointed out that edge computing is scalable, accommodating increasing IoT endpoints and supporting ecosystem growth.
- *Distributed processing*: Chen [204], Krishankumar and Ecer [205], and Mistry et al. [206] concluded that edge computing spreads data processing across multiple devices, enhancing system efficiency and performance.
- *Lower costs*: Demestichas and Daskalakis [207] and Xu et al. [208] highlighted that edge computing reduces costs associated with data transmission, storage, and processing, minimising data transfer costs and cloud service fees.
- *Edge analytics*: Talebkhah et al. [209], Khalil et al. [210], and Hossein Motlagh et al. [57] pointed out that edge computing allows for local analytics, enabling immediate insights and decision-making based on IoT data.
- *Adaptability*: Albreem et al. [211] and Farahzadi et al. [212] concluded that edge computing devices can adapt to network conditions and latency requirements, prioritising and processing data based on application needs.
- *Autonomy*: Liu et al. [213], Bhat and Alqahtani [214], and Song et al. [136] highlighted that edge computing devices can operate autonomously, making local decisions without constant communication with a central server.

- *Customisation*: Perera et al. [215], Kubiak et al. [216], and Taneja et al. [217] pointed out that organisations can tailor edge computing solutions to their IoT needs, selecting hardware and software configurations according to their requirements.
- *Environmental sensing*: Min [218], Diez-Olivan et al. [219], Malik et al. [220], and Dang et al. [221] concluded that edge computing in environmental monitoring detects anomalies, provides early warnings, and triggers actions locally, such as shutting down equipment or sounding alarms.
- *Enhanced user experience*: Sun et al. [222], Javadzadeh and Rahmani [223], and Rathore et al. [224] highlighted that edge computing enhances user experiences in IoT applications by supporting real-time responses and reducing delays in consumer-facing applications like smart homes and augmented reality.

Edge computing is pivotal in addressing key challenges and providing solutions for various IoT-related problems, enhancing efficiency, security, and effectiveness across industries and use cases.

The CE and the IoT are transforming how stakeholders manage resources, marking a significant shift from traditional linear models to regenerative approaches focused on waste minimisation and resource maximisation. CE principles like recycling, rebuilding, and reusing or creating closed-loop systems reduce the environmental impact and promote sustainability.

The IoT reshapes industries by enabling the real-time monitoring, analysis, and control of physical objects through interconnected devices and sensors. Its integration with CE principles fosters a new resource management and sustainability era.

Integration of the IoT in the CE:

Innovation and efficiency: extend product lifespan, reduces environmental footprint, and fosters a sustainable, resource-efficient future.

Product-as-a-service models: encourage durable, repairable, and recyclable product designs, promoting the CE and resource efficiency.

Supply chain management: enhances transparency and traceability, promoting ethical sourcing and informed consumer decisions.

At the final stage of the overview, this research presents a SWOT analysis: integrating the IoT and the CE for a sustainable future.

By integrating IoT technologies into CE initiatives, stakeholders revolutionise resource management, drive sustainable innovation, and create a resilient, regenerative economy. This integration promises greater efficiency, reduced waste, and increased profitability, painting an optimistic future where sustainability and economic growth coexist. Leveraging the IoT for CE initiatives fosters a sustainable, resilient, and resource-efficient future, driving the transition to a greener economy.

3. SWOT Analysis: Unleashing the Transformative Power of Integrating Internet of Things and Circular Economy for a Sustainable Future

This analysis envisions the potential and progress in the relationship between IoT technologies and the Sustainable Development Goals (SDGs). By thoroughly examining the existing literature and conducting several SWOT (strengths, weaknesses, opportunities, and threats) analyses, this research highlights AI-driven technologies as powerful facilitators or potential barriers to each SDG. The SWOT analysis of integrating the IoT and CE principles is crucial in understanding this transformative approach's strengths, weaknesses, opportunities, and threats. This analysis empowers stakeholders, guiding them in leveraging IoT technologies to enhance circular practices, driving locally and internationally sustainable development. By understanding these aspects, stakeholders can better utilise the IoT to promote sustainability and resource efficiency, which is crucial for success in this transformative approach.

The results from these analyses lay the groundwork for a broader exploration, showcasing the strides made in applying AI technologies to SDGs, identifying opportunities for

further advancement in the current decade and addressing ongoing challenges to target crucial progress.

This study analysed six categories or perspectives of human needs: life (including health and safety), economic and technological development (including job creation and innovation), social development (including education and community building), equality (including gender and racial equality), resources (including energy and water), and the natural environment (including biodiversity and climate change). This research concludes with a crucial discussion of prospects, fundamental guidelines, and lessons learned. These guidelines are essential to steering AI developments and applications in a positive direction, fully supporting the attainment of the SDGs by 2030.

Integrating the IoT and CE principles offers substantial strengths. IoT technologies can track product lifecycles, optimise resource use, and enhance waste management efficiency. This integration can lead to significant environmental benefits, such as reduced CO_2 emissions and efficient energy use, as shown in various case studies on Industry 4.0 and lean principles in manufacturing [225]. Moreover, the IoT facilitates the transformation of waste into valuable resources, contributing to environmental improvement and job creation [226].

However, notable weaknesses include high investment costs and technological readiness barriers [225]. The complexity of implementing IoT solutions, especially in traditional sectors, can hinder adoption. Additionally, interoperability, scalability, data security, and privacy challenges remain significant [227].

The opportunities are more than just vast. They are revolutionary. The IoT is at the forefront of driving the Fourth Industrial Revolution, transforming sectors such as energy and agri-food supply chains [228,229]. Predictive maintenance becomes a reality with the IoT, enhancing operational efficiencies and reducing waste. The potential for new business models and value chains based on the IoT and CE principles is immense, fostering sustainable development on a global scale [230].

While the opportunities are promising, it is crucial to acknowledge the potential hurdles. Threats such as excessive bureaucracy, lack of infrastructure, and social acceptability issues can pose significant challenges to the transition towards sustainability [231]. Legal and regulatory challenges and competition barriers also present risks to the widespread adoption of the IoT in CE initiatives [227].

In particular, artificial intelligence (AI) and digital technologies, such as big data, blockchain, cloud computing, and virtual and augmented reality, are revolutionising our society, propelling its transformation in the Fourth Industrial Revolution [232]. These technologies should consolidate as a societal and economic lever for transformation on a global scale, driving sustainability and efficiency across various sectors [188].

According to Palomares et al. [233], integrating AI and digital technologies has profound implications for achieving the United Nations' SDGs by 2030. Similarly, integrating the IoT with CE principles can significantly promote sustainability and resource efficiency, offering substantial benefits. However, this integration also presents strategic challenges that stakeholders must address proactively to ensure success.

3.1. Strengths

Enhanced resource efficiency: The IoT enables the precise tracking and monitoring of resources, optimising their use and reducing waste [234]. For instance, in agriculture, IoT sensors can monitor soil moisture levels, allowing farmers to water their crops more efficiently and reduce water waste. Smart sensors and connected devices provide real-time data, enabling efficient resource management and minimising the environmental impact [235–238].

Improved lifecycle management: The IoT facilitates the monitoring of product lifecycles, enabling better maintenance, repair, and recycling processes [239,240]. It leads to extended product lifespans and supports the reuse and refurbishment of materials, which are funda-

mental principles of the CE system aimed at eliminating waste and the continual use of resources [241,242].

Data-driven decision-making: The IoT provides valuable insights through data analytics, helping businesses make informed decisions about resource utilisation, production processes, and waste management [48,243]. It can lead to significant cost savings and improved sustainability outcomes [44].

3.2. Weaknesses

High implementation costs: Integrating IoT technologies requires significant investment in infrastructure, sensors, and data management systems [244,245]. However, in some strategies, such as competitive innovation projects, each involving a small- and medium-sized enterprise (SME) and a large firm, the SMEs mitigate these costs by pursuing a synergistic mix of three distinct coopetition strategies: co-distribution, technology licensing, and R&D co-development [246].

Data privacy and security concerns: The widespread use of IoT devices raises concerns about privacy and security [247,248]. Ensuring that sensitive information is protected and secure is crucial to maintaining trust among stakeholders [35].

Complexity in integration: Combining the IoT with CE principles involves complex processes and systems [249,250]. Implementing the CE requires complex and dynamic changes in technical and behavioural aspects. The need for standardised protocols and interoperability among devices can pose challenges in achieving seamless integration [251].

3.3. Opportunities

Innovation and new business models: IoT-driven CE practices can spur innovation and lead to new business models, such as product-as-a-service and circular supply chains. For instance, understanding product circularity as "three-dimensional"—encompassing high material recirculation, high utilisation, and high endurance—can guide businesses to develop models that promote product reuse and reduce waste [252]. By adopting these principles, companies can ensure that materials are recovered, used intensely, and retain their value, thus aligning with CE objectives and fostering sustainable practices. This approach supports sustainability and opens new revenue streams by shifting from a traditional ownership model to a service-oriented one.

Van Eechoud and Ganzaroli's [253] research underscores the pivotal role of dynamic capabilities in digital circular business model innovation. Their findings demonstrate that capabilities like market scanning, collaborative innovation, and strategic digital servitisation are crucial for sensing and seizing opportunities in circular business models. Moreover, AI capacities, such as perceptive, predictive, and prescriptive, enhance resource efficiency and support the development of AI-enabled circular business models (CBMs) through automation and augmentation. Integrating these initiatives into the core business necessitates robust IT project management and supply chain collaboration, underpinned by a long-term vision for digital circular business model innovation [254]. Finally, dynamic capabilities in value discovery, realisation, and optimisation are essential for aligning with customer ecosystems and realising the full potential of AI-enabled CBMs.

Santa-Maria et al. [255] stress the necessity of adopting a lifecycle perspective, formulating a sustainability strategy, and involving stakeholders for successful circular business model transformation. They identify specific practices vital for long-term business model innovation, such as top management commitment and early customer engagement, which align well with the IoT's potential to revolutionise circular practices.

By leveraging IoT technologies, businesses can develop innovative solutions like advanced product–service systems and more efficient circular supply chains, ultimately driving sustainable development locally and globally. Liu et al. [256] highlight how emerging Industry 4.0 technologies create opportunities to enhance sustainable supply chain management (SSCM) under the CE perspective. These technologies help manufacturers meet evolving customer demands while minimising the environmental impact and pre-

serving resources for future generations. Integrating the IIoT and emerging technologies enables real-time information sharing, fostering capabilities like digital sensing, seizing, and reconfiguring [257]. This digital transformation supports business model innovation and cultural shifts towards sustainability. Furthermore, integrating digital capabilities can address challenges in societal sustainability by enabling secure and rapid information exchange, promoting social equity and improving relationships with key suppliers.

Taddei et al. [258] underscore the pivotal role of IoT, big data analytics, and cloud computing in enabling circular supply chains and enhancing efficiency and competitiveness. When implemented systematically, these technologies can drive the transition towards circular supply chains, making it more feasible for businesses to adopt sustainable practices.

By harnessing these digital capabilities, companies can create innovative product–service systems that reduce waste and promote reuse. Advanced circular supply chains facilitated by the IoT and other Industry 4.0 technologies can significantly enhance operational efficiency, reduce environmental impact, and foster sustainable development. These technologies, such as big data, AI, and blockchain, enable companies to design resource and energy efficiency processes and increase profits from green products, overcoming barriers to sustainable operations [193]. As organisations integrate these technologies, they can better manage supply chains and implement effective strategies to achieve sustainability goals [259]. This integration supports global sustainability goals and opens new avenues for revenue generation and competitive advantage.

Understanding and utilising these dynamic capabilities enable companies to stay competitive and contribute to achieving the Sustainable Development Goals by promoting resource efficiency and sustainability [260].

Global collaboration: The IoT facilitates global collaboration by providing a platform for sharing data and best practices. It can help scale up CE initiatives and achieve SDGs globally. Dantas et al. [261] highlight the potential of integrating the CE with Industry 4.0 technologies to achieve the Sustainable Development Goals (SDGs). These technologies, including cyber–physical systems, IoT, big data, and cloud computing, can optimise production processes and enhance sustainable industry practices. These technologies drive sustainable smart manufacturing by leveraging data-driven analytics and IoT sensing networks to improve resource efficiency [262]. Integrating Industry 4.0 technologies with CE principles helps companies achieve eco-efficiency and strong sustainability, facilitating collaboration between managers and researchers [263]. Moreover, IoT tools address CE challenges, enabling manufacturing firms to transition towards more sustainable operations by aligning with government and supplier expectations [264]. The interconnected nature of Industry 4.0 technologies enables comprehensive data collection and intelligent manufacturing, driving innovation and efficiency.

The combination of the CE, Industry 4.0, and the IoT fosters systematic shifts towards sustainability by closing production cycles and maximising resource use, thus reducing raw material extraction. IoT-related technologies enable circular economies by supporting efficient resource utilisation and waste reduction [43]. Moreover, Industry 4.0 technologies significantly contribute to sustainable development by aligning with the triple bottom line and sustainable business models, enhancing social, economic, and environmental benefits [191]. This integration encourages global collaboration towards more sustainable and resilient production systems. By leveraging these advanced technologies, businesses can scale up their circular initiatives, facilitating broader international collaboration. This integration accelerates achieving Sustainable Development Goals (SDGs) and supports the development of sustainable supply chains and communities.

Ciliberto et al. [265] emphasise that integrating the CE and Industry 4.0 technologies creates a synergistic environment essential for achieving holistic sustainability in production systems. Industry 4.0, characterised by the IoT, cyber–physical systems, big data, and cloud computing technologies, is a crucial enabler of sustainable performance and circular production models. This integration promotes a closed-loop supply chain with reused and recycled products, aligning with CE principles and optimising resource use. More-

over, leveraging these technologies helps businesses transition towards sustainable lean manufacturing, improving economic efficiency and reducing complexity in process flows.

Implementing CE-based business models supported by Industry 4.0 enables companies to redesign their strategies to focus on sustainable development. This approach drives innovation and ensures long-term environmental and economic benefits. Integrating the CE and Industry 4.0 technologies fosters a collaborative ecosystem, encouraging proactive partnerships between industrial companies and policymakers to promote continuous eco-innovation and sustainable growth [266]. Furthermore, adopting Industry 4.0 within sustainable manufacturing frameworks significantly enhances resource efficiency and product quality while reducing environmental impacts [267].

Enhanced consumer engagement: The IoT plays a crucial role in promoting sustainable practices by providing consumers with real-time information about the environmental impact of their choices. By leveraging IoT devices and advanced analytics platforms, retailers can offer consumers personalised insights into their purchasing habits, encouraging more eco-friendly decisions [268]. Additionally, sensor technologies in agriculture demonstrate how real-time data can improve transparency and traceability, enhancing consumer awareness and promoting sustainable consumption patterns [269]. Implementing IoT technologies can significantly influence consumer behaviour towards sustainability by providing real-time information on the environmental impact of their choices. According to Sima et al. [270], integrating the IoT in consumer engagement strategies can drive behavioural change and enhance demand for sustainable products by offering personalised and immediate feedback on consumer actions. Additionally, Allioui and Mourdi [271] emphasise that the IoT's capability to improve decision-making processes and operational efficiency can instil confidence in consumers regarding the positive environmental impacts of their choices, thereby fostering greater adoption of sustainable practices.

3.4. Threats

Technological dependence: Overreliance on IoT technologies can result in vulnerabilities if systems fail. Xing [272] discusses how the malfunction of one IoT device can trigger cascading failures across interconnected devices, highlighting the importance of understanding and mitigating such risks to ensure the reliability of IoT systems. Mishra et al. [273] emphasise the need for a comprehensive approach to assess threats, identify vulnerabilities, and design corresponding mitigation strategies, especially in microgrid systems, to ensure resilience against physical and cyber threats. However, more is needed to understand and mitigate these risks. It is essential to develop backup plans and ensure system resilience to reduce the risks associated with technological dependence on IoT, and this is a task that stakeholders cannot delay.

Regulatory and compliance challenges: Successfully navigating the varying regulations and compliance requirements across different regions is a challenge and a strategic imperative for businesses in the evolving landscape of IoT cybersecurity. Chiara [274] examines the impact of the fast-evolving European cybersecurity regulatory framework on the IoT domain, advocating for the need for separate horizontal legislation on cybersecurity for connected products to avoid fragmentation of the EU's Single Market. Similarly, Oyewole et al. [275] explore the transformative potential of Natural Language Processing (NLP) within financial reporting, highlighting the multifaceted implementation challenges and regulatory considerations. The study underscores the strategic importance of addressing these challenges to enhance the precision and reliability of financial reports, advocating for developing a robust framework for NLP applications in financial reporting.

Environmental impact of IoT devices: Addressing the lifecycle management of IoT devices is crucial to minimise their environmental footprint, as the production and disposal of these devices can have ecological impacts. Nižetić et al. [44] emphasise the need for careful monitoring and evaluation of the fast development of IoT technologies from an environmental perspective to limit harmful impacts and ensure intelligent resource utilisation. Similarly, Oláh et al. [276] discuss the negative effect of Industry 4.0 on ecological

sustainability, highlighting issues such as air pollution, poor waste discharge, and intensive use of raw materials and energy. However, they also suggest that integrating Industry 4.0 with Sustainable Development Goals can enhance environmental sustainability and create a more positive ecological impact, offering solutions to existing environmental challenges.

4. Conclusions

The future of synergy between the IoT and the CE concept is promising. Technological advancements, evolving business models, and regulatory frameworks geared towards sustainable economic growth drive this potential. Embracing these trends empowers businesses to leverage the IoT's transformative potential, paving the way for a circular and sustainable future with immense benefits. It is not just a suggestion but necessary for maximising the benefits and achieving the Sustainable Development Goals by 2030.

Humans cannot overstate the increasing importance of data in IoT-based sustainability solutions. Big data fuels artificial intelligence systems, making them indispensable for achieving SDGs globally. Integrating the IoT and CE principles offers significant potential for sustainable development and attaining the SDGs. However, it necessitates addressing various challenges, including high implementation costs, regulatory compliance, and environmental impact considerations. Stakeholders who effectively navigate these complexities are advised and empowered to capitalise on strengths, seize opportunities, mitigate threats, and remain attentive to future trends, advancing towards a more sustainable future.

In conclusion, while integrating the IoT and CE principles offers substantial opportunities to enhance sustainability and resource efficiency, addressing challenges related to implementation costs, data security, regulatory compliance, and technological dependence is crucial. This imperative for success underscores the urgency and importance of the task. Stakeholders can chart a course towards a more sustainable future by leveraging strengths, mitigating weaknesses, capitalising on opportunities, and addressing threats.

CE dimensions such as interconnectivity, information transparency, and technical assistance enable real-time monitoring, predictive maintenance, and data-driven decision-making, aligning with CE resource optimisation and waste reduction principles. Similarly, CE dimensions focusing on design for longevity, resource efficiency, and waste reduction complement contemporary practices by promoting sustainable product design and circular supply chain operations.

The joint effects of the IoT and CE foster resource optimisation, smart manufacturing, predictive maintenance, and data-driven circular design, empowering stakeholders to make informed decisions prioritising sustainability across the product lifecycle. Moreover, DM methods emerge as essential tools for navigating the complexities of decision-making in the IoT domain, facilitating informed choices that optimise resource utilisation and promote sustainable practices.

As the IoT continues to evolve, the integration of DM methods becomes increasingly crucial for ensuring the successful implementation and utilisation of IoT technologies across diverse sectors. By providing a structured approach for evaluating alternatives based on multiple criteria, DM techniques enable organisations to effectively navigate the challenges of sustainability and efficiency in the context of the CE.

Author Contributions: Conceptualization, Z.T. and V.Š.; methodology, Z.T.; investigation, Z.T. and V.Š.; writing—original draft preparation, Z.T.; writing—review and editing, V.Š.; visualization, Z.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The research is based on the investigation of the articles referred in the WoS "Clarivate Analytics" and Scholar Google databases.

Conflicts of Interest: The authors declare no conflict of interest.

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