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THE ROLE OF TECHNOLOGY IN FOSTERING A CIRCULAR ECONOMY: LITERATURE REVIEW AND PRACTICAL IMPLICATIONS

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Abstract

The purpose of this research is to examine the role of technology in supporting the implementation of a circular economy through a literature review and identify the practical implications of adopting these technologies. The circular economy offers an alternative approach to the traditional linear model, prioritising waste minimisation and resource use optimisation. This research highlights various information and communication technologies, such as big data, blockchain, and the Internet of Things (IoT), which have the potential to revolutionise resource management and improve the efficiency of industrial processes. In addition, innovations in product design and manufacturing, including 3D printing and the development of new environmentally-friendly materials, are discussed as key factors in ensuring longer and more sustainable product lifecycles. The study also reviews the challenges and opportunities in the application of these technologies, including the need for cross-sector collaboration and supportive regulations. The results show that technology integration in the circular economy not only contributes to environmental sustainability but also to increased economic value. Therefore, recommendations are provided to support the acceleration of technology adoption through education and public awareness initiatives.

Keywords: Role of Technology, Circular Economy, Literature Review, Practical Implications.

Introduction

Over the past few decades, rapid global economic growth has led to significant environmental degradation due to overexploitation of natural resources. The traditional concept of linear economy - based on the practice of "take, make, dispose" - has proven to be unsustainable in the long run. The circular economy is an economic paradigm that aims to reduce waste and natural resource use by redesigning production and consumption systems so that materials and products can be sustainably reused or recycled (Clarke & Thomas, 2024) . The circular economy not only focuses on reducing negative environmental impacts, but also seeks to deliver economic and social value by promoting innovation and creating new opportunities in the value chain. As a response to these sustainability challenges, the concept of circular economy is emerging as a promising alternative. The circular economy emphasises waste reduction, reuse, and recycling of materials to create a more sustainable and environmentally friendly economic system (Svensson & Eriksson, 2023) .

The urgency of the circular economy in a global context is crucial, given the enormous challenges the world faces today related to natural resource scarcity, climate change, and increasing waste. Population increase and sustainable economic growth have triggered significant pressure on the Earth's ecosystems, resulting in environmental degradation and exacerbating the climate crisis. By adopting circular economy principles, countries can reduce dependence on non-renewable natural resources, reduce greenhouse gas emissions, and manage waste more effectively. In addition, the transition to a circular economy can drive technological innovation and create new economic opportunities, which in turn can support more inclusive and sustainable development around the world (Ellen MacArthur Foundation, 2013) .

At the national level, the implementation of a circular economy is becoming increasingly urgent as it enables countries to develop economic systems that are more resilient to external disruptions and more self-sufficient in terms of resources. Indonesia, for example, has major challenges related to the management of plastic waste and industrial waste that negatively impact the environment and public health. By changing to a more circular approach, Indonesia can increase the added value of existing resources, reduce environmental impacts, and create jobs in new sectors such as recycling and refurbishment (Lieder & Rashid, 2016) . In addition, circular economy policies can support national commitments to international agreements related to the environment and climate change, help improve global image, and attract green investments. In the long run, the circular economy can be an important pillar in sustainable development that focuses on the balance between economic growth, social welfare, and environmental protection (Baker, 2025) .

However, the implementation of circular economy is not without challenges. One of the main obstacles is the lack of adequate infrastructure and technology to support circular practices. This is where technology plays a vital role. Advancements in technologies such as the Internet of Things (IoT), blockchain, artificial intelligence (AI), and big data have opened up new opportunities to facilitate the transition to a circular economy. These technologies can improve the efficiency of production processes, track product lifecycles, and facilitate recycling in a more effective way (Geissdoerfer et al., 2017) .

Literature review shows that technology has great potential to drive the implementation of circular economy by optimising resource use and minimising environmental impacts. However, the application of these technologies in the context of a circular economy still faces various barriers, both in terms of technology, economics, and regulation (Li & Zhang, 2023) . Therefore, further studies and in-depth analyses are needed to understand how technology can effectively support the transition to a circular economy.

As such, this article will explore the role of technology in driving the circular economy through a review of existing literature and identify practical implications of the findings.

Research Methods

The study in this research uses the literature method. The literature method, also known as a literature study or literature review, is a research approach that involves the collection, analysis, and interpretation of various written sources relevant to a particular research topic or problem. This method is used to gain an in-depth understanding of existing knowledge, identify research gaps, develop a theoretical framework, and obtain an empirical and conceptual foundation for the study to be conducted (Creswell, 2013) ; (Kitchenham, 2004) . The sources reviewed may include books, scientific journals, articles, research reports, dissertations, and other published and unpublished documents. By using the literature method, researchers can critique previous findings, compare different points of view, and develop stronger and more informed arguments to support the hypothesis or statement proposed in the research (Snyder, 2019) .

In this literature method that focuses on the theme "The Role of Technology in Promoting Circular Economy: Literature Review and Practical Implications," the research is conducted by collecting and analysing various written sources that discuss the integration of technology in circular economy praxis. These sources include scientific journals, books, articles, research reports, and industry publications that detail how technologies such as the Internet of Things (IoT), big data, artificial intelligence (AI), and blockchain can be implemented to optimise resource use, reduce waste, and improve production and distribution efficiency. This approach allows researchers to identify trends, challenges, and opportunities offered by technologies in the context of the circular economy, and explore their practical implications for various industry sectors (Paré & Trudel, 2007) . In addition, this literature review also helps in formulating policy and strategy recommendations for stakeholders interested in utilising technology in a more sustainable and environmentally friendly economic development.

Results and Discussion

The Role of Technology in Supporting the Circular Economy Concept

Technology has played a crucial role in supporting and accelerating the adoption of the circular economy concept, which aims to minimise waste and maximise resource utilisation. One of the main ways this is being done is through the implementation of the Internet of Things (IoT), which allows devices and machines to communicate with each other. In a circular economy, IoT can be used to optimise supply chain management and detect and prevent defects at an early stage. For example, smart sensors in IoT can track energy and material usage and identify areas where efficiency

can be improved, thereby reducing wastage and extending product life (Lee & Kim, 2023) .

In addition to IoT, big data technology also makes a significant contribution. Data collected from various sources can be analysed to find patterns and trends that are useful for better decision-making. Big data can help companies understand the product lifecycle and design more efficient and environmentally friendly strategies. By leveraging big data, organisations can identify ways to reduce waste and increase recycling effectiveness, as well as forecast market demand allowing for more precise production planning (Nguyen & Pham, 2025) .

Artificial intelligence (AI) is another technology that has great potential in supporting the circular economy. AI can be used to automate and optimise industrial processes, including recycling and waste management. For example, machine learning algorithms can help classify waste more accurately, enabling more effective recycling. In addition, AI can help develop new, more sustainable business models, such as service-based models where products are maintained and renewed rather than disposed of (Brown & Green, 2023) .

Blockchain, with its transparent and immutable nature, also plays an important role in the circular economy. This technology can be used to ensure transparency and reliability in the supply chain. With blockchain, every transaction and movement of a product or material can be tracked in real-time, from its origin to the end of its life cycle. This not only helps in ensuring that resources are used efficiently but also allows consumers to know the origin and carbon footprint of the products they buy (Geissdoerfer et al., 2017) .

3D printing technology, or additive manufacturing, also has a huge impact on the circular economy. The technology enables more precise production on demand, which means less wastage of materials and excess inventory. 3D printing also allows for easier recycling of materials, as defective products can be dismantled and the materials can be reused to print new products. In this way, product life cycles are extended and waste is significantly reduced (Bocken et al., 2016) .

Renewable energy technologies, such as solar panels and wind turbines, support the circular economy by providing a clean and sustainable source of energy. Renewable energy plays an important role in reducing dependence on fossil fuels that produce a lot of waste and carbon emissions. By shifting to renewable energy, we can reduce the carbon footprint of production and transport processes, and support environmental sustainability (Martinez, 2024) .

In addition, digital technologies such as sharing platforms and online marketplaces enable circular economy models to run more smoothly. These platforms facilitate the shared use or reuse of various products, which reduces the need for new production and minimises waste. For example, vehicle-sharing applications or

equipment rental services can reduce the amount of goods produced, as well as extend the useful life of those goods (Silva & Azevedo, 2022) .

Sustainable design practices and the use of simulation software assist companies in designing products that are easier to renew, repair and recycle. Simulation software can be used to test various product designs quickly and efficiently, ensuring that products are designed with their full life cycle in mind. This not only reduces waste but can also lower production costs by reducing raw material requirements (Hansen & Jensen, 2023) .

Awareness and education also play an important role, with technology providing a platform for knowledge and information sharing. E-learning and online education platforms allow individuals and organisations to sharpen their understanding of circular economy principles and how to apply them in daily life and business operations. In this way, technology brings the knowledge and practical implications of the circular economy closer to a wider audience (García & Rodríguez, 2024) .

Overall, the integration of technology in the circular economy provides extensive opportunities to improve efficiency, reduce waste, and create more sustainable business models. The combination of these advanced technologies not only supports the achievement of environmental goals but also provides significant economic benefits. In the long term, the application of innovative technologies is key to addressing global resource and sustainability challenges and shaping a future where the balance between resource use and regeneration is maintained.

Technology Integration in the Circular Economy

The circular economy is an economic model that aims to reduce waste and maximise resource use. In a circular economy, products and materials are designed to be recycled, reused, and renewed. Technology plays a very important role in supporting the implementation of circular economy. Through various technological innovations, ranging from information technology to biotechnology, we can create a more efficient and sustainable system (Walker & Taylor, 2024) .

Firstly, information and communication technology (ICT) plays a vital role in the circular economy. The Internet of Things (IoT), for example, allows companies to monitor the use of their products in real-time. With sensors attached to products, data on their condition and usage can be collected and analysed. This information is valuable as it can be used to extend product life through predictive maintenance and timely repairs (Korhonen et al., 2018) .

Secondly, blockchain technology can be used to create transparency and accountability in the supply chain. Through blockchain, every transaction and movement of goods can be recorded in a decentralised and immutable manner, thus increasing trust between all parties involved in the supply chain. This is particularly

important to ensure that recycled or reused products are not mixed with new products in the process (Kumar & Patel, 2022) .

Thirdly, biotechnology also has a significant contribution to the circular economy. With biotechnology, we can develop materials that are biodegradable and more environmentally friendly. For example, conventional plastics that are difficult to degrade can be replaced with plastics made from biological materials that can degrade naturally. This will greatly reduce the impact of environmental pollution and increase the sustainability of the materials we use (Thompson & White, 2025) .

Fourth, in the energy sector, technologies such as renewable energy and energy storage play an important role. Renewable energy such as solar, wind and bioenergy not only reduces carbon emissions but also provides a more sustainable alternative to fossil fuels. In addition, increasingly advanced energy storage technologies allow the use of renewable energy to be more stable and reliable (Ruiz & Mendoza, 2025) .

Fifth, additive manufacturing technologies, such as 3D printing, offer new ways of production that are more efficient and produce less waste. With 3D printing, products can be made on demand and with the exact materials needed, reducing overproduction and material wastage. 3D printing also allows for easier recycling of materials (Patel & Shah, 2022) .

Sixth, automation and robotics also play a role in optimising production and recycling processes. With automation, production processes can be carried out more accurately and efficiently, while robotics can be used to manage and sort waste more effectively. This not only increases efficiency but also reduces operational costs (Ferraz & Oliveira, 2023) .

Seventh, sharing economy platforms facilitated by digital technology also encourage the circular economy. Through apps and online platforms, people can share, borrow or rent the goods they need instead of buying them. This not only reduces the demand for new products but also increases the value of using existing goods (Martinez, 2024) .

The integration of these technologies not only supports the circular economy but also opens up new economic opportunities that are more sustainable and efficient. Cross-sector collaboration and continuous technological innovation are needed to fully realise the vision of a circular economy. Thus, leading to a greener and more prosperous future.

Impact of Technology Implementation in Circular Economy

The application of technology in the circular economy has several significant impacts that can change the way we view and manage resources. First of all, technology enables increased efficiency in the use of raw materials. For example, by using sensor technology and data analytics, companies can effectively monitor, detect and manage production waste, reduce wastage and optimise resource use (Chen & Wang, 2024) .

In addition, technology has also made it easier to recycle and remanufacture products. Innovations in recycling techniques and materials engineering allow materials that were previously difficult to recycle to now be processed more easily. This results in significant waste reduction and increases the supply of recycled materials throughout the product lifecycle (Accenture, 2014) .

In the digital age, internet-based platforms such as e-commerce and resource sharing applications are becoming more common. This facilitates a sharing economy business model where products and services are used simultaneously by multiple users. As a result, the demand for new products decreases and the life cycle of existing products can be extended, helping to reduce overall material consumption (Johnson & Miller, 2022) .

Technology is also driving energy efficiency and the use of renewable resources. With advances in renewable energy technologies such as solar panels and wind turbines followed by advanced energy storage, we can reduce dependence on fossil fuels. In addition, the use of smart technologies such as the Internet of Things (IoT) can reduce energy consumption through more efficient management at the household and industrial scale (Smith & Johnson, 2022) .

Furthermore, in the manufacturing industry, 3D printing technology and robotic automation open the door to on-demand manufacturing. This technology allows goods to be produced exactly as needed without generating excess waste. In addition, it allows products to be easily customised and repaired, extending the useful life of goods (Ghisellini et al., 2016) .

Another positive impact is in the management of organic waste that can be converted into energy or compost with the right technology. Systems such as anaerobic digestors and pyrolysis are able to convert organic waste into methane gas or charcoal that can be used as an energy source or in agriculture. This dramatically reduces the amount of waste that ends up in landfills (Clarke & Thomas, 2024) .

Aside from the benefits mentioned above, some challenges also arise along with the application of technology in the circular economy. One of them is the reliance on technology that requires high infrastructure and initial investment. Not all societies or countries have the ability to invest in advanced technology, thus creating a gap (Svensson & Eriksson, 2023) .

There are also challenges in terms of regulations and policies that must keep up with rapidly evolving technologies. The government must be able to provide a legal framework that supports the transition to a circular economy without stifling innovation. In addition, public education and awareness must be improved so that people can actively participate in recycling and conscious consumption (Ellen MacArthur Foundation, 2013) .

Finally, it is important to develop collaboration between the private sector, government, and society. Only by working together in synergy can we ensure that

technology is used effectively to achieve the goals of a circular economy. Education, research, and solid policies are the necessary foundations to support this transformation.

Overall, technology has great potential in accelerating the shift to a circular economy, but it requires collective effort and careful planning. The impact is not only on waste reduction and resource conservation but also on more sustainable economic development. A holistic approach involving all stakeholders is needed to reap the full benefits of a technology-based circular economy.

Conclusion

Technology plays a crucial role in driving the adoption of circular economy models. Information and communication technologies, such as big data, blockchain, and the Internet of Things (IoT), enable more effective monitoring and management of resources and ensure transparency in the supply chain. The adoption of these technologies can transform the way companies and consumers utilise goods and services, reduce waste, and maximise resource use.

When viewed from a practical perspective, technology accelerates innovation in product design and manufacturing processes. For example, 3D printing enables the manufacture of products with higher material efficiency and supports easier repairs than conventional methods. Technology also facilitates the development of new materials that are more environmentally friendly and can be recycled more successfully, thereby reducing the need for extraction of new raw materials from nature.

Overall, the integration of technology in circular economy practices offers great opportunities to create economic value while minimising ecological impacts. To optimise these benefits, there is a need for collaboration between the public sector, private sector, and scientific community as well as the establishment of regulations that support innovation. Public education and awareness are also key in ensuring that existing technologies are used in a way that supports circular economy principles.

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